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UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION
(UNIDO)

Review and Selection of Low and Non-Waste Technologies in Energy Production
Six Case Studies:

Brazil
Czech Republic
Egypt
Guyana
Hungary
Romania

UNIDO Project UC/GLO/93/061
UNIDO Contract No. 97/127P
Vienna, Austria

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ABSTRACT

In 1993, the United Nations Industrial Development Organization (UNIDO) initiated a program to assist developing countries and countries with economies in transition to reduce the environmental impacts associated with energy production. As a result of this on-going program, UNIDO and its contractors have (1) conducted training workshops on low and non-waste technologies (LNWTs) and (2) prepared case-studies on waste management and the potential application of LNWTs in six countries: Brazil[1], Czech Republic, Egypt, Guyana, Hungary, and Romania[1].

To prepare for future follow-on demonstration projects, UNIDO selected ICF Kaiser Consulting Group (ICF), USA to perform technical evaluations of the six case studies on waste management and co-generation practices prepared by a separate contractor. ICF evaluated these case studies to determine if the reports contained sufficient information (type and detail) to obtain an understanding of the current waste management and co-generation practices in each of the six countries.

ICF also developed and implemented methodologies to (1) select the most appropriate LNWTs for each country, and (2) choose the two most appropriate technologies and countries for industrial-scale demonstrations. ICF then prepared block designs, functional specifications, and cost analyses for the two selected LNWTs.

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[1] Waste Management Only.

LIST OF ABBREVIATIONS/UNITS

BFB	Bubbling Fluid Bed
BIG-GT	Biomass Integrated Gasification-Gas Turbine
Btu	British Thermal Unit
Btu/Kwh	British Thermal Units per Kilowatt hour
Btu/lb	British Thermal Units per Pound
C&I	Capital and Interest Costs
CFB	Circulating Fluidized Bed Technology
CETESB	Companhia de Technologia de Saneamoto Ambiental (The State Agency for Environmental Protection)
E-Plus	EPA's Energy Project Landfill Gas Utilization Software
FBC	Fluidized Bed Combustion Facilities
FEEMA	**[Not Defined in Original Source]**
ft^3/lb	Cubic Feet per Pound
Gwh	Giga Watt Hour
Gwh/a	Giga Watt Hours per Acre
Gwh/yr	Giga Watt Hours per Year
ICF	ICF Kaiser Consulting Group, USA
IGCC	Integrated Gasification Combined Cycle
IRR	Internal Rate of Return
Kc	Crowns (Czech Currency)
KJ/kg	Kilo Joules per Kilogram
Kwh	Kilo Watt Hour
Kwh/m^3	Kilo Watt Hours per cubic metre
Kwh/ton	Kilowatt Hours Per Ton
LFG	Landfill Gas
LNWT	Low and Non-Waste Technology
m^3/day	Cubic Metres per Day
m^3/yr	Cubic Metres per Year
MMBTU	Million British Thermal Units
MMBTU/yr	Million British Thermal Units per Year
mmcf/year	Milli Metres Per Cubic Feet Per Year
MRF	Materials Recovery Facilities
MSW	Municipal Solid Waste
Mt/a	Mega Tons per Acre
MW	Mega Watts
Mwh/a	Mega Watt Hours per Acre
NEAP	National Environmental Action Plan
NEP	National Environmental Policy
Nm^3/a	**[Not Defined in Original Source]**
NPV	Net Present Value
O&M	Operations and Maintenance
PJ	Peta Joule
RDF	Refuse-Derived-Fuel
t/a	Tons per Acre
TDP	Tons Per Day
t/day	Tons Per Day

LIST OF ABBREVIATIONS/UNITS (Continued)

t/yr	Tons Per Year
TS	Mass Percent (Total Solids)
U.S. DOE	U.S. Department of Energy
U.S. EPA	U.S. Environmental Protection Agency
UNIDO	United Nations Industrial Development Organization
VS	Mass Percent (Volatile Solids)

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SECTION 1.0

PROJECT INTRODUCTION

1.1 Overview

In 1993, the United Nations Industrial Development Organization (UNIDO) initiated a program to assist developing countries and countries with economies in transition to reduce the environmental impacts associated with energy production. As a result of this on-going program, UNIDO and its contractors have (1) conducted training workshops on low and non-waste technologies (LNWTs) and (2) prepared case-studies on waste management and the potential application of LNWTs in six countries: Brazil[2], Czech Republic, Egypt, Guyana, Hungary, and Romania[1].

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1.2 Introduction to LNWTs

Municipal solid waste (MSW) and industrial waste can be utilized as an energy source in many ways. The most common options are to burn these wastes as a fuel in special power stations or to cover them and allow them to ferment in a properly protected landfill, where the methane gas is then tapped for residential and industrial use or fired in gas engines for production of energy. Other new approaches include sorting the waste and utilizing the "clean" organic, high-energy part of the waste stream (wastes from slaughter houses, diary plants, industries, etc.) in special biogas plants where the waste is fermented to produce large amounts of methane (400 cubic meters per ton of waste). The residue material is a valuable resource, especially in less fortunate countries because it can then be used as rich fertilizer and soil conditioners.

Thermal Systems

Waste-to-energy (WTE) systems reduce the volume of waste by approximately 90 percent and the weight by 75 percent, thus decreasing the amount of MSW and industrial waste that must be placed in landfills. WTE facilities provide for conservation of energy resources by converting the Btu value of discards into electricity or steam. There are about 120 energy recovery facilities operating in the U.S., which represents a total design capacity of nearly 97,000 t/day (tons/day).

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[2] Waste Management Only.

WTE combustion is similar to conventional combustion of solid fuels such as coal. The waste (fuel) is burned in either its original form with little preprocessing (mass burn) or after the extraction of recyclable materials, is converted to refuse-derived fuel (RDF) for more efficient combustion. The fuel handling equipment, boiler, ash disposal, emissions control, and power plant controls are similar to those for coal-fired power plants. The most important differences between the two arise from the much greater variability of the MSW/industrial waste stream and the much higher proportion of compounds that adversely affect boiler and emissions control operations. The net effect of the fuel variability is that operating and maintenance costs tend to be high and performance tends to be uneven. The use of RDF instead of unprocessed MSW/industrial wastes improves boiler performance, but at a significant fuel preparation cost.

Environmental Benefits from WTE

A city of approximately 700,000 people located in the Midwestern United States has derived several direct, significant environmental benefits from its WTE facility. A local utility purchases steam from the plant rather than burning coal. For every three tons of waste combusted, the utility avoids burning one ton of coal.

In 1989, as a result of this decreased use of coal, hydrocarbon emissions to the local atmosphere were reduced by 35 percent, nitrogen oxides by 20 percent, and particulate matter by 17 percent. Moreover, in 1989, the combined utility and WTE facility emissions of sulfur dioxide were 11,849 tons, but would have reached 24,895 tons had the WTE facility not been in service.

A second type of WTE facility is a modular controlled-air incineration system, generally prefabricated and shipped to the site, with a capacity of less than 50 tons per day. Modular systems feed waste into a primary chamber where incomplete combustion produces a combustible gas that is burned in a second chamber, usually in conjunction with oil or gas. This technology produces very low particulate emissions, but its low-pressure steam is not suitable for the generation of electricity for sale to utilities.

RDF facilities consist of an RDF processing area and an RDF-fired stoker boiler. RDF processing includes flail milling, trommel screening, magnetic separation, and size reduction. The resulting fuel, with an approximate heat content of 5,900 Btu per pound, is transported by conveyor to the power plant, where it is injected by the spreader stoker and combusted in suspension and on the grate. Assuming a moisture content of 28.2 percent and heat value of 5,663 Btu per pound, a 40-megawatt RDF plant can consume 1,396 tons of fuel per day. This example plant would have a thermal efficiency of 20.7 percent, gross capacity of 46 megawatts, and a heat rate of 16,464 Btu per kilowatt-hour.

A fourth WTE technology is pyrolysis. A pyrolysis system decomposes organic waste in a high-temperature, oxygen-deficient chamber. Efforts to continue to commercialize this technology have declined, and operating facilities using this technology have closed down.

WTE facilities are very capital-intensive undertakings; in many cases, they are the single most expensive public works project confronting a municipality. Most facilities are developed as a result of an alliance between a developer/vendor and a municipality.

Biological Systems

Anaerobic digestion -- the generation of combustible gases (e.g., methane) through the decomposition of waste -- can occur in an uncontrolled environment such as a landfill or compost pile, or in a controlled environment such as confined vessel or reactor. Anaerobic digestion generally refers to the production of methane from the organic fraction of waste in enclosed, controlled reactors as follows:

- the waste is pre-processed to isolate organics;
- nutrients (e.g., sewage sludge and/or chemicals) are added to aid digestion;
- the mixture is placed in the digester where it undergoes chemical reactions; and
- methane gas is captured as a by-product of decomposition.

The remaining solids are significantly reduced in volume during the process.

Puente Hills Landfill Gas Recovery Facility

The Puente Hills Energy facility in California is successfully recovering gas from the Puente Hills landfill to produce electricity. The facility, owned and operated by the Los Angeles County Sanitation Districts, began operation in November 1986 after three years of development.

The 1,365 acre landfill contains more than 45 million tons of waste. The waste is tapped for its methane gas, using an extensive network of vertical wells and collection pipes. Once collected, the methane gas is burned to produce electricity through a steam driven turbine system that produces and estimated 50,000 kilowatts of electricity.

Revenues from the sale of electricity total $90.7 million (US) for the first three years. This revenue has already paid for the $33 million (US) in capital costs to develop the facility and covers operating expenses estimated at $319,000 (US) per month. In 1990, the facility grossed $43 million (US) in revenue and was expected to increase revenues by 6 to 7 percent annually.

Integrated Waste Management (IWM)

The desire of communities to dispose of their waste in the most cost-effective and environmentally-sound manner has given rise to the concept of "integrated waste management" or managing waste options (recycling, composting, waste-to-energy, and land filling) to minimize total cost. Reducing the quantity of materials entering the waste stream in the first place (source reduction) may also be considered an aspect of integrated waste management.

Probably the most significant use of waste that has influenced the amount of waste available for combustion is recycling. In the United States, more than 140 recycling laws were enacted by 38 states by 1990, and the U.S. EPA has mandated at least 25 percent of total MSW be directed to recycling by the year 2000. A similar trend is observable in other countries, including Europe, Canada, and Asia.

Recycling may or may not lessen the energy efficiency of waste combustion. Recycling of newspapers, other paper, and paperboard reduces both the volume and Btu content of the waste, making it less attractive as a fuel. On the other hand, removing yard trimmings reduces the volume but increases the per-unit energy content of the waste. It also reduces the moisture content of the waste stream, thus improving the overall combustibility of the mix. Furthermore, recycling of glass, aluminum, and other metal noncombustibles reduces the volume of trash while leaving its energy content unaffected, which raises its per-unit energy value.

Demonstration Projects

A project for utilizing MSW can act as a demonstration case and model for other countries that have limited energy sources. MSW can contribute a large amount of methane if the "clean waste" (organic) part is utilized in biogas plants and the rest buried in sealed landfills, and the extracted gas utilized. MSW and industrial organic waste can generate 800 KWH or more per ton from biogas plants and 300 KWH per ton from sealed landfills. Utilization of biogas plants could supply a large amount of the electricity required in many developing countries.

It is also important to recognize that recycling and composting impose costs and are not always the most efficient components of integrated waste management. Recycling incurs financial costs for collection, sorting, and processing; recycling also has environmental consequences, including emissions from collection vehicles and processing centers, and uncertain environmental effects during remanufacturing.

Finally, lack of demand in the markets for some recycled materials or limitations in market development could restrict growth in recycling. Composting also faces obstacles, particularly when specialized composting facilities are used. Although a number of smaller facilities are operating, larger facilities have, so far, been much less successful.

1.3 Critical Review and Evaluation of the Six Case-Study Reports - Overview

ICF reviewed each of the six case-study reports to gain an understanding of the waste management and co-generation practices utilized in Brazil, Czech Republic, Egypt, Guyana, Hungary, and Romania. ICF also reviewed the case-study reports to determine if they adequately covered, in sufficient detail, the types of information necessary to obtain an understanding of the current waste management and co-generation practices in each country. The types of information that ICF expected to see covered in each of the reports include (but are not limited to) the following:

- Current Waste Management Situation
  - demographics (population and industry)
  - waste streams (quantities and qualities)
  - existing waste management system
  - existing and anticipated problems
  - management goals
  - management alternatives

- Evaluation of Management Alternatives
  - cost
  - environmental impact
  - integration with waste management system
  - political feasibility and implementability
  - other goals

- Public Attitudes
- Public Education Programs
- Public Involvement
- Laws and Regulations

- Overview of Local Economics

- Markets for Recyclables
- Materials Recovery Facilities
- Composting and Environmental Impacts
- Collection Systems
- Source Reduction at the Local Level

1.4 Minimum Required Waste Stream Characterization Information

Prior to selecting and designing the most appropriate and efficient waste management system, it is absolutely necessary to have basic information about the physical and chemical composition of the waste stream. There are many different types of sources which produce extremely different types of Municipal Solid Wastes (MSW), special category wastes, and industrial non-hazardous and hazardous wastes. The major categories of sources are:

- Residential
- Commercial
- Institutional
- Construction and Demolition
- Municipal Services
- Treatment Plant Sites
- Industrial
- Agricultural

The technologies chosen to handle such a diverse collection of waste needs to be tailored to the amount and chemical composition of that particular waste stream. The following is a discussion of the types of information necessary to continue with a thorough evaluation of the best waste management technology.

1.4.1 Assessing the Current Waste Stream

Two basic methods of current waste stream assessment exist. The first method involves actually performing a local waste characterization study. The second method involves using existing data to characterize the local waste stream. Probably the most accurate method if conducted accurately would be to actually separate, sample, and weigh the waste produced at a particular point in the waste stream. The samples must be taken systematically and over a period of time to account for random and seasonal fluctuations. The second method of using existing waste stream information is possible if enough demographic information is available on the community from local officials.

It is extremely important to avoid generalizing from community to community. The percentage and type of waste depends on the particular lifestyles of each community's residents. Thus, all three categories which characterize the waste stream--quantity, physical composition and chemical composition--vary by the level of "sophistication" of the particular waste-generating society.

1.4.2 Quantity

Before one can begin to select and design the most appropriate management system, it is necessary to know information on waste generation rates. Specifically, the system must be sized to handle the total amount of solid waste that is being generated. Fluctuations in waste generation during the year need to be considered (e.g. seasonal variations). The weight and volume of different components of the waste are needed. The quantity of waste expressed either for an entire community or on a per capita basis is necessary to determine equipment capacity. Lastly, this information should be expressed on a mass-basis, rather than a volume basis in order to remove the uncertainties associated with volume reduction or compaction activities.

1.4.3 Composition--Physical

Because of the diversity of elements in waste streams, it is necessary to breakdown the different components into both physical and then chemical categories. The weight, volume, and moisture content of each category is useful information.

Below is a basic list of types of solid waste (adapted from Tchobanoglous, 1993, p.49):

Organic

Food wastes
Paper
Cardboard
Plastics
Textiles
Rubber
Leather
Yard wastes
Wood

Inorganic

Glass
Tin cans (steel)
Aluminum
Other metal
Dirt, ash, etc.
Construction rubble

Special Wastes

Medical
Low toxicity institutional
Hazardous industrial wastes
Non-haz. industrial wastes
Sewage sludge
Agricultural

Once the waste is broken down into these categories, it is possible to see how much of the waste can be recycled, landfilled, or further processed.

1.4.4 Composition--Chemical

The next necessary step in analyzing the waste stream is to determine the chemical composition of the waste. The identification and selection of successful LNWTs requires the engineer to understand the chemical composition of the wastes under consideration. For example, the feasibility of combustion depends on the chemical composition of the solid wastes. Typically, wastes can be thought of as a combination of semi-moist combustible and non-combustible materials. If solid wastes are to be used as fuel, the four most important properties to be known are:

1. *Proximate analysis* (tests on moisture, volatile combustible matter, fixed carbon, and ash)
2. *Fusing point of ash* (temperature at which ash will form a solid)
3. *Ultimate analysis* (determining percent carbon, hydrogen, oxygen, nitrogen, sulfur and ash)
4. *Energy content.*

The selection and evaluation of most any solid waste treatment technology from composting to land filling to combustion, requires the analytical results from the ultimate chemical analyses to help determine the eventual composition of the residuals.

1.4.5 Future Changes

As waste management technologies are being evaluated, it is important to consider recent and future trends of the waste stream composition. The composition of the solid waste generated is rapidly changing as quickly as peoples' lifestyles. Four categories that are currently undergoing transitions are: food wastes, paper and cardboard, yard wastes, and plastics. With technological advancements, the wastes from each of these categories are changing. The sizing of the treatment units should be directly related to future anticipated volumes so the capacity can accommodate future demands. The technologies chosen must take into consideration these recent qualitative and quantitative trends and be flexible enough to adjust to future ones. There are numerous examples of WTE facilities being built for anticipated quantities and quality of wastes that were not realized, thereby changing the economics of the entire project (e.g., changes in tipping fee revenue or inability to meet contractual energy generation levels).

Owners of WTE Unit Balk at Demand for Lower Fee
(*Waste News*, January 12, 1998)

"Hudson Falls, N.Y. - Waste Management of Eastern New York said it may stop taking its trash to a waste-to-energy facility operated by Warren and Washington counties in New York unless they trim the site's $69 tipping fee....While the county is charging $69 per ton, area landfills are charging $50 to $54 per ton in tipping fees...Washington and Warren counties have to deal wit the plant's budget shortfall of more than $2 million from 1997..."

SECTION 2.0

REVIEW AND EVALUATION OF CASE-STUDY REPORTS ON LNWTS

ICF reviewed and evaluated each of the six case-study reports on LNWTs using accepted engineering practices. ICF notes that both the quantity and quality of information presented in the six case studies varied considerably. ICF also notes that some of the information identified above in Sections 1.3 and 1.4 as being necessary was either missing, presented in a confusing manner (due to typographical errors), or incomplete. Just a few of the many examples included:

- on page 5 of the Brazil report, electrical prices were quoted as being "U.S. $4/KWhr", which is approximately two orders of magnitude too high,
- on page 10 of the Brazil report, it was stated that Brazil produces 8,700 tons of municipal solid waste (MSW) per day, compared to 13,000 t/day of MSW produced in São Paulo - how can São Paulo generate more MSW than all of Brazil?
- MSW generation rates cited in one section did not match rates used in other sections of the reports - on page 52 of the Romania report, the waste generation rate was cited as 600,000 t/yr, while on page 53, the waste generation rate was cited as ranging between 800,000 to 900,000 t/yr, and.
- Information on the population demographics, waste generation, or waste characterization was not provided in the case study report for Hungary.

In addition, very little waste characterization data was provided in any of the reports. Crucial information on values such as moisture content (necessary for evaluation of combustion technologies vs. anaerobic digestion technologies), break-outs of "organic" or "kitchen" waste categories (necessary estimations of solids contents or useful substrate for biological consumption), or specific assumptions were neither provided nor documented. Lack of assumptions (and spelled-out units) made it very difficult for us to both understand why a particular technology was selected and to verify calculations. In some cases, information on waste generation rates was provided on a volume basis, rather than on a mass basis -- information on generation rates provided on a volume basis, without details regarding degree of compaction are difficult to use. Nonetheless, ICF proceeded to critically review the six case studies and, as necessary, augmented the six case studies using information either contained in the technical literature or provided to us by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), and several vendors of waste-to-energy technologies.

ICF presents several general observations and the results of our overall review of each case-study report in the Sections 2.1 and 2.2 through 2.7, respectively.

2.1 General Observations

Although, the identification of energy conservation or efficiency practices is outside the scope of this project, ICF believes that the promotion of efficient energy consumption practices and generation technologies is necessary to ensure plentiful sources of energy in any community or country, regardless of the entities's degree of sophistication. Regardless of economic status or world location, it is necessary (and desirable) to improve both energy efficiency in generation and consumption prior to developing new energy production capabilities. Clearly, all of the study countries should embrace energy efficiency practices that will enable what sources of energy they currently utilize to last longer and serve more users. Energy conservation measures reduce energy consumption and often represent "low hanging fruit" (i.e., opportunities that are easy to implement with little to no cost or have immediate or very short pay-back periods) that everyone can implement.

The selection and implementation of more efficient LNWTs can be impeded by highly polluting, inefficient production, and consumption technologies, that rely on imported fuel stocks when users are not paying true costs. Specifically, nationally subsidized energy costs or the availability of inexpensive disposal options make it difficult for planners to embrace LNWTs that promote resource recovery, recycling, and waste minimization. Finally, as is generally the case in less developed nations, the promotion of industry often occurs at the expense of the environment.

2.2 Review and Identification of Missing Information by Country - Brazil

A summary of the necessary information provided in the case study is presented below by applicable section. Sections and/or subsections without information indicates that the report did not present information for that particular category. As necessary, ICF augmented the missing and/or incomplete information presented in the case study using information either contained in the technical literature or provided to us by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), and several vendors of waste-to-energy technologies.

2.2.1 Current Waste Management Situation

Demographics (population and industry)

- Mogi das Cruzes, a medium sized city, has a population of 300,000 (p. 12)

Waste Streams (quantities and qualities)

- 8,700 tons of municipal solid waste are produced in Brazil per day.
- In São Paulo, the largest city in Brazil 13,000 tons are produced per day and by the year 2000 this number is expected to reach 16,000. (p.10)
- Mogi das Cruzes generates 120 t/day of municipal solid waste (p. 12)
- São Paulo's waste consists of residence material, tree cuttings, street sweepings, and some industrial solid waste.

  - Residential waste is: waste collected from markets and private residences;
  - Sweepings: waste collected from street sweeping;
  - Medical: waste from hospitals, clinic, laboratories, prisons, and airports;
  - Miscellaneous: tree cuttings, animals, secret documents, rubble;
  - Particular: inert industrial waste, large commercial centers, shopping centers, places with private waste collection
    [See Table 1. **MSW production in t/day in São Paulo City**] (p.15)

- The composition of solid waste is influenced by the social and economic situation, culture, local climate, and area occupation. (p. 16)

- Classifications are made between

  - Recycling materials: papers, plastics, glass, and metals;
    Composting materials: organic matter;
  - Other: anything not mentioned above.
    [Pages 17 - 19 have charts showing the composition of waste in São Paulo]

Existing Waste Management System

  - In 1979 it was proposed that landfills be constructed for the purpose of energy production. The landfills were constructed with this technology but were never used as anything other than a sanitary landfill. (p. 10)

  - The existing landfill in Mogy (?) das Cruzes accepts 120 tons of municipal waste as well as non-incinerated hospital wastes. This site does not have any kind of protection to prevent ground water contamination. (p. 13)

  - There are currently three sanitary landfills, two composting facilities, two medical waste incinerators, and one recycling center in São Paulo. (p. 19)

  - The composting plant treats 1,000 t/day of waste, the compost is sold to area farmers. The current production at these facilities exceeds the demand for the product. The excess product is often stored in open containers for extended amounts of time. (p. 19)

  - The combined capacity of the landfills is 12,000 t/day. Table 5 on page 20 shows the capacities for each individual landfill. (p. 19)

  - The medical incinerator does not produce energy as it handles only 180 t/day of waste. (p. 19)

  - The recycling center handles 2 t/day although expectations are to increase recycling effort until they handle 10% of the total waste generated. (p. 19)

  - [The original report was written in 1993 and therefore this information may not be relevant.]

    - "...São Paulo municipality has already ordered two MSW incinerators 2,500 t/day each, to be in operation by mid 1997. Moreover, it is expected by the end of 1994 to bid for another incinerator, with 1,500 t/day capacity, to enter in operation in 1998/1999." (p. 21)

    - "It is predicted to build a MSW treatment center, in order to receive approximately 8,000 t/day of waste, which will burn 5,000 t/day producing electric energy and steam. In this center the organic matter of the MSW will be separated, increasing heating capacity of the waste to be burned up to 8,400 kJ/kg. (p. 23)

Existing and Anticipated Problems

- The city of Mogi das Cruzes is facing a legal suit against dumping trash in improper landfills. (p. 13)

[The report made reference to several instances where litigation has been forcing local governments to take immediate action in dealing with their waste management problems.]

Management Goals

Management Alternatives

- A 1981 proposal suggested that a waste-to-energy facility be constructed. The WTE facility would have a capacity of 1,800 t/day; spread out over three modular plants each with a capacity of 600 t/day. This particular proposal would produce: (p. 10)

    - lower calorific value: 5,650 kJ/kg (São Paulo data)
    - annual energy capacity: 149,000 Mwh
    - installed power: 20Mwh
    - life: 10-20 years
    - total investment: US $97,000,000

    - An alternative for São Paulo is to install three incinerators in different regions of the city.

    - Two of the incinerators would have a capacity of 2,500 t/day and will produce 200 KWh per ton of waste burned.

    - The third incinerator would have a capacity of 2,100 t/day.

    - Of the total waste produced 3,000 t/day is organic matter and proposals have been made to compost the material rather than incinerate it. This is expected to produce 2,100 t/day of compost for agricultural purposes.(p.13)

    - Another alternative for São Paulo is an anaerobic process that allows for electrical energy production. This may be a viable alternative because the waste generated in São

Paulo has three times as much organic matter as waste generated in Europe. The higher organic matter will lead to greater production of usable fuel. (p. 13)

- The city of Mogi das Cruzes has proposed building composting facilities to deal with their waste. Mogi is an agricultural area and therefore could provide a market for the compost product. Much of the land in the city is already being used and the city of Mogi is surrounded by an environmental reserve which prevents them from expanding further and therefore siting of a compost and landfill facility may be difficult.

- An alternative for São Paulo is an anaerobic composting plant where the energy produced could subsidize the transportation costs of moving the compost to a market willing to buy the product. (p. 23)

- AVECON International Ltd has developed technology which could convert organic household waste and sewage sludge into biogas (i.e. Methane and Carbon dioxide) which would allow for energy recovery. This would decrease the reliance on landfills and composting facilities and offer energy alternatives.

- Since there is so much waste produced in São Paulo smaller facilities should be constructed with a 45,000 t/a capacity that could operate two shifts daily.

- This alternative would cut down on the distance waste must travel. It would also allow access to various different markets for the final fertilizer product. (p. 25)

  [Table 6 on page 25 shows the composition of the waste.]

- [This alternative provides energy and compost as end products neither of which were mentioned in the report as being in great demand. Brazil already uses 94% hydropower and makes use of other "clean" energy sources i.e. natural gas, bagasse, energy forests, and fluidized bed combuster.]

- An anaerobic facility would be composed of a pretreatment plant: with a receiving silo, screen, crusher, magnetic separator, conveyor belt, control room and a biological treatment plant: with mix separators, biomass pumps, digesters, gas cleaning system, process water system, mechanical dewatering equipment, and bio-filters. (p. 27)

- The anaerobic alternative can facilitate the production of 12 Gwh/a and heat 19 Gwh/a.
    - The plant will consume 1.8 Gwh/a and 3.5 Gwh of heat.
    - The digested sludge would become 26.4 Mt/a of fertilizer.
    - If regulations permit, the surplus water (1,300 t/a) can be used for agriculture.
    - Twenty percent of the waste is inert material which must be separated and treated. This will amount to 10,000 t/a. (p. 30)

- São Paulo could use electrical energy production from the technologically prepared sanitary landfills with "eventual steam production for process related industries." (p. 24)

- The Biomass Integrated Gasification-Gas Turbine (BIG-GT) and Integrated Gasification Combined Cycle (IGCC) may be an energy source competitive with fossil fuels. This process could use paper mill wastes i.e. bark, paper, sludge to produce electricity.

- [Although this alternative would provide extra electricity it is limited as a solution to dealing with the country's waste problems.]

2.2.2 Evaluation of Management Alternatives

Cost

- The 1981 WTE proposal, if a cost of $14.60 US per ton of incinerated waste were assumed, would yield an annual revenue of $16,000,000 US and would allow an investment payback period of 6.2 years. (p. 10)

- For the Mogi alternative no cost analyses have been made and a characterization of the waste stream has not been completed. Therefore, estimating the cost of a compost facility is not possible. (p. 14)

Environmental Impact

- A waste-to-energy alternative can only be successful if steps are taken to guarantee adequate pollution control, including emission monitoring.(p.11)

- The anaerobic alternative would not remove any heavy metals from the end product and therefore may not be a useful agricultural fertilizer. (p. 27)

Integration With Waste Management System

Political Feasibility And Implementability

- A concern with a waste-to-energy alternative is that there must be political and administrative support where priority is given to social, sanitary, and environmental issues. (p. 11)

- The Mogi alternative does not address the issue of industrial waste and therefore does not have the support of the more than 50 industrial facilities in the city. (p. 14)

Other Goals

- If waste-to-energy alternatives are to succeed investment must come from the private sector this will insure that businesses take advantage of the opportunities associated with the urban waste problem in Brazil (p. 11)

- The Mogi alternative would also require a cleaning of the existing landfill and incineration of much of the waste. To accomplish this it may be necessary to form an international team to study the problem and develop the most economically feasible solution. This study would be useful to other cities throughout Brazil that are faced with similar problems. (p. 14)

2.2.3 Societal Considerations

Public Attitudes

Public Education Programs

Public Involvement

Laws And Regulations

- "In accordance with the 1988 Brazilian Constitution, in its article 30, the responsibility for the organization, collection system, transportation and final disposal of the urban municipal solid waste belongs exclusively to the municipalities.
- However, as it is a subject directly related to the public health, the federal government retains the authority to define the laws and regulations to be followed by the cities of the country.
- Meanwhile, there are organizations for each state, for instance, CETESB in São Paulo and FEEMA in Rio de Janeiro, which are responsible for the regulations and controls to be applied in their respective states.
- The consequence of the political organization pictured above, is that the municipal waste management does not present an uniform approach around the country." (p.12)

Overview Of Local Economies

- "The Federal Government of Brazil is without funds for investments and have serious deficiencies in the areas of housing, education, and health, and should encourage participation from the private sector."
- In the past the Federal Government has used the price of electricity to control inflation keeping the price unnaturally low. This has led to a situation where there is no incentive to improve energy efficiency. (p. 11)
- [The report cites energy prices in Brazil as being "US$ 4/kWh in the beginning of 1993" and "US$ 6/kWh in October of 1993" The report also cites the "normal international charge rate which is around US$ 8-9/kWh." These costs are ~100 times too high.] (p. 5)

2.2.4 Market Considerations

Markets For Recyclables

Materials Recovery Facilities

Composting And Environmental Impacts

- The primarily metropolitan area of São Paulo may have problems encouraging composting activities in the future. The areas surrounding São Paulo have also agreed to start composting efforts and their combined efforts may cause an over production of compost product. (p. 13)

Collection Systems

- Collection in São Paulo is completed by 9,000 employees and 730 trucks as well as private contractors hired by the city.
- Waste from residences is collected by compacting trucks which have a 7 t/trip capacity. Collections are either made daily or twice a week.
- Waste from sweeping is usually done once a week, although in some areas it is done daily. The waste is collected in plastic bags and then transported by the residential trucks.
- Waste from the "slums" is collected from large containers located in specific places. (p.19)

Source Reduction At The Local Level

2.3 Review and Identification of Missing Information by Country - Czech Republic

A summary of the necessary information provided in the case study is presented below by applicable section. Sections and/or subsections without information indicates that the report did not present information for that particular category. As necessary, ICF augmented the missing and/or incomplete information presented in the case study using information either contained in the technical literature or provided to us by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), and several vendors of waste-to-energy technologies.

2.3.1 Current Waste Management Situation

Demographics (population and industry)

- Kladno District: 20 km NW of Prague, 150,000 people, 99 communities.
- The biggest administrative center is Kladno: pop. 75,000.
- "The district has a great industrial potential with metallurgy and coal mining round Kladno and agriculture and other manufacturing industries in the northern part."(p.16)

Waste Streams (quantities and qualities)

- For the Kladno district, average annual amount per capita (domestic waste, street garbage, and back yard waste) = 0.39 tons.

"Average composition of household waste:
--derived from project results of the Local Management Research Institute of Prague."(p.18)

Household Waste Compounds	**%**	**t/yr**
Paper	9.6	4,566
Plastics	5.9	2,801
Textile	3.8	1,804
Wood	0.7	332
Kitchen waste	7.2	3,419
Iron scrap	5.8	2,754
Aluminum waste	0.5	237
Other metals	0.1	47
Glass and shreds	7.0	3,324
Inorganic waste	9.0	4,273
Ash and cinder	50.4	23,925
Total	*100%*	*47,482*

- It would not be appropriate to base any technologies on this information because as of 1997, it is 12 years old. The past 12 years have drastically affected the way of life in the Czech Republic. As stated in the report, "it could be expected that production of ash and cinder is lower due to the installation of natural gas lines in some central and local heating facilities and that the amount of aluminum, plastic and paper package materials have likely increased." (p.18)

- ***Those wastes with annual production >3000 tons in 1992: (p.22)***

Inert Waste (total)	*(433,702 t)*
Waste rock and ballast	392,952 t
Excavated soil	40,749 t

Ordinary Waste (total)	*(1,221,440 t)*
Agriculture and sugar refiner	662,346 t
Iron scrap	252,524 t
Rubble and construction debris	120,836 t
Coal sludge	21,668 t
Metallurgical waste	125,430 t
Metal shaping waste	14,130 t
Other ordinary waste	24,506 t

Special waste (total)	*(253,137 t)*
Waste from energy prod. (ash, cinder)	119,536 t
Electric furnace slag	109,245 t
Sewage treatment sludge	15,735 t
Spoiled vegetable products	4,285 t
Slaughter house waste	3,064 t
Other special waste	1,272 t

- "The volume of municipal waste generated annually in the district is 58,000 tons. This figure comprises domestic waste, street garbage and back yard waste. Average annual amount per capita in that district is 0.39 tons. In addition, there are other producers of 'waste similar to domestic' and their production is 5,570 tons...In the whole, the total figure of municipal wastes generated in the district is 63,750 t/yr. The communities are also responsible for rubble and reconstruction wastes (99,350 t/yr) and sewage waste from household septic and sewage tanks (118,870 t/yr)." (p.17)

Existing Waste Management System

- **"Municipal waste from towns, communities and other producers is neutralized as follows:** (p.20)

Method of Handling	Amount (t/yr)	%
Deposited to landfills	60,000	94.5%
Incinerated	974	1.5%
Composted	2,583	4.0%
Total:	*63,750 t/year*	*100%*

- "**Incineration** of domestic waste was recorded in three communities, even though a bigger portion of incinerated waste is anticipated. About 840 tons of domestic-type waste are incinerated at the energy center of Poldi Kladno under high temperatures. Waste is added to fossil fuel in ration 1:9 with no flue gas cleanup system. Most of this waste comes from a crushing and sorting facility for old cars." (p.19)

Existing and Anticipated Problems

- "*a) Limited landfill capacity and poor quality.*

In Kladno district, there are no landfills with proper containment, gas utilization, etc. None of the landfills meet requirements of the new regulation no. 513/1992. Fortunately, from the environmental point of view, waste disposal in these landfills has become progressively more expensive because of a special tax imposed on each ton of waste. The tax is higher in the case of landfills that are not well engineered. The additional taxes go to the Czech Environmental Fund." (p.20)

- "*b) Low charges and lack of investment in waste management:*

Most of the operators are community-owned companies and as an after-effect of the former economic system they have been hesitating to increase charges and develop market economy principles in waste management, mainly in the field of household waste disposal." (p.21)
The prices at landfills have been slowly increasing--see the Management alternatives--Costs section for more details.

- "*c) Low recycling:*

Extremely cheap disposal does not encourage people to recycle or minimize generated waste. It means that a lot of potential raw and potential recycling materials are deposited into landfills. The positive effects of the newly introduced system could be expected within two or three years."(p.22)

- *"d) a lack of separated collection of hazardous compounds in household wastes.*

  Thanks to stricter legislature issued recently, new neutralization facilities have emerged during the last two years (neutralization of fluorescent tubes, recycling of acetonic thinners). The only recycling scheme which was provided for car Pb accumulators (batteries) is now threatened by higher costs of transportation and stricter requirements on their storage in the recycling yards." (p. 22)

- *"e) Old landfill sites and potential pollution*

  Although a survey of most significant landfills in the district as completed, only few of them are regularly monitored, there is a lack of previous landfill records and nearly now reclamation projects are prepared."(p.22)

Management Goals

- Reduction in dependence on coal for energy

Management Alternatives

- The Report proposed the following:

  "An anaerobic digestion process suitable for organic household waste and sewage sludge which allows recovery of biogas thus giving possibilities to recover energy from this type of waste and to produce good type of fertilizer. This process is one solution to decrease the biological load on the disposal places, extract energy and usable end products from waste and improve the environmental conditions." (p.23) {This process takes place at an "anaerobic digester" or a "biogas plant"}

2.3.2 Evaluation of Management Alternatives

- Waste Composition used in the Biogas plant:

  The composition that they expect to treat with the biogas plant is:

Material	Percentage (%)	Amount (t/yr)
Organic kitchen waste	36%	5,400
Paper	30%	4,500
Plastics	12%	1,800
Metals	3%	450
Stones	3%	450
Glass	5%	750
Sand	5%	750
Textiles	6%	900
Sludge	(TS = 15%)	25,000

The total annual treatment capacity is 15,000 tons of municipal waste and 25,000 tons of sludge.

- Components of the waste treatment plant:

The waste treatment plant consists of 1) a pretreatment plant, and 2) a biological treatment plant. (see figures 4,5 on pages 25,27 for details on the two plants.)

The major components of the two plants are as follows:

Pretreatment Plant	*Biological Treatment Plant*
Receiving silo	Mix-separators
Screen	Biomass pumps
Crusher	Digester
Magnetic separator	Gas cleaning system
Conveyor belts	Heat Recovery
Control Room	Process water system
	Mechanical de-watering equipment
	Bio-filter

The end products of the system are: (p.26)

End product	**amount**	**remarks**	**final use**
Biogas	3.2 x 10^6 Nm^3/a	CH_4 59%	to be used in a power gen. plant
Digestive (slurry)	14,000 t/a	TS 35%	serves as fertilizer
Surplus water	18,500 t/a		to be used as a liquid fertilizer
Disposable products		3,900 t/a	the separated and treated 30% inert material

Sewage sludge and other organic waste serves as a fertilizer.

"The biogas is used in a power generation plant, producing electricity a total of approx. 6,000 Mwh/a and heat 12,000 Mwh/a. The internal electricity consumption of the plant is approx. 700 Mwh/a and the heat consumption is approx. 2,000 Mwh." (p.26)

Cost

- ***Anaerobic Digester***
  "The cost of the plant can not be given exactly before undertaking a thorough prefeasibility/feasibility to determine the parts that will be manufactured in the Czech Republic and those which are going to be imported." (p.28)
  a plant of this size can be operated 5 days a week, 8 hours per day by 4 operators.
  a similar plant in Vasa, Finland would be the appropriate location for on site, practical staff training.

- *Landfills:*

"Charges for waste paid at the entrance of landfills varied from 50 to 120 Czech crowns (Kc) per ton. Kladno citizens paid nearly 400 Kc annually for a 110-liter garbage can. However, in some small communities people paid negligible charges for household waste disposal. The total expenditures in the district were 13.31 million Kc, which means 78 Kc/head with a large difference between the Kladno catchment area and the rest of the district. Limited investments and low operation costs were the main reasons for the unsatisfactory state of waste management in the district as well as in the whole republic." (p.20)

The landfill tipping costs have been on the rise as shown below: (p.21)

Landfill groups	**Standard (Kc per ton)**	**Substandard (Kc per ton)**		
		1992	1993	1994
Soil and mine tailings	0	1	3	6
Ordinary waste	10	5	70	140
Household waste	20	20	70	210
Special waste	40	110	320	640
Hazardous waste	250	3000	4000	5000

Notice that there may be some incentive to address hazardous wastes separately as the price for its disposal is increasing rapidly.

Environmental Impact

- The end products still include 3,900 t/yr of products that must be disposed.
- Also, there is no discussion about possibly harmful metal residues.

Integration With Waste Management System

Political Feasibility And Implementability

Other Goals

2.3.3 Societal Considerations

Public Attitudes

- Judging by the "bring system," people seem willing to recycle. However, we do not have actual figures showing that this system was successful.

- "Solar, geothermal, wind, and biomass energy as well as energy from wastes, heat pumps etc. are still regarded as advanced gadgets which have not yet found any widespread use. One reason for that is the long years of subsidized energy prices. In the near future, these new and renewable sources will not be of any major importance. Nevertheless, state support will be given to the development of these sources [The pertinent bill is yet to be made into law.] for local projects." (p.15)

Public Education Programs

Public Involvement

Laws And Regulations

- With regards to environmental laws: "Legislation is rather advanced but enforcement is problematic."(p.10)

- "Waste management program was worked out on new legislative background in the Czech Republic. All essential laws, acts and notices were passed in 1991 and 1992 and they are quite similar to relevant mandates in Germany and Austria." (p.16)

- There is "abundant red tape including all levels of management in the fuels and energy sector."(p.7)

Overview Of Local Economies

- Have been dependent on energy imports.
- Current economic stagnation. (remember that this report was written in 1993)
- Being flooded by (mostly out-of-date) technology
- "Privatization and market competition are the main urgent tasks to start with in moving to conditions of market-oriented prices for energy." (p.9)

- ***Industry***: energy-intensive: "high share of metallurgy, heavy engineering and similar energy-consuming industries; the efficiency of energy utilization is low and the environmental impacts are considerable." (p.9)
  Coal is the dominant primary source of energy.
  "The policy of cheap power for industry resulted in a high waste of energy resources; power prices for industry sector are now climbing but they still lag behind the international level."(p.9)

- "Goal: to increase share of natural gas in energy production" (p.12)

2.3.4 Market Considerations

Markets For Recyclables

- "As a result of small-scale privatization, about 30 private entrepreneurs have merged and found small recycling yards. Unfortunately, half of them concentrate only on **attractive commodities** such as copper, lead, aluminum, and iron scrap." (p.18)

- There are numerous recycling yards which collect metals, iron scrap, paper, glass, leather, AC lead accumulators, textiles and film fixatives. (p.19)

Materials Recovery Facilities

- In 1992, "the Kladno District area started to be supplied by colored containers for separated collection of household waste. This is a starting point for the development of a so-called 'bring system' where people can bring sorted waste to these containers within their reach (5 minutes walk)." --> this shows that residents and the government are willing to make an effort to recycle!

The report goes on to describe 2 different test systems: collecting colored glass, clear glass and paper; and glass, plastic, paper, textile, and iron scrap.

Composting And Environmental Impacts

- "**Small scale composting** is operating in 22 communities, producing only 134 t/yr. of low level compost. Some unsound practice like the usage of fossil fuel ash as an additive cannot be excluded. Composting of 2,200 tons of crushed and screened household waste is done on more sophisticated level at Gondard facility in Libusin...Even that waste sorted at Gondard cannot meet requirements of Czech norm for "industrial composts" due to a high content of undesirable compounds (glass, small pieces of plastics) and due to heavy metals pollution (Hg, Cd, etc.). These composts are only used for industrial estate reclamations." (p.20)

Collection Systems

- **For the Situation in Kladno:**

  "the situation is **well organized collection and transportation (garbage cans and containers at the door and special delivery trucks) serves about 80% of the district's population.** Five to 10% of the population brings their waste to nearby bulk containers (within 10 minutes reach) and the rest of population transports waste to landfills by their own vehicles." (p.18)

- "There are several companies which are involved in household waste collection and transportation within the district:" (p., 17)

Company	**Number of communities, (population)**		**Central/local landfills, (locality)**
TS Kladno	24	(91,804)	central Libusin
TS Slany	5	(22,583)	local landfills
TS Stochov	5	(10,125)	local landfills
TS Slany	6	(3,984)	central (Nabdin)
OU Vinarice	4	(3,033)	central (Vin.hora)

- "In some marginal parts of the districts, household waste collection and transportation is provided by similar organizations from neighboring districts (mainly Kralupy). In some smaller communities transportation is provided by local agriculture cooperative companies but as a counter-service they usually use local landfills for dumping their waste." (p.17)

Source Reduction At The Local Level

2.4 Review and Identification of Missing Information by Country - Egypt

A summary of the necessary information provided in the case study is presented below by applicable section. Sections and/or subsections without information indicates that the report did not present information for that particular category. As necessary, ICF augmented the missing and/or incomplete information presented in the case study using information either contained in the technical literature or provided to us by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), and several vendors of waste-to-energy technologies.

2.4.1 Current Waste Management Situation

Demographics (population and industry)

- In Egypt arable land constitutes 4% of the total land area. Egypt is therefore classified as an "agriculture deficient" country. (p. 9)

- Despite the fact that there is little organic matter produced in rural areas biofuels provide 50% of their energy needs. (p. 9)

- Port Said City has a population of 300,000 and has 70,000 housing units (p. 17)

Waste Streams (quantities and qualities)

- Sources of biomass in Egypt are:

    - agriculture and livestock wastes
    - poultry waste
    - municipal refuse
    - sewage sludge (p. 10)

- Sewage waste consists mainly of human excreta and variable quantities of industrial effluent. The potential for human excreta based on the population from (1980-1988) is 3-3.7 million tons of dry solids. By 1995 the figures were expected to reach 4.44 million t/yr. (p. 15)

- Municipal solid waste is household and commercial refuse. In Egypt solid waste consists of: (p. 15)

waste food	50 - 60%
paper	15 - 13%
metals	3.5 - 3%
glass	3 - 2.5%
plastics	2 - 1.5%
bones	1.2 - 1%
rubber	0.6 - 0.5%
scrap	3 - 2.5%
other	21.5 - 16%

- Compostable and digestable material constitutes 75% of the solid waste stream. Based on the population figures from 1980-1988 the amount of solid waste for these years is expected to be around 4.5 - 5.6 million tons. Using these figures the amount of solid waste would be 6.75 million tons by the year 1995. (p. 15)

- Organic waste in Port City: (p. 17)

Municipal solid waste in t/day	150
Sewage waste in tons of dry matter/day	60
Animal waste in tons fresh manure/day	50
Industrial organic waste in t/day	5
TOTAL	215

- Slaughter houses present another form of organic waste. One slaughter house in Cairo produced: (p. 25)

Animal	**Capacity (heads/day)**	**Manure (50% solids)**	**Washing H_2O (2.3% blood+organic)**
Camel	85	17	70
Cow	350	35	140
Sheep	850	13	50
Pig	150	0.6	15
Stable		20	
Total	1435	85.6	275
	500 kg/day condemned meat		

- Food processing facilities produce organic waste in the form of: (p. 28)

Digestable organic waste	6.65 t/day
Indigestable organic waste	2.75 t/day
Total organic waste	9.40 t/day
Working days/year	365 days

Existing Waste Management System

- Biomass resources are inefficiently used. These resources are exposed to direct combustion in open fuel wood stoves and ovens in villages. Poultry, municipal, and sewage resources are used only as fertilizer. (p. 10)

- Agro-Industrial wastes are derived from the handling of the available biomass in Egypt. This waste is burned which wastes energy as well as causing ecological problems. (p. 11)

- Bagasse from the sugar cane industry and rice husks are used for energy production. Of the 3 million tons of bagasse, 70% is used as fuel in the sugar industry, a significant portion is also used in brick manufacturing. (p.11)

- Organic waste matter is drained into lakes, sea, or other waterways. Part of the waste is used directly as fertilizer or burned in an uncontrolled environment. (p. 16)

- At the slaughter houses the washing water is drained directly into the sewage network. (p. 25)

- Part of the manure is used as fertilizer and the rest is dumped into landfills. (p. 25)
- The condemned meat is either burned or dumped into landfills. (p. 26)

Existing and Anticipated Problems

- Demand for energy in Egypt is greater than the available supply. (p. 2)
- The air is polluted due to inefficient burning and emission of greenhouse gases. (p. 16)
- In Port Said City the garbage collectors (Zabbalin) have a "miserable situation leading to bad social situations." (p. 17)
- Industrial and sewage waste have been improperly treated affecting sea and lake water pollution, fishing, and public health. (p. 17)
- Secondary energy recovery measures have been ignored thus wasting potential energy. (p. 17)
- Food processing factories have organic refuses that are not treated properly. The majority of the wastes are drained into the surrounding waterways or are burned. In addition to organic wastes there is also a lot of industrial waste Heat lost in these factories. (p. 28)
- In food processing facilities hot waste waters have a concentration of 0.5% organic matter that is drained into the nearest water stream. The indigestable and digestable wastes are also drained into these same waterways. (p. 28)

Management Goals

- A waste management alternative should provide electrical energy either through conservation or "production." (p. 3)
- A solution must have the technical feasibility and economic attractiveness to encourage the private sector to take part with minimum government intervention. (p. 16)

Management Alternatives

- [**Table 3. Rough Estimations of Potential Number of Digesters for Rural Areas of Egypt Classified According to Type and Characteristics** demonstrates the potential effect of the use of biogas technology in rural areas.] (p. 12)
- [Table 4 is mentioned to prove that the number of biogas units could reach one million. With this many units 0.9 million tons of kerosene equivalent could be produced each year. This could serve 9 million people in rural areas, if the system is working at full capacity. (Table 4 as labeled does not appear to be included in the report.)] (p.11)
- Proposals have been made for the construction of improved technology biomass fired power plants; large scale biogas plants that use solid waste; medium and household scale biogas plants

that use animal and agricultural wastes; large scale factories for fertilizer production from solid wastes and gasifiers. (p. 15)

- [Table 5. Expected annual biomass resources of Egypt in the year 2000 displays the expected results of the construction of a biomass digester.] (p. 16)

- [Figure 6 shows a flow diagram describing the proposed method of dealing with the waste management situation. This process will generally involve separation of wastes, recycling, biogas technology, and land filling.] (p. 19)

- Part of the Port Said City solution involves the production of an anaerobic digester which allows for the recovery of methane and carbon dioxide from organic household wastes and sewage sludge. (p. 20)

- The amount of solid waste is 60,000 t/a. It is proposed that smaller plants of 30,000 t/a capacity be built each having a two shift operation schedule. (p. 20)

- The end products of this process are compost, biogas, and electricity/heat. (p. 20)

- The assumed start values are as follows: (p. 20)

Material	**Percentage**	**Amount (t/yr)**
Organic kitchen waste	64%	19,200
Paper	13%	3,900
Plastics	11%	3,300
Metals	3%	900
Stones	3%	900
Sand	3%	900

- The waste treatment plant consists of a pre treatment plant and a biological treatment plant. (p. 22)

pretreatment: receiving silo
screen
crusher
magnetic separator
conveyor belts
control room

biological: mix separators
biomass pumps
digester
gas cleaning system
heating system
process water system
mechanical dewatering system
bio-filter

- The end products are as follows: (p. 22)

Material	**Amount**	**Remarks**
Biogas	3.9 x 10^6 Nm^3/a	CH_4 58%
Digested Sludge	17,600 t/a	TS 35%
Surplus Water	870 t/a	
Disposable Products	6,500 t/a	

- The end products can be used in the following ways:
    - Biogas can be used in a power generation plant producing 8 Gwh/a and heat 13 Gwh/a. The internal energy consumption is 1.2 Gwh/a and heat 2.3 Gwh. The total gross energy content of the biogas is 23 Gwh/a. (p. 24)
    - Digested sludge is a good fertilizer and can replace imported fertilizers. The usable portion of sludge will be 17.6 million t/a. The sludge will contain heavy metals and therefore may not be able to be used for agricultural purposes. (p. 24)
    - The surplus water, if regulations permit, can be used for agriculture in the amount of 900 t/a. (p. 24)
    - The waste is assumed to contain more than 20% inert material which must be separated and treated. The amount of inert material is expected to be 7,000 t/a. (p. 24)
- [Figure 10 outlines the proposed solution to the waste management problems in slaughter houses. Generally, the proposal includes creating a market from fertilizer, treating waste water, conservation of heat and the use of organic waste materials to produce electricity.] (p. 28)
- A solution to the food processing facilities waste management problems is outlined in Figure 12 which states generally that through energy conservation and cogeneration heat losses will be prevented and biotreatment processes will be used to break down digestable matter and a boiler will be used to dispose of indigestable matter. (p. 28)
- The proposed solution to the waste problems in the tourist villages along the Red Sea and South Sinai are outlined in Figure 15. Generally, they involve the conversion of solid waste to biogas and the creation of a "green area" where waste water and fertilizer could be applied. In this system electricity would be both provided and conserved (p. 36)

2.4.2 Evaluation of Management Alternatives

Cost

- The proposals for biogas technology have not been realized primarily due to financial difficulties. (p. 15)
- The Port Said City solution is both technically feasible and economically attractive (p. 20)
- The cost of the suggested solution in Port Said City is estimated at $8.1 million US for a plant with a capacity of 30,000 million t/yr. (p. 25)

Environmental Impact

- The proposed solution for Port Said City will produce proper treatment with minimum effects on the environment. (p. 20)
- Efficient recycling of organic wastes especially potential energy production wastes. (p. 20)
- The slaughter house solution will insure the proper treatment of all waste with minimal effects of the environment. It will also involve efficient recycling of all available waste material. (p. 28)
- The food processing facility will insure proper recycling of all waste material. (p.31)

Integration With Waste Management System

- The Port Said City solution will help the Zabbalin realize a better social situation. (p. 20)
- The food processing solution can be easily duplicated in other facilities. (p. 31)

Political Feasibility And Implementability

- Many rural villages are clustered together and there is little land available for siting waste treatment facilities. (p. 10)
- Many rural households do not have an abundance of animal wastes because few of them own animals. (p. 10)
- Biogas Technology has been less than successful in many developing countries because government agency officials have not integrated it with the existing social systems. (p. 11)
- The food processing facility solution will be both technically and economically feasible. (p. 31)

Other Goals

- The slaughter house solution will provide energy. (p. 28)

- The food processing facility's solution will aid in the production of energy as well as the conservation of energy. (p. 31)

2.4.3 Societal Considerations

Public Attitudes

Public Education Programs

Public Involvement

Laws And Regulations

Overview Of Local Economies

2.4.4 Market Considerations

Markets For Recyclables

Materials Recovery Facilities

Composting And Environmental Impacts

Collection Systems

Source Reduction At The Local Level

2.5 Review and Identification of Missing Information by Country - Guyana

A summary of the necessary information provided in the case study is presented below by applicable section. Sections and/or subsections without information indicates that the report did not present information for that particular category. As necessary, ICF augmented the missing and/or incomplete information presented in the case study using information either contained in the technical literature or provided to us by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), and several vendors of waste-to-energy technologies.

2.5.1 Current Waste Management Situation

Demographics (population and industry)

- Industries include: Bauxite mining, Gold mining (small scale and Omai mines), Sand, and Diamonds (p. 3)

- 66 sawmills; 47 food processing plants; 5 distilleries/breweries; 7 sugar refineries; 9 detergent/soap manufactures; 8 metal-working/foundry operations; 6 chemical/pharmaceutical companies and 4 plastics companies. (p. 10)

- Georgetown has a core population of 80,000 and a greater area population of 200,000 (p. 6)

- Guyana has five constituted municipalities: Georgetown; New Amsterdam; Linden; Corriverton; and Rose Hall.

- 32.2% of the country's total population (800,000) live in these urban areas. (p. 7)

- Eighty percent of Guyana is forest land; 6% is permanent pasture; 2.4% is suitable for cultivation; and 11.6% does not fit into any of these categories (p. 2)

- Guyana is subject to both seasonal droughts and seasonal flooding (p. 2)

- The city of Georgetown sits 2 meters below sea level but has a protective sea wall and an assortment of canals and drains. (p. 7)

Waste Streams (quantities and qualities)

- Municipal wastes in rural areas consist mainly (87%) of organic wastes. The rest, which consist of metal, glass, dust represent 13% of the total wastes. (p. 6)

- The city of Georgetown generates 60 tons of solid waste per day. This is the equivalent of 200 g/person/day.

Table 1. Household Waste Composition

Item	Percentage by weight
Food	21.5
Garden & Yard	29.8
Paper	14
Plastic	9.4
Rubber & Leather	1.4
Textiles	8.6
Wood	2.4
Ferrous Metals	3.7
Copper	0.01
Aluminum	0.7
Non-Ferrous (Other)	0.0
Glass & Ceramics	2.4
Dirt, Rubble, Ash, Rock	6.1

- Special wastes consist mainly of hospital wastes: general, pathological, chemical, infectious, "sharps," and pharmaceutical wastes. (p. 12)

- **Table 3. Municipal Solid Waste Composition in Georgetown (p. 18)**

Material	Percentage	Amount t/yr
Organic kitchen waste	57%	5,700
Paper	14%	1,400
Plastics	9%	900
Metals	4%	400
Stones	7%	700
Glass	3%	300
Rubber & Textiles	5%	500
Sludge	N/A	15,000

- This provides a capacity of 10,000 tons of "biowaste" per year and 15,000 tons of dewatered sewage sludge (TS = 15%) per year. This is the equivalent of 40 t/day of "biowaste" and 60 t/day of dewatered sewage sludge. (p. 20)

Existing Waste Management System

- Omai Gold Mining operations use a "standard waste disposal system" consisting of a tailings dam and aeration pond to treat the water-cyanide solution before it is discharged into the river. (p. 5)

- The sewage after being mechanically minced is directly discharged into the environment, causing odor nuisance and hygienic problems, after which it flows to the river. (p. 5)

- The main sewage system in Georgetown covers 80,000 residents. The rest have septic tanks which are not emptied regularly. Neither of these wastes are treated because of the absence or malfunction of treatment facilities. They are discharged into the Demerara River. (p. 6)

- Industrial waste is discharged into rivers without treatment. (p. 6)

- Sanitation in the Georgetown area is: (p. 15)
  Sewer system (no treatment) - 49,000 pop.
  Septic tank & filter box - 103,000 approx.
  Pit latrines -8,000
  Public toilets -8

- Georgetown is the only municipality with liquid waste disposal. Its system is as follows:

- Central Georgetown: the waste treatment facility covers 1.6 acres and serves one-third of the city's 80,000 residents. It was constructed in 1929 and has 24 pumping systems on a ring main or trunk sewer. Power outages, aging pumps, and solid waste dumping interfere with flow and discharge into the lower estuary of the Demerara River.

- University of Guyana Campus: The sewerage system was installed 20 years ago to serve the campus but is currently inoperative.

- Tucville area: the sewer system in this area does not have an operative plant at this time. (p. 7)

- Outside of the Georgetown communal sewerage system septic tanks and pit latrines are used to serve the remaining 120,000 people in the city. All other communities in Guyana use similar methods to deal with waste. (p.7)

- The current waste incinerator works at 10% capacity. A new landfill location is being explored outside of the city area. (p. 9)

- Agricultural lands are drained into nearby waterways, and solid waste matter is burnt or composted. (p. 12)

- Hospital wastes are bagged in plastic, collected, and taken to the old incinerator. (p. 12)

Existing and Anticipated Problems

- The sugar industry relies on herbicides and pesticides whereas, the rice industry relies heavily on pesticides and fertilizers. (p. 3)

- Sawmill wastes are increasing water turbidity and BOD as well as creating a solid waste problem. (p. 3 &10)

- Mercury poisoning may cause a problem with the gold mines either from contact with skin or through inhalation. Inhaling mercury can cause permanent damage to human nervous system and can be fatal.

- Mercury from these facilities is often released into the environment where it becomes an accumulative pollutant and can become concentrated in the food chain. (p. 4)

- [Although the report did say that testing has not concluded that this is currently a problem]

- The handling , transportation, and operation of hazardous mining related materials has been a problem in recent years. In the course of the last year three accidents took place and cyanide was reported to have been leaked to the environment in two occasions. (p. 5)

- [This may suggest that at least preliminary treatment of mining wastes should occur on site. This may be more feasible at the larger mines]

- [A discussion of Potential Negative Impacts for Liquid Waste and Solid Waste are located on page 13 and 14]

- Many rural areas in the interior are not easily accessible, and improvement activities must be self-sustaining. (p. 10)

- Agricultural wastes, most notably fecal material, are often put in open deposit storage areas that runoff with rainfall and may drain into adjacent rivers and place an unnatural demand for their oxygen. (p. 11)

- [There was mention here of cradle-to-grave disposal regulations for all herbicide, pesticide and fertilizer containers and products to guard against partially treated wastes leaching into groundwater]

- Without a trained workforce, an adequate budget, and improved technical operations no satisfactory solid waste management program can be implemented. (p. 17)

Management Goals

- Extend coverage to all new homes and other buildings in the Georgetown area. Study the results of these improvements and focus on other urban areas. (p. 15)

- Special attention should be paid to improving the operation and maintenance of the sewerage systems in Georgetown. This includes increased budget and manpower to put in place and guarantee improved operation and maintenance procedures. (p. 16)

- Increase collection of waste to two or three times a week to guard against illegal dumping (p. 17)

- As part of the sewage extension, the question of treating the sewage before it is discharged into the Demerara River should be examined in the hope of installing preliminary treatment facilities to reduce the polluting potential of the city's sewage. (p. 16)

Management Alternatives

- To deal with sawmill wastes it was suggested that a study provide information on the feasibility of using sawmill waste *in situ* as fuel in its own power plant through gassifiers-prime mover; surplus could be densified, transported and sold as a substitute to fuel wood. (p. 6)

- [this may prevent some of the dependence of rural people to burn organic/ biomass as fuel and allow these products to be used a fertilizer instead]

- Alternatives for industrial waste water disposal:

    1. collection in public sewers and treatment in the same plant as domestic sewage
    2. treatment before individual wastewater disposal into a water body of acceptable size for adequate dilution
    3. maintain the status quo. (p. 16)

- [information about the city sewer system should be gathered (i.e. is it a combined or separated system) from the storm water system. Adding additional volumes of water to a facility already working at or above capacity may cause additional problems]

- The implementation of an anaerobic digestion process that could deal with organic household waste and sewage sludge. (p. 17)

- This alternative consists of a:

  - pretreatment plant with a receiving silo, screen, crusher, magnetic separator, conveyor belt, and control room and a;

  - biological treatment facility with a sewage sludge receiving tank, mix separator, biomass pump, bioreactor/digester, gas cleaning system, heat recovery, process water system, mechanical dewatering equipment, and biofilter. (see figures 3 and 4)

- The mix separator and twin reactor remove the stones, plastic, and glass which cannot be digested. The resulting sludge will therefore be of a higher quality for agricultural purposes. (p. 22)

- The end products of the anaerobic process are: (p. 22)

Material	**Amount**	**Remarks**
1. Biogas	1.8×10^6Nm (3/a)	CH_4 61%
2. Digested Sludge	8,400 t/a	TS 35%
3. Surplus water	12,000t/a	
4. Disposable Product	2,500 t/a	

- The end products can be used in various ways:

  - Biogas can produce 4,000 Mwh/a and heat 6,000 Mwh/a. The internal usage of the plant for electricity is 450 Mwh/a and the heat consumption is 750 Mwh.
  - The sludge produced can be used as a fertilizer and the production should yield 8,500 t/a. (The actual allowable uses will depend on local regulations concerning, in particular heavy metals.)
  - Waste water, if no regulations prohibit it, should be spread on fields (12,000 t/a) otherwise it should be treated in a waste water treatment facility.
  - The disposable products are all inert substances and should therefore be able to be disposed of safely. (p. 24)

- The facility itself can be operated 5 days a week 8 hours a day by 4 operators not including administrative personnel. Training can be conducted by the operators at a similar plant in Vasa, Finland. (p. 24)

2.5.2 Evaluation of Management Alternatives

Cost

- The anaerobic digestion alternative reduces transportation costs of fertilizer end product by reducing the mass of the product

- Since the plant should cause no harm to neighbors it can be centrally located which will reduce collection and transportation costs. - The plant is more compact than other alternatives and therefore land space and costs are minimized. (p. 17)

- The use of bio-fertilizers will decrease import of chemical fertilizers, which will cut costs for agriculture production. (p.18)

- Determining an exact cost for the facility is difficult since there will be site specific modifications that must be made but it should be around $7 - 9 million US. (p. 24)

- [It was not clear whether this figure included the cost of finding an appropriate site and obtaining the necessary permits (if applicable)]

. *Environmental Impact*

- The sawmill alternative would: prevent water pollution from sawmill activities and decrease air pollution by using a renewable biofuel. (p. 6)

- Anaerobic digestion is environmentally sound on the national, regional, and international scales.
- In addition, it prevents health risks for neighbors and staff by having a closed process. (p. 17)

- [It is not clear what is meant to be done with the sludge if there are regulations already in place that put restrictions on the allowable levels of heavy metals that can be applied to agricultural areas.]

Integration With Waste Management System

- In the anaerobic digestion alternative both organic matter and refuse derived fuel (RDF) are used as domestic fuel to produce energy. (p. 17)

Political Feasibility And Implementability

- In the anaerobic digestion alternative fertilizers, metal scraps, and glass can be produced from the waste. (p. 18)

- The technology for the anaerobic digester is not sophisticated and therefore can be easily transferred. (p. 18)

Other Goals

2.5.3 Societal Considerations

Public Attitudes

- Management of industrial wastes has lower priority than municipal wastes in Guyana, which like many developing countries, encourages industry regardless of any resulting environmental problems. (p. 6)

- Rural peoples, especially Amerindians, do not accept external changes of their social systems easily. (p.10)

- A stigma attached to solid waste perpetuates its management with a low level of untrained workers. (p.15)

- Typical local government health scenario- the problems are known and understood, but the solutions are not in the present socio-economic climate. (p.16)

Public Education Programs

- Education efforts have been largely ineffective; however, a regular Clean-up Campaign in the city has been effective, and a Women-and-Environment movement has shown promise. (p. 15)

Public Involvement

- Mining and other companies are assisting the local governments by providing water and waste management to the public. (p. 15)

Laws And Regulations

- Environmental Policy is not clearly defined although a National Environmental Action Plan (NEAP) and National Environmental Policy (NEP) are in the process of development and approval. (p. 1)
- Relevant current acts: The Water Authority Act, The Demerara Conservancy Act, Sea Defense Act, The Fisheries Act, Transport and Harbors Act, Drainage and Irrigation Areas Act, Municipal and District Councils Act. (p. 1)

Overview Of Local Economies

- Except for the mining and forestry companies, funding for activities and cost recovery possibilities are minimal. (p. 10)

2.5.4 Market Considerations

Markets For Recyclables

Materials Recovery Facilities

Composting And Environmental Impacts

Collection Systems

- The City Council responsible for solid waste collection was dissolved at the beginning of the year, and an Interim Committee is taking over the work. (p.6)
- The city's lack of collector vehicles has led to the use of contractor vehicles. However, these contractors are often not paid which leads to non-collection of solid waste or the dumping of waste in nearby public areas rather than at the distant official site. (p. 8)
- Collection is complicated by the fact that there is little separation between garden waste and indoor waste.

- There are 19 city collectors, 10 contract collectors, and two private collectors.

- Uncovered loads account for 37% of the loads.

- The frequency of collection is as follows:

  town- weekly
  market- daily
  residential- bi-monthly
  hospital- daily
  others- daily (p. 8)

Source Reduction At The Local Level

2.6 Review and Identification of Missing Information by Country - Hungary

A summary of the necessary information provided in the case study is presented below by applicable section. Sections and/or subsections without information indicates that the report did not present information for that particular category. As necessary, ICF augmented the missing and/or incomplete information presented in the case study using information either contained in the technical literature or provided to us by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), and several vendors of waste-to-energy technologies.

2.6.1 Current Waste Management Situation

Demographics (population and industry)

Waste Streams (quantities and qualities)

Existing Waste Management System

- "Large producers can be considered the same as in any other countries as Hungary is well managed in the field of waste collection. Transportation system can be considered modern and is supplied with western type of special trucks. The payment system is totally centralized: self-governments collect fees from citizens, and the public utilities get a budget from self-governments." (p.34)

- "Municipal wastes of the capital are processed in a modern incineration plant. This has been operating for some years so its expected age can be considered several decades. Also hospital wastes partly serve as fuel for indoor boilers."(p.34)

- "The general way of waste management for municipal wastes is landfill in the country. Landfills are generally not technically designed, not supplied with drainage systems and artificial protecting layers, but mostly natural reservoirs."(p. 35)

Existing and Anticipated Problems

Management Goals

- "The main goal of the current energy policy is to eliminate the unilateral import dependency and to establish the opportunities of diversified supply." (p. 30)

- Energy system modernization, (see page 31 for more detailed, energy-related goals.): all of this has very little to do with waste management.

- Improving environmental protection.

- The report does not have goals which involve waste management.

Management Alternatives

- The report proposes a cogeneration diesel power plant which uses "natural gas, heavy fuel oil and light fuel oil as fuel. The electric energy is produced by a diesel generator set, enabling high fuel efficiency in a wide load range." (p.36)

- "Heat will be recovered in exhaust gas boiler and also of engine block cooling water, charge air and lubrication oil by heat exchangers." (p.36)

- The plants they propose will be meant for smaller communities--This allows combined heat and power production. (p.35)

2.6.2 Evaluation of Management Alternatives

Cost

- "Hungary has been granted favorable and long-term loan for investments which is a must for building power plants." (p.35)

Environmental Impact

- The most important benefit of the cogeneration is that "the heat and power is produced in the same power plant. This means considerable reduction of fuel consumption compared to the separate production."(p.37)

- The emissions are environmentally benign or controllable. (p.38)

- The plant is designed to meet noise regulations. (p.38)

- "The changing trends towards decentralized small scale heat and power production and natural gas becoming increasingly important due to its environmental friendliness. A Wartsila diesel power plant concept fulfills the present energy policy targets of efficient power production and environmental protection." (p.36)

Integration With Waste Management System

- There is no discussion of integration with waste management system, thus this report is fairly irrelevant.

Political Feasibility And Implementability

- "Most of the large power plants (above 100 MW) will not be cogeneration and it is obvious because such a big heat load which is required to dump the heat is not available or there are too few of them." (p.35)
- Various criteria and applications are discussed on pages 36,37.

Other Goals

2.6.3 Societal Considerations

Public Attitudes

- Hungary is similar to other developed countries, thus it can be assumed that the public expects a well-managed waste management system.

Public Education Programs

Public Involvement

Laws And Regulations

- "Officials managing public utilities can not give data on the waste composition and amounts of wastes without the authorization by the Ministry of Internal Affairs." (p.34)
- "Supervision of hospitals--as main sources of the biological wastes--belongs to the Ministry of Health Care."(p.34)
- Public utilities are responsible for the collection and management of municipal, societal and biological wastes. This can be considered to be a well managed sector with a regular collection of household wastes, cleaning the streets and collecting societal wastes regularly from institutions." (p. 34)

Overview Of Local Economies

- Currently dependent more on natural gas than on oil; coal = an average share; nuclear power = more than average share. (p.29)
- Current energy situation is extremely harmful to the environment.
- "Costs of disposal are increasing." (p.29)

2.6.4 Market Considerations

Markets For Recyclables

Materials Recovery Facilities

Composting And Environmental Impacts

Collection Systems

- Hungary being very similar to any other developed country has a similar well-managed collection system with western style trucks

Source Reduction At The Local Level

2.7 Review and Identification of Missing Information by Country - Romania

A summary of the necessary information provided in the case study is presented below by applicable section. Sections and/or subsections without information indicates that the report did not present information for that particular category. As necessary, ICF augmented the missing and/or incomplete information presented in the case study using information either contained in the technical literature or provided to us by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), and several vendors of waste-to-energy technologies.

2.7.1 Current Waste Management Situation

Demographics (population and industry)

Waste Streams (quantities and qualities)

- "According to the data made available by the town hall of Bucharest municipality, the wastes resulted in the capital are:" (p. 53)

Domestic wastes	5,500 m^3/day
Street wastes	800 m^3/day
Industrial wastes	1,200 m^3/day

This is equivalent to about 800,000 - 900,000 t/yr.

Existing Waste Management System

- "Up to the present, these wastes were collected and stored in pits. For environmental protection reasons and as a consequence of the problems raised by storing wastes in such a volume, it was tried to incinerate them. Thus, two pilot units were built, based on Romanian design, in Militari and Pantelimon areas, each one being equipped with two lines for wastes processing with a rated capacity 5 tons/hr. The technique used is that of 1970's and the incineration technology applied produces noxious chemical compounds which are not retained by the gas discharge units, in amounts exceeding the present regulations concerning the environmental protection. The reliability of the mechanical system is low, and it can only be used for less than 505 of the annual operating time. For these reasons, the pilot units cannot represent a final alternative to solve the problem of the collected wastes in Bucharest municipality." (p. 53)

- "In Romania there is no coal gasification combined cycle, but there are pilot plants in operation in Bucharest. At the same stage of development is the application of pressurized fluidized bed combustors." (p.50)

- "Biothermal fermentation of wastes has been developed in Romania with stimulating results for digesting most of animal wastes from farms and to a lesser extent domestic wastes. The use of this method is the advantage that wastes can be wholly turned to best use as after completion of fermentation, the resulted product has a calorific power about 6.5 kWh/m^3

  This sludge could be dried and used as briquettes for combustion or fertilizer in agriculture. They have the advantage, compared with the synthetically fabricated fertilizers, that the former are biologically degraded and do not pollute the soil, surface and ground waters neither they produce GHQ as Nitrous Oxides."(p.52)

- "The average consumption of methane gas for Bucharest populations (about 2 millions inhabitants) is 7.56 PJ. On the other hand, the amount of wastes collected in Bucharest is roughly 0.8 kg per capita/day, therefore 300 kg/y per capita, which is roughly 600,000 t/yr."(p.52)

Existing and Anticipated Problems

Management Goals

- There have been numerous studies "regarding the improvement of energy efficiency and decreasing environmental emissions made by foreign companies as well as by Romanian research and development institutes." (p.47) Their conclusions are discussed on pages 48-50:

A) Improving Energy Situation: (p.48)

- "Romanian government being aware of the importance of encouraging more efficient energy production and use, has created in 1991, ARCE, National Agency for Energy Conservation....The Agency's strategy includes:"
- Promotion of specific research for energy efficiency equipment
- Promotion of NO_x reduction
- Encouragement of investments in energy efficiency
- Promotion of international cooperation in technical assistance, information dissemination, demonstrative actions, training and logistic support.
- Institutional reinforcement.

B) Decreasing Emissions from Energy Production: (p.49-50)

- "RENEL's policy for decreasing the emissions from energy production is given below:"
- Policy for the environment:
- Upgrading and control of combustion processes

  - Energy generation improvement through clean fuel technologies
  - Increasing the performances of electrostatic precipitators.
  - Endowing power plants with measuring and monitoring equipment for emissions.
  - Ash Utilization
  - Promoting energy efficiency policy to own equipment, aimed at the consumers.

- Romania is planning its future investments and also other projects on LNWT (Low and Non-Waste Technology).(p.51)

Management Alternatives

- "Cogeneration gives...flexibility for the general parameters of the system. Concerning waste using in energy production, emphasis should be put on biogas technology, incineration and gasification." (p.52)

2.7.2 Evaluation of Management Alternatives

- "A pilot plant is suggested to treat a part of the solid waste in the city of Bucharest. The treatment capacity of the plant is assumed to be 60,000 t/yr; and the composition of the waste is assumed as follows:" (p. 53)

Waste Composition

Material	**Percentage (%)**	**Amount (t/yr)**
Organic kitchen waste	81%	48,600
Paper	8%	4,800
Plastics	3%	1,800
Metals	4%	2,400
Stones/dust	1%	600
Glass	3%	1,800

The waste treatment plant consists of 1) a pretreatment plant, and 2) a biological treatment plant.

The major components of the two plants are as follows: (p.53-54)

Pretreatment Plant	***Biological Treatment Plant***
Receiving silo	Mix-separators
Screen	Biomass pumps
Crusher	Digester
Magnetic separator	Gas cleaning system
Conveyor belts	Heat Recovery system
Control Room	Process water system
	Mechanical de-watering equipment
	Bio-filter

- "The Finnish process known as Waasa process includes components as the Mix-separator and the Twin digester which remove efficiently undesired materials such as glass, stones and plastics from the end products. This makes the input staff of much higher quality than in conventional composting, hence the sludge could be used directly in the field. The anaerobic process does not, however, remove metal trace, and the decision to remove them rest with the consumer. The percentage of the metal trace in the sludge depends to a great extent on the amount of industrial waste mixed with municipal waste." (p.54)

- End products

"The output corresponding to the input materials mentioned above is as follows:" (p.54)

End product	amount per year	remarks	final use
Biogas	6.6 x 10^6 Nm^3/y	CH_4 59%	used in a power gen. plant
Sludge	24,000 t/yr	TS 35%	serves as fertilizer
Surplus water	21,000 t/yr		used as a liquid fertilizer or treated
Disposable products	7,000 t/yr		separated/treated/disposed.

- "The biogas is to be used in a cogeneration diesel plant to produce electricity of about 13 Gwh/y and heat of about 21 Gwh/y. The electricity consumption of the plant itself will be roughly 2.7 Gwh/y and the heat consumption, 2.5 Gwh/y." (p.54)

Cost

- The Government of Romania is currently seeking funding from a variety of sources including the World Bank, the EC, and foreigner organizations. "Romanian towns have their own funds allocated by the Romanian Government from the National Budget to improve the environmental conditions." (p.52)

- "A plant of the above size will operate 5 days a week and 16 hours per day (two shifts). It will thus need 2 x 5 operators. Training of the operators on new plants could take place on site in Waasa which has been operating since 1990. The cost of constructing such plant in Romania could be given only after undertaking a detailed pre-feasibility/feasibility study to determine exactly the parts that are going to be manufactured locally and those which are going to be imported." (p.54)

Environmental Impact

- The report discusses Romania's general environmental status with respect to air quality, surface waters, and ground water quality on pages 46-47. {Are more details needed here?}

- "Cogeneration or the simultaneous production of electricity and heat is a well established technology which has proven its technical and economic viability for many years in Romania." (p.50)

- "Cogeneration plants save annually more than 30% of the primary energy. In other words, the cogeneration unit consumes about 65% of the fuel needed for running two single plants producing the same output of electricity and heat. This subsequently means that the cogeneration plant will produce about 32% less pollutants than two single plants producing the same amount of electricity and heat." (p.50)

- "The environmental impacts of So_x, No_x and CO_2 are already known but the benefits of decreasing their emissions could be difficult to estimate in terms of money. What is sure is the costs of controlling these pollutants in two separate plants are more than the costs of controlling them in one cogeneration plant." (p.50)

- "in addition to normal savings in building and running a cogeneration plant in comparison to two single plants, the environmental savings will also result from: scrubbing particulates, scrubbing No_x, controlling So_x, controlling CO_2." (p.50)

Integration With Waste Management System

Political Feasibility And Implementability

Other Goals

2.7.3 Societal Considerations

Public Attitudes

Public Education Programs

Public Involvement

Laws And Regulations

- When this report was written, Romanian legislation concerning energy was undergoing major transitions. The energy prices are becoming market oriented and are therefore increasing rapidly. (p.45) As of 1993, Romania's electricity prices were still low compared with western European countries. (0.035 US$/kWh) However, the ratio of "kWh price/average monthly wage" in Romania was approximately 5 times higher than in Germany or France. These unique economic aspects of a different price scale needs to be considered.

Overview Of Local Economies

- "After 1989, the decline in the electric and thermal energy production was due to decrease of the demand in industry, as a result of the political transition and the lack of foreign currency for fuels imports. Romania has a relatively low electricity consumption (3.2 Mwh/inhabitant) and a low household consumption (0.3 Mwh/inhabitant). In 1992 electricity consumption (in 1000 Mwh) was divided among the different economic sectors consumers as follows:" (p.41)

1992 Electricity Consumption: (p.41)

Industry	29,912 GWh
Civil building	995 GWh
Transport/telecommunication	2,062 GWh
Agriculture/forestry	3,537 GWh
Public consumption	2,796 GWh
Domestic consumption	7,549 GWh
Total	*46,851 GWh*

- "The predominance of industry among the various economic sectors also appears from energy consumption data because the industrialization strategy was based on energy-intensive industries."

- "The energy intensive industries of Romania are illustrated in Fig. 10:" (p.43)

Industry	Thermal energy (%)	Electricity (%)
Metallurgy	9.7	31.7
Chemistry	28.5	20.9
Refining	17.9	6.4
Metal processing	10.3	16.4
Food	12.2	7.5
Others	21.4	17.1
Total manufacturing	100	100

- Biomass and Natural gas are the predominant energy sources. (p.44)

2.7.4 Market Considerations

Markets For Recyclables

Materials Recovery Facilities

Composting And Environmental Impacts

Collection Systems

Source Reduction At The Local Level

SECTION 3.0

CRITICAL REVIEW AND EVALUATION OF THE CASE STUDY REPORTS

Based upon our review of the six case-study reports, it appears as though the consortium of contractors suggested that the AVECON anaerobic digestion process (or other biothermal fermentation process) be utilized to generate a biogas that could then be burned in power plant (cogeneration unit, typically diesel powered) in five of the six countries (i.e., Brazil, Czech Republic, Egypt, Guyana, and Romania). For Hungary, the consortium suggested the utilization of a cogeneration diesel fuel plant (without any consideration of waste material input; we did not evaluate this case study as it is not a LNWT).

ICF's evaluation of the AVECON anaerobic digestion process selected for Brazil, Czech Republic, Egypt, Guyana, and Romania by the consortium of contractors is presented below. As discussed below, the case-study reports were difficult to evaluate as they generally contained numerous errors, lacked proper documentation of assumptions, and did not present cost information (some rough-order-of-magnitude cost estimates were provided). Information on waste composition was augmented, as necessary, using information presented by Tchobanoglous, Theisen, and Vigil. This information is presented below in Exhibit 3-1.

EXHIBIT 3-1

Typical Distribution of Components in Residential Municipal Solid Waste for Low, Middle, and Upper Income Countries, Excluding Recycled Materials

(Adapted from "Integrated Solid Waste Management, Engineering Principles and Management Issues, 1993, Tables 3-4 and 3-5, pages 49 and 50, respectively)

Components	Percent by Weight (Range)			
	Low Income	Middle Income	Upper Income	United States
Food Wastes	40-85 1/	20-65	6-30	6-18
Paper			20-45	25-40
Cardboard	1-10	8-30	5-15	3-10
Plastics	1-5	2-6	2-8	4-10
Textiles	1-5	2-10	2-6	0-4
Rubber			0-2	0-2
Leather	1-5	1-4	0-2	0-2
Yard Wastes			10-20	5-20
Wood	1-5	1-10	1-4	1-4
Misc. Organics				

EXHIBIT 3-1 (Continued)

Components	Percent by Weight (Range)			
	Low Income	Middle Income	Upper Income	United States
Glass	1-10	1-10	4-12	4-12
Tin Cans			2-8	2-8
Aluminum	1-5	1-5	0-1	0-1
Other Metals			1-4	1-4
Dirt, Ash, etc.,	1-40	1-30	0-10	0-6

Low Income: Per capita income of < US$750 in 1990.
Medium Income: Per capita income of > US$750 and < US$5,000 in 1990.
Upper Income: Per capita income of >US$5,000 in 1990.

1/ Food wastes composed predominantly of waste from the preparation of food (corn husks, melon rinds, banana leaves, etc.,)

We note that this information is approximate and that, in general, the composition of MSW in less developed countries is comprised mostly of food wastes because most vegetables and fruits are not pre-trimmed and there are few garbage disposals installed in kitchens. Whereas, in more developed countries, the MSW stream contains more packaging wastes (paper, cardboard, plastics, aluminum, and glass) than that generated in less developed countries.

3.1 Brazil

During the course of our review, we noted numerous errors and inconsistencies which generally affected our ability to completely review the material. For example:

- Electrical prices cited in the report were much too high -- probably off by 2 decimals, e.g., "US $ 4/Kwhr" should have been "US $ .04/Kwhr" at the bottom of page 5. This also applies to the other electrical prices listed.

- Figures on solid waste generation were inconsistent (page 10), e.g. "8,700 tonnes of municipal solid waste are produced per day" compared with "only in Sao Paulo, ..., 13,000 tonnes of solid waste are produced daily". Clearly, this is a typographical error -- how can there be more solid waste generated in Sao Paulo than in all of Brazil?

- On pages 22 and 23, and Figures 5 and 6, the composting block shows the output going to landfill; this compost should be going to agricultural lands as fertilizer.

- On page 27, Figures 8 and 9 are mislabeled; they should be Figures 4 and 5. The parameters of the digester shown in Figure 5, the Vaasa process, are not specified. For example, the temperature, hydraulic retention time, influent total and volatile solids, and type of mixing and recirculation are very important with respect to predicting the performance of the digester and its end products as listed in Table 7.

Other more serious examples include, missing information on the composition of the organic matter found in the various waste streams. For example, on pages 17 and 18, the percent of organic matter is listed as over 60% in 1991, yet the components and the moisture content (or total solids content) is not given. These values are very important when using this material for anaerobic digestion.

Again on page 25, the composition and moisture content of the organic kitchen waste in Table 6 are not specified. We like the fact that, in suggesting a waste management program for the Sao Paulo district, the plant is sized for a fraction of the total waste. This smaller plant is more suitable for anaerobic digestion; for example the organic kitchen waste at 28,800 tonnes per year is equivalent to about 100 tonnes per day, which is in the range of working successful anaerobic plants in Europe (IEA, 1994).

Exhibit 3-2 compares the reported information with our calculated digester performance based upon published data (Williams, et al, 1994). As shown, the calculated biogas production, 2.3×10^6 cubic meters per year, is much less than the reported biogas production, 5.9×10^6 cubic meters per year. Possible reasons for this difference are as follows:

1) The total solids content of the waste is higher than our assumed value.
2) The paper waste, 5850 tonnes per year on page 25, could be included in the digester input.

The calculated electrical production is also much lower than the reported value, due to the lower biogas energy input to the generator. Another concern, on page 29, is the reported heat consumption of the anaerobic plant, 3.5 Gwh. This is only 10 % of the total biogas energy content, 34 Gwh. Based on our experience (project work and other published reports), at least 20 % of the gross biogas production is required for maintaining optimum digester temperatures, 35 to 50 C.

One final comment regarding the Brazil case study, is the fact that this country has extensive experience in the use of renewable fuels from biomass, namely ethanol from sugar cane. Reeser, et al (1995) reported that during 1986, ethanol production peaked at 11.7 billion liters and resulted in reducing petroleum imports by 70%. Ethanol production from sugarcane is complementary with biogas production from organic wastes in that the wastes compatible for biogas are different from those used for ethanol. In fact, the wastewater byproduct from ethanol production, stillage slops, is suitable for anaerobic treatment to produce biogas that provides a portion of the process energy for ethanol production.

3.2 Czech Republic

During the course of our review, we noted numerous errors and inconsistencies (similar to those noted above in Section 3.1) throughout the report, which generally affected our ability to completely review the material. For example, in the case study described on page 18, the percentages of kitchen and paper wastes are very low, i.e., 7 and 10 %, respectively. These values, when compared to like values presented in the other case-study reports, are too low. For the proposed waste treatment system described on page 24, the combination of organic kitchen waste and sewage sludge make up over 75% of the total waste stream. Again, a comparison was developed in Exhibit 3-2. For this comparison, the total solids content of the organic wastes was assumed to be 20%, due mainly to the inclusion of sewage sludge, which has a low solids content of 15%, in the digester input. The calculated biogas production and thus the sludge, electricity and heat quantities are somewhat lower, about 75 to 80%, compared with the reported values listed on page 26.

3.3 Egypt

During the course of our review, we noted numerous errors and inconsistencies, which generally affected our ability to completely review the material. For example:

- On page 4, Figure 1 shows the specific fuel consumption in units of g/Kwh. The type of fuel is not specified; was it petroleum, natural gas, or coal?

- On pages 4 and 5, the term "toe" is used in referring to quantities of energy. The text does not define this term; is this tons of oil equivalent?

On page 12, Table 3 lists the potential number of digesters at over one million. This is a very optimistic number and will require a massive effort of promotion and incentives to accomplish. We note that based on the Chinese experience in the 1960's and 1970's, there may be huge problems of maintaining and operating such a large number of digesters of varied designs. We believe that a more workable approach would be to have fewer, larger-scale digesters that each collects the waste from communities and regions.

For the case study of treatment of solid waste described in Table 6, page 20, some of the same comments as written for the Brazil case study apply. Again, a comparison was developed in Exhibit 3-2. For this comparison, the total solids content of the organic wastes was assumed to be 35%, due in part to the warmer drier climate, and the fact that other, drier organic wastes were probably included in the "organic kitchen wastes." By assuming a higher total solids content, the calculated biogas production and thus the sludge, electricity and heat quantities are closer to the reported values given in Table 7, page 22. Still, the calculated values are low, about 70 % of the reported values. Again, as in the Brazil case, if paper were included in the digester input, the biogas, sludge and electricity production would be higher and more in line with the values reported in Table 7.

3.4 Guyana

During the course of our review, we noted numerous errors and inconsistencies (similar to those noted above in Section 3.1), which generally affected our ability to completely review the material. For example, the case study described on Table 3, page 18, that the percent of organics was very high -- over 80% of the total solid wastes. Again, a comparison was developed in Exhibit 3-2. For this comparison, the total solids content of the organic wastes was assumed to be 20%, due mainly to the inclusion of sewage sludge, which has a low solids content of 15%, in the digester input. The calculated biogas production and thus the sludge, electricity and heat quantities are very close to the reported values listed on page 22.

3.5 Romania

During the course of our review, we noted numerous errors and inconsistencies (similar to those noted above in Section 3.1), which generally affected our ability to completely review the material. For example, the case study described on pages 53/54, that the percent of organics was very high -- over 80% of the total solid wastes. Again, a comparison was developed in Exhibit 3-2. For this comparison, the total solids content of the organic wastes was assumed to be 20%, due mainly to the inclusion of sewage sludge, which has a low solids content of 15%, in the digester input. The calculated biogas production and thus the sludge, electricity and heat quantities are similar to the reported values listed on page 54.

3.6 Estimated Cost of Digestion Systems

Exhibit 3-2 also lists the estimated capital costs of the various digester systems. The range is based upon recent work reported by Pinnacle Biotechnologies International (1998). The costs vary depending upon the total annual throughput of solid waste in tonnes/year, the fraction of organic waste, and the energy output in KW from the methane production and subsequent conversion to electricity. Another factor is whether the anaerobic plant includes pre-processing equipment such as sorting and recycling equipment.

The capital costs range from US$800,000 to US$2.1 million for plants handling between 25,000 to 60,000 tonnes per year, and producing 3 to 8 GWH of electricity per year (equivalent to 400 to 900 KW continuous electrical output).

EXHIBIT 3-2

DIGESTER END PRODUCTS AND PERFORMANCE LNWT IN BRAZIL, EGYPT, CZECH REPUBLIC, GUYANA, AND ROMANIA - COMPARISON OF CALCULATED AND REPORTED VALUES

PARAMETER	COUNTRY				
	BRAZIL	**EGYPT**	**GUYANA[1]**	**CZECH[1] REPUBLIC**	**ROMANIA[1]**
Total Solid Waste, tonnes/yr.	45,000	30,000	25,000	40,000	60,000
Organic Kitchen Waste, tonnes/yr.	28,000	19,200	20,700	30,000	48,000
Assumed Total Solids (TS), %	20%	35%	20%	20%	20%
Calculated TS, tonnes/yr.	5,600	6,720	4,140	6,000	9,600
Assumed Volatile Solids(VS), % of TS	0.8	0.8	0.8	0.8	0.8
Calculated VS, tonnes/yr.	4,480	5,376	3,312	4,800	7,680
Assumed Biogas Production, m^3/kgVS	0.5	0.5	0.5	0.5	0.5
Calculated Biogas Production, m^3/yr	2,240,000	2,688,000	1,656,000	2,400,000	3,840,000
Calculated Digested Sludge, tonnes/yr.	10,000	11,500	7,100	10,300	16,500
Calculated Electricity @ 35% eff, Gwh/yr.	4.57	5.49	3.38	4.9	7.84
Calculated Heat @ 55% eff, Gwh/yr.	7.19	8.62	5.31	7.7	12.3
From LNWT Reports:					
Biogas Production, m^3/yr.	5,900,000	3,900,000	1,800,000	3,200,000	6,600,000
Digested sludge, tonnes/yr.	26,400	17,600	8,400	14,000	24,000
Electricity, Gwh/yr.	12	8	4	6	13
Heat,Gwh/yr.	19	13	6	12	21
Estimated Capital Cost, Range of Reported Actual Full Size Anaerobic Digester Systems for Solid Waste, US$	1,100,000 to 1,400,000	1,400,000 to 1,700,000	800,000 to 1,000,000	1,200,000 to 1,500,000	1,700,000 to 2,100,000

[1] Organic waste includes sewage sludge.

SECTION 4.0

SELECTION OF ALTERNATIVE LNWT TECHNOLOGIES AND DEMONSTRATION COUNTRIES

4.1 Introduction

Concurrent with our review and evaluation of the six case-study reports, we developed a methodology for ranking the technological and socio-economical selection factors associated with the following eight potentially applicable waste-to-energy (WTE) technologies:

- Mass Burn Facilities
- Modular Combustion Facilities
- Refuse Derived Fuel (RDF) Facilities
- Fluidized Bed Combustion (FBC) Facilities
- Pyrolysis Units
- Gasification Plants
- Anaerobic Digestion Units
- Landfill Gas Recovery Operations.

ICF developed "selection factors" based on what we believed were important criteria/factors that needed to be considered during the decision-making process to rank (and ultimately select) potentially applicable LNWTs.

4.2 Technological Criteria/Factors

The specific technological criteria/factors evaluated included the following:

- energy produced
- energy consumed
- labor needed
- skilled labor needed
- land needed
- infrastructure demand
- proven technology
- efficiency of the technology
- capital costs
- O&M costs
- by-products generation
- wastes generated (quantity)
- wastes generated (quality)
- environmental impact

Although we undertook a "qualitative" approach to grading the technological selection factors, our analysis did rely on quantitative information as appropriate. Specifically, when evaluating the capital costs associated with each potential technology, we used the capital costs estimated by the U.S. EPA, U.S. DOE, and several vendors. Based on these sources, the capital costs estimated for the mass-burn, modular combustion facilities, refuse derived fuel facilities, and fluidized bed combustion facilities ranged between U.S. $80,000 to U.S. $120,000 per ton, with the $120,000 cost associated with a modern plant with all the appropriate environmental controls. We, therefore, used the $120,000 cost, which is approximately $20,000,000 per M W. The capital costs estimated for a landfill gas recovery project was U.S. $1,660,000 per MW. The capital cost estimated for an anaerobic digestion plant was U.S. $10,000,000 per MW.

ICF presents the technological factors considered, an explanation of each factor, and a simple description of the qualitative scoring measure in Exhibit 4-1.

ICF developed the criteria scoring system in a way that would allow us to rank the overall utility of specific full-scale technologies. The criteria scoring system assigned more points to technologies that had been demonstrated as both technologically and economically feasible and easy to implement than it assigned to technologies that were not in full-scale development, technologically or economically feasible, or easy to implement. We used this scoring (or ranking) system to select the two most appropriate WTE technologies by selecting the two highest ranking technologies. Exhibit 4-2 presents the completed spreadsheet used to score the eight WTE technologies by the technological selection factors.

ICF used both in-house information sources, such as “Unit Operations in Environmental Engineering,” by Robert Noyles, ed., 1994 and U.S. DOE’s Integrated Waste Management Report (Draft Final), 1992, and vendor materials to facilitate scoring of selected technologies. Appendices A-C present a summary of relevant information collected from Noyles, EPA, and Foster Wheeler Power Systems, Inc., respectively. Appendix D presents a detailed summary of the principles of fluidized bed combustion (FBC).

Foster Wheeler Power Systems Cost Estimates
for WTE Technologies - Mass Burn and RDF/CFB Plants

	Mass Burn		**RDF/CFB**	
	800 TPD	1600 TPD	800 TPD	1600 TPD
EPC Cost ($MM U.S)	95	150	100	155
Total Capital ($MM U.S.)	130	200	135	205
Fixed Operating Cost ($MM U.S./Yr.)	5.3	7.0	6.8	8.7
Variable O&M ($MM U.S./Yr.)	1.1	2.0	1.1	2.0
Net Electrical Output (MW)	16	33	13.5	28
Ash Quantity (Tons/Yr.)	55,000	110,000	22,500	45,000

Assumes a typical, high organic waste with a higher heating value of 4,240 Btu/lb (LHV of 3,400 Btu/lb).

EXHIBIT 4-1

DESCRIPTION OF TECHNOLOGICAL SELECTION FACTORS AND SCORING SYSTEM

Selection Factors	Explanation	Scoring
Energy Produced	Quantity of energy expected to be generated by the technology, irrespective of the setting/country.	1 = small quantity of energy relative to other technologies; 3 = large quantity relative to other technologies
Energy Consumed	Quantity of energy used by the technology to convert waste to energy.	1 = large quantity relative to other technologies; 3 = small quantity of energy relative to other technologies
Labor Needed	The size of the labor pool, skilled or unskilled, needed to construct and operate the technology.	1 = large; 3 = small
Skilled Labor Needed	The size of the pool of skilled labor needed to construct and operate the technology.	1 = large; 3 = small
Land Needed	The "footprint" of the technology (i.e., the amount of land needed to site the project).	1 = large; 3 = small
Infrastructure Demand	The degree to which existing infrastructure (e.g., roads, telecommunications, power) needs to be in-place in order to construct and operate the technology.	1 = extensive, well-developed infrastructure needed; 3 = little infrastructure needed
Proven Technology	Is the technology in use as a pilot- or full-scale project elsewhere?	1 = not in use, 2 = pilot-scale, 3 = full-scale
Efficiency of the Technology	How efficient is the technology in terms of amount of product generated per cost of generating the product?	1 = relatively inefficient, 3 = relatively efficient
Capital Costs	Expenditures needed to construct/install the technology.	1 = relatively high capital costs; 3 = relatively low capital costs
O&M Costs	Expenditures needed to operate and maintain the installed technology.	1 = relatively high O&M costs, 3 = relatively low O&M costs
By-products Generated	Degree to which useful by-products are generated by the technology.	1 = no useful by-products generated, 3 = two or more useful by-products generated
Wastes Generated Quantity	The amount of waste generated in operating the technology.	1 = relatively large quantities of waste generated, 3 = relatively small quantities of waste generated
Quality	The level of contamination of the waste, ranging from non-hazardous solid waste to hazardous waste as defined by U.S. EPA regulations.	1 = some or all wastes generated exhibit hazardous characteristics, 3 = all wastes generated exhibit only non-hazardous characteristics
Environmental Impact	The degree to which the environment surrounding the facility is affected.	1 = surrounding environment could be substantially affected, 3 = little or no affect on surrounding environment

EXHIBIT 4-2: COMPLETED TECHNOLOGICAL SELECTION FACTORS SCORING SPREADSHEET

Technological Selection Factors		WASTE-TO-ENERGY (WTE) TECHNOLOGIES							
		Mass Burn	Modular Combustion	RDF	FBC	Pyrolysis	Gasification	Anaerobic Digestion	Landfill Gas Recovery
energy produced		3	3	3	3	2	2	2	1
energy consumed		1	1	1	1	1	1	3	3
labor needed		3	2	2	2	1	2	2	3
skilled labor needed		3	3	3	3	2	2	3	3
land needed		2	2	2	2	2	2	2	2
infrastructure demand		1	1	1	1	2	2	2	2
proven technology		3	3	3	3	1	3	3	3
efficiency of the technology		2	2	3	3	1	2	3	2
capital costs		1	1	1	1	1	1	2	3
O&M costs		1	1	1	1	1	1	3	3
by-products generated		1	1	3	2	2	2	3	1
wastes generated	quantity	3	3	2	2	2	2	3	3
	quality	1	1	2	2	2	2	3	3
environmental impact		1	1	2	2	2	2	3	3
Total Score		26	25	29	28	22	26	37	35

As shown in Exhibit 4-2, the two highest-ranked technologies were determined to be anaerobic digestion and landfill gas recovery. These projects are discussed in greater detail in Section 5.

4.3 Socio-Economic Factors

We then devised a similar methodology for selecting the two best countries for industrial-scale demonstration projects. As was done in developing the methodology used to rank potential LNWTs, this methodology also incorporated criteria (or conditions) on which decisions or judgments were based; they were qualitative or quantitative -- as appropriate. Our methodology for selecting waste management and co-generation practices/technologies included considerations such as:

- ease of implementation;
- level of sophistication (technology and country);
- total cost and cost effectiveness;
- environmental impact (e.g., human health, quality of environmental media, species abundance, and safety);
- overall integration with the existing waste management system
- political feasibility;
- useful energy (the actual energy used to perform a useful function); and
- overall energy balance (the stocks and flows of all forms of energy, from their origins through final uses, with quantities expressed in terms of a single accounting unit for purposes of comparison and addition).

Waste-To-Energy Incineration Is Competitive Only in Some Places

WTE plants, which produce electricity and steam as they burn solid refuse, are competitive alternatives for waste disposal only where economic and environmental considerations discourage landfills, according to a comprehensive international study.

The studies of projects in four countries, however, show WTE plants cannot match the energy outputs or economics of conventional power plants. Moreover, public skepticism and exceptionally high construction costs also limit WTE incinerators' attractiveness as waste disposal options, the researchers said.

Still, WTE facilities may represent a reasonable alternative in certain cases, such as in densely populated areas where land is expensive, where high water tables make landfill construction especially costly, and where electricity is being generated by outdated conventional power plants that burn dirtier kinds of fossil fuels. In addition, WTE production processes can "maximize energy efficiency" by marketing both steam and electricity as well as pre-sorting waste to enhance its combustible energy content. Lastly WTE environmental impacts are reduced by developing ways to reuse the ash and pre-sorting the waste to reduce the potential for air toxics, the researchers concluded.

The methodology for identifying and evaluating potential sites included factors such as:

- aesthetics;
- air quality;
- environmentally sensitive areas;
- energy customer proximity;
- waste generation proximity;
- ground water hydrology;
- land use compatibility/equity;
- soils and geology;
- surface water hydrology;
- topography;
- traffic; and
- water availability.

Exhibit 4-3 presents the socio-economic selection factors considered, and explanation of each factor, and a simple description of the qualitative scoring measure.

EXHIBIT 4-3: DESCRIPTION OF SOCIO-ECONOMIC FACTORS AND SCORING SYSTEM

Socio-economical

Public Acceptance	Would the population of the region in which the technology would be sited support the technology? Are changes in current lifestyles necessary to accommodate the technology (e.g., sorting household garbage before pick-up, transporting household garbage to a centralized pick-up point in lieu of home pick-up)?	1 = little acceptance of the technology expected, and public would experience substantial changes in lifestyle in order to accommodate the technology; 3 = public would generally be receptive to the technology and would experience little or no changes in lifestyle
Public Involvement	What level of involvement of the public would be expected in siting the technology (e.g., participation in the siting of the project, changes in lifestyle brought about by operating the project)?	1 = public expected to be very involved with siting the project; 3 = little involvement expected
Government/ Corporate Outreach	To what degree will local/national government and/or corporate entities need to provide outreach to the public (e.g., public hearings)?	1 = government and/or corporate entities would probably need to provided significant level of outreach; 3 = little or no outreach needed.
Available Labor	How large is the available labor pool in the region?	1 = little or no available labor; 2 = labor pool adequate for the project; 3 = surplus labor available
Available Skilled Labor	How much of this labor pool could be considered skilled (e.g., engineers, licensed operators, managers)?	1 = little or no skilled labor available; 2 = adequate skilled labor pool; 3 = surplus skilled labor pool
Land Available to Site Project	How much land is available in the selected region to site the project?	1 = little or no land available to site the project; 3 = surplus land available
Potential for Privatization	Would it be possible to privatize the project in the chosen region?	1 = privatization not possible; 3 = privatization would be encouraged by local and/or national government
Laws & Regulations	To what degree are laws and regulations in place to govern the construction and operation of the technology.	1 = no laws or regulations in place; 3 = regulatory structure is well-established for the technology
Availability of Raw Materials	Are adequate quantities/qualities of wastes available to support the technology?	1 = waste streams needed to support the technology are not present; 3 = surplus waste streams available
Market Demand	Is there a market for the energy to be generated by the technology?	1 = no demand/market for the energy; 3 = demand would exceed supply generated by the project
Market Capacity	Are there competing technologies for the service(s) the technology would provide?	1 = several competing technologies or projects exist; 3 = no competing technologies or projects
Environmental Impact	To what degree is the environment surrounding the project expected to be affected by the construction and operation of the technology?	1 = environment would be greatly affected; 3 = no affect on surrounding environment

Exhibits 4-4 through 4-9 present the completed spreadsheets used to score the socio-economic selection factors for each country.

EXHIBIT 4-4: COMPLETED SOCIO-ECONOMICAL SELECTION FACTORS SCORING SPREADSHEET - BRAZIL

Socioeconomic Selection Factors	**WASTE-TO-ENERGY (WTE) TECHNOLOGIES**							
	Mass Burn	Modular Combustion	RDF	FBC	Pyrolysis	Gasification	Anaerobic Digestion	Landfill Gas Recovery
public acceptance	1	1	1	1	1	2	3	3
public involvement	3	3	3	3	2	2	3	3
government/corporate outreach	1	1	1	1	1	2	3	3
available labor	3	3	3	3	3	3	3	3
available skilled labor	1	1	1	1	1	1	2	1
land available to site project	2	2	2	2	2	2	3	3
potential for privatization	3	3	3	3	3	3	3	3
laws & regulations	1	1	1	1	1	1	2	2
availability of raw materials	3	3	3	3	3	3	3	3
market demand	3	3	3	3	3	3	3	3
market capacity	2	2	2	2	2	2	3	3
environmental impact	1	1	2	2	2	2	3	3
Total Score	24	24	25	25	24	26	34	33

EXHIBIT 4-5: COMPLETED SOCIO-ECONOMICAL SELECTION FACTORS SCORING SPREADSHEET - CZECH REPUBLIC

Socioeconomic Selection Factors	**WASTE-TO-ENERGY (WTE) TECHNOLOGIES**							
	Mass Burn	Modular Combustion	RDF	FBC	Pyrolysis	Gasification	Anaerobic Digestion	Landfill Gas Recovery
public acceptance	1	1	1	1	1	2	3	3
public involvement	2	2	2	2	2	2	3	3
government/corporate outreach	2	2	2	2	2	2	2	2
available labor	3	3	3	3	3	3	3	3
available skilled labor	2	2	2	2	2	2	2	2
land available to site project	2	2	2	2	2	2	2	3
potential for privatization	3	3	3	3	3	3	3	3
laws & regulations	2	2	2	2	2	2	2	2
availability of raw materials	3	3	3	3	3	3	3	3
market demand	3	3	3	3	3	3	3	3
market capacity	3	3	3	3	3	3	3	3
environmental impact	1	1	2	2	2	2	3	3
Total Score	27	27	28	28	28	29	32	33

EXHIBIT 4-6: COMPLETED SOCIO-ECONOMICAL SELECTION FACTORS SCORING SPREADSHEET - EGYPT

Socioeconomic Selection Factors	**WASTE-TO-ENERGY (WTE) TECHNOLOGIES**							
	Mass Burn	Modular Combustion	RDF	FBC	Pyrolysis	Gasification	Anaerobic Digestion	Landfill Gas Recovery
public acceptance	1	1	1	1	1	2	2	3
public involvement	3	3	3	3	2	2	3	3
government/corporate outreach	1	1	1	1	1	2	3	3
available labor	3	3	3	3	3	3	3	3
available skilled labor	1	1	1	1	1	1	1	1
land available to site project	1	1	1	1	1	1	1	3
potential for privatization	1	1	1	1	1	1	1	1
laws & regulations	1	1	1	1	1	1	1	1
availability of raw materials	3	3	3	3	2	2	2	2
market demand	3	3	3	3	3	3	3	3
market capacity	2	2	2	2	2	2	2	3
environmental impact	1	1	2	2	2	2	3	3
Total Score	21	21	22	22	20	22	25	29

EXHIBIT 4-7: COMPLETED SOCIO-ECONOMICAL SELECTION FACTORS SCORING SPREADSHEET - GUYANA

Socioeconomic Selection Factors	**WASTE-TO-ENERGY (WTE) TECHNOLOGIES**							
	Mass Burn	Modular Combustion	RDF	FBC	Pyrolysis	Gasification	Anaerobic Digestion	Landfill Gas Recovery
public acceptance	1	1	1	1	1	1	2	3
public involvement	3	3	3	3	2	2	3	3
government/corporate outreach	1	1	1	1	1	2	3	3
available labor	3	3	3	3	3	3	3	3
available skilled labor	1	1	1	1	1	1	1	1
land available to site project	1	1	1	1	1	1	3	3
potential for privatization	1	1	1	1	1	1	1	1
laws & regulations	1	1	1	1	1	1	1	1
availability of raw materials	3	3	3	3	2	2	3	2
market demand	3	3	3	3	3	3	3	3
market capacity	2	2	2	2	2	2	3	3
environmental impact	1	1	2	2	2	2	3	3
Total Score	21	21	22	22	20	21	29	29

EXHIBIT 4-8: COMPLETED SOCIO-ECONOMICAL SELECTION FACTORS SCORING SPREADSHEET - HUNGARY

Socioeconomic Selection Factors	WASTE-TO-ENERGY (WTE) TECHNOLOGIES							
	Mass Burn	Modular Combustion	RDF	FBC	Pyrolysis	Gasification	Anaerobic Digestion	Landfill Gas Recovery
public acceptance	1	1	1	1	1	2	2	3
public involvement	2	2	2	2	2	2	3	3
government/corporate outreach	2	2	2	2	2	2	3	3
available labor	3	3	3	3	3	3	3	3
available skilled labor	2	2	2	2	2	2	2	1
land available to site project	2	2	2	2	2	2	2	3
potential for privatization	3	3	3	3	3	3	3	3
laws & regulations	2	2	2	2	2	2	2	2
availability of raw materials	3	3	3	3	3	3	3	3
market demand	3	3	3	3	3	3	3	3
market capacity	3	3	3	3	3	3	3	3
environmental impact	1	1	2	2	2	2	3	3
Total Score	27	27	28	28	28	29	32	33

EXHIBIT 4-9: COMPLETED SOCIO-ECONOMICAL SELECTION FACTORS SCORING SPREADSHEET - ROMANIA

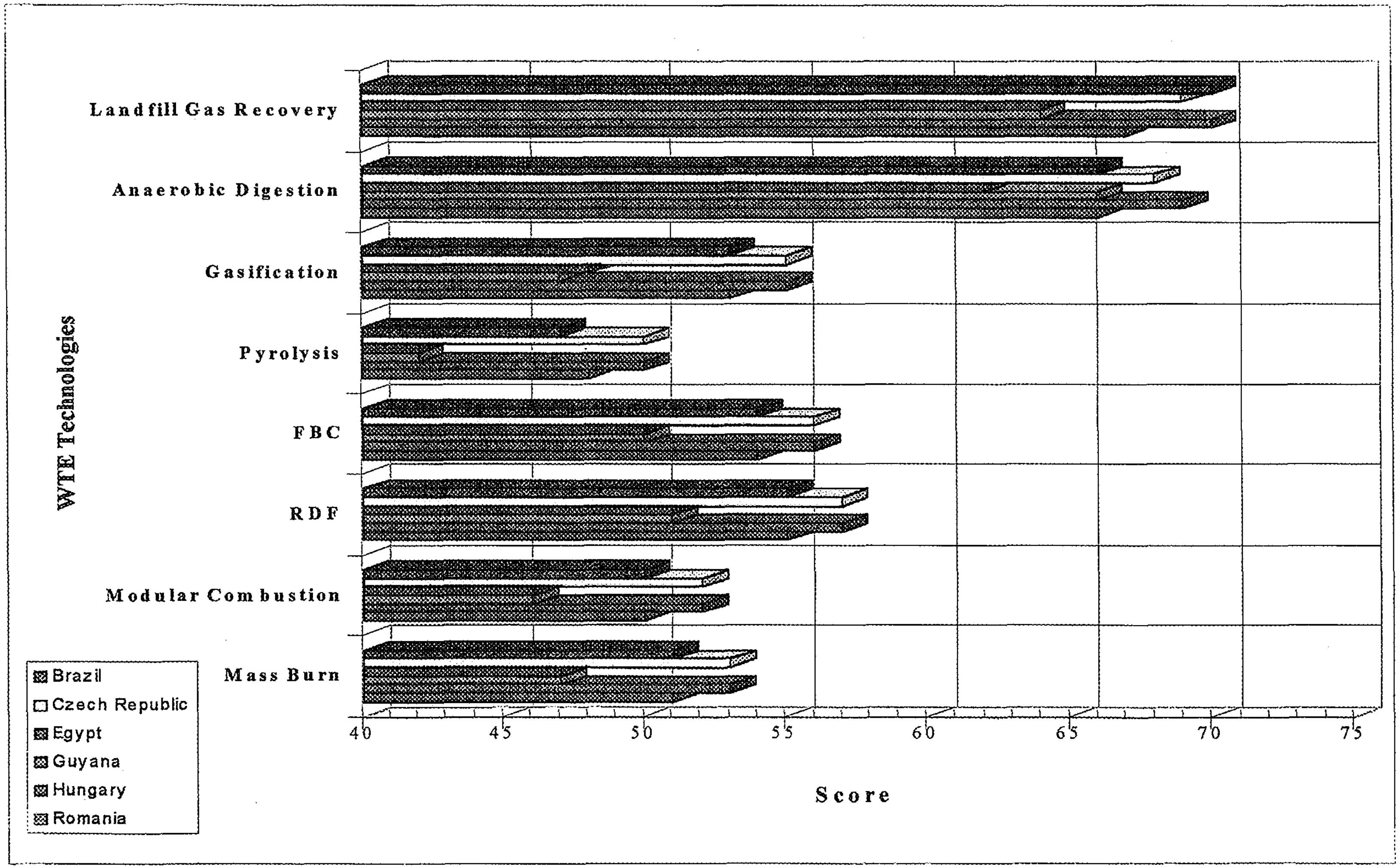
Socioeconomic Selection Factors	WASTE-TO-ENERGY (WTE) TECHNOLOGIES							
	Mass Burn	Modular Combustion	RDF	FBC	Pyrolysis	Gasification	Anaerobic Digestion	Landfill Gas Recovery
public acceptance	1	1	1	1	1	2	2	3
public involvement	2	2	2	2	2	2	3	3
government/corporate outreach	2	2	2	2	2	2	2	2
available labor	3	3	3	3	3	3	3	3
available skilled labor	2	2	2	2	2	2	2	2
land available to site project	2	2	2	2	2	2	2	3
potential for privatization	2	2	2	2	2	2	2	2
laws & regulations	1	1	1	1	1	1	1	2
availability of raw materials	3	3	3	3	3	3	3	3
market demand	3	3	3	3	3	3	3	3
market capacity	3	3	3	3	3	3	3	3
environmental impact	1	1	2	2	2	2	3	3
Total Score	25	25	26	26	26	27	29	32

To facilitate the selection of the two countries best suited to conduct full-scale demonstration projects (and the two most appropriate technologies), we graphed the socio-economical scores by country. Exhibit 4-10 presents a graphical summary of both the socio-economic scores and the technology scores by country (and technology).

As shown below in Exhibit 4-10, Brazil and Czech Republic appear to be the most suitable for hosting LNWTs demonstration projects. We note that the selection of these two countries is supported by our analysis of the information presented in the six case studies, as augmented by the information collected from the U.S. EPA, U.S. DOE, and technology vendors. Specifically, Brazil has an established track record in pursuing energy projects and has considerable experience in baggase and ethanol projects. Although the case-study report for Czech Republic was lacking in detail, our own professional experience in Czech Republic suggested that it also appeared to be a suitable host because the government is encouraging more efficient energy production and has developed infrastructure (such as waste collection). In addition, both countries are facing serious landfill shortages.

ICF stresses that the selection of the most suitable LNWTs and countries for full-scale demonstration is preliminary - at best. Additional information collection and cost estimation work should be done prior to initiating further work. In addition, the selection of any technology can be overridden by further consideration of additional information regarding prevailing energy prices, tipping fees (i.e., disposal charges assessed per ton of waste managed), etc. For example, future projects involving any of the combustion technologies may actually become more feasible should the countries assess more “real” costs for energy production and disposal costs. In addition, in emerging or developing countries, there often is a misconception regarding the “value” of the waste material being used as fuel. Specifically, people many times consider it unreasonable to pay a tipping fee to the owner/operator of the WTE facility because they view the waste as free fuel for the plant -- and therefore, they shouldn’t have to pay a charge for disposal. However, WTE combustion facilities rarely become economically viable unless real rates are assessed for energy and tipping fees approach US$90/ton. Other problems involve the long-term commitment to providing guaranteed daily volumes of waste (fuel), with substantial economic penalties for short falls, or fluctuating markets for “recyclables.”

EXHIBIT 4-10: GRAPHICAL PRESENTATION OF SUITABLE LNWTS BY COUNTRY



SECTION 5.0

FUNCTIONAL SPECIFICATIONS, FLOW DIAGRAMS, AND COST ANALYSIS OF SELECTED LNWTS: ANAEROBIC DIGESTION AND LANDFILL GAS RECOVERY

ICF presents the functional specifications, system block diagrams, material balances, performance summaries, and the results of the cost analysis for the two selected projects below.

5.1 Anaerobic Digestion Projects

The following is an analysis using an economic computer model developed by Pinnacle Biotechnologies International, Inc. in Stanton, California, who have developed a high solid anaerobic digestion process for municipal solid waste. The analysis includes both technical and economic specifications for solid waste anaerobic digestion for two case studies: Sao Paulo, Brazil, and the Kladno District, Czech Republic.

5.1.1 Sao Paulo, Brazil

The total daily input of solid waste for the Sao Paulo metropolitan area is estimated to be at 6,000 metric tons (tonnes) per day; the paper fraction makes up 780 tonnes and the organic kitchen wastes fraction is 3,840 tonnes per day. These two organic fractions will be anaerobically digested in a series of modular units, each taking in 200 tonnes per day of the paper/kitchen waste fractions. This size is determined by the high solids digestion technology employed and the limitations of the materials handling and process design.

Figure 1 shows the system block design for each 200 tonne/day module with energy and mass flows. As shown, the wet organic kitchen waste is combined with the dry paper and shredded prior to being mixed and pumped into the digester. This influent mixture has the desired solids content, about 35%, for being anaerobically digested by the bacteria in the bioreactor. The volume of the daily influent is approximately 270 cubic meters; since a 17-day retention time is required for the bacteria to digest the solid waste, the bioreactor must have at least 17 times the volume of the daily influent, approximately 5000 cubic meters, in order to maximize biogas production. The daily biogas production of 39,000 cubic meters contains 51% methane which fuels a large internal combustion engine-generator set producing 2700 KW, and providing the hot water needed to keep the bioreactor at 55 degrees C. The digested sludge is then dewatered by a screw press and these solids are composted to produce 11 tonnes/day of compost soil amendment. The liquid fraction is then available as a liquid fertilizer for agricultural crops.

Exhibit 5-1 lists the functional specifications and cost analysis of the digestion system for one of the digestion modules in Brazil. Exhibit 5-2 summarizes the cost analysis of the treatment system for the entire 6,000 tonnes per day of solid waste. As shown, the estimated capital cost of the entire 30-module digestion system is US$159,000,000, and with the electricity and compost credits, the required tipping fee would be $16.80 per tonne for the system to break even.

1

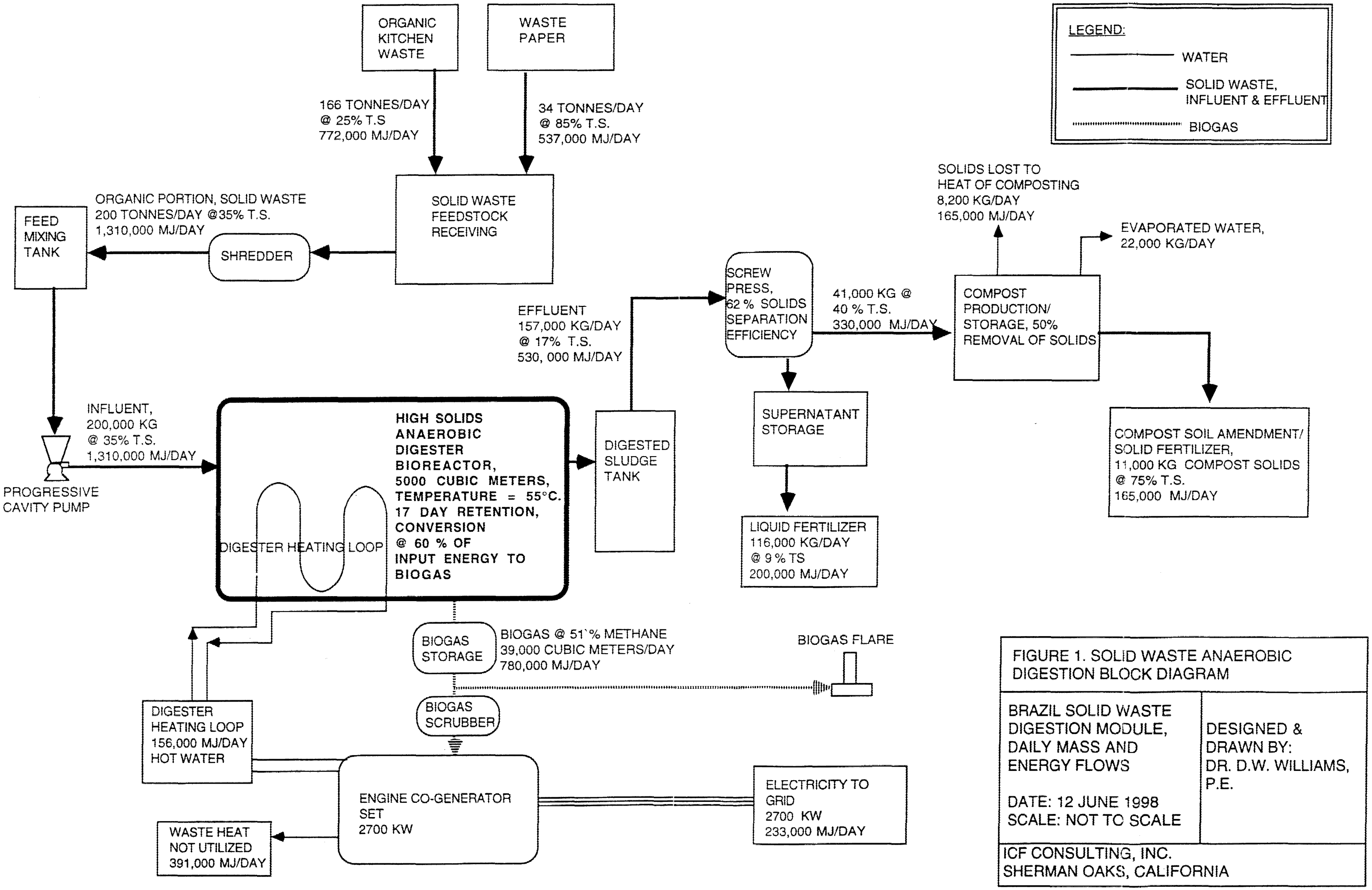


FIGURE 1. SOLID WASTE ANAEROBIC DIGESTION BLOCK DIAGRAM

BRAZIL SOLID WASTE DIGESTION MODULE, DAILY MASS AND ENERGY FLOWS

DATE: 12 JUNE 1998
SCALE: NOT TO SCALE

DESIGNED & DRAWN BY:
DR. D.W. WILLIAMS, P.E.

ICF CONSULTING, INC.
SHERMAN OAKS, CALIFORNIA

EXHIBIT 5-1

FUNCTIONAL SPECIFICATION - 200 TONS PER DAY DIGESTION MODULE

	Paper	Organic Kitchen Waste
A. Solid Waste Input Specification:		
Tonnes per day	34	166
Mass percent total solids (TS)	85%	25%
Mass percent volatile solids(VS)	72%	20%
Bulk density, kg/cubic meter	450	850
B. Digester Specifications:		
Total solids percent in digester influent	35%	
Digester residence time, days	17	
Percent volatile solids converted to biogas	75%	
Biogas production, cubic meters/day	39,000	
Methane production, cubic meters/day	20,000	
Gross methane yield, cubic meters/kg VS	0.38	
Volume methane /volume digester	4.0	
VS loading rate, kg VS/cubic meter digester/day	11.2	
C. Cost Analysis		
Costs:		
Total capital cost, $	$5,300,000	
Annual interest rate, %	10%	
Facility life, years	20	
Labor costs:		
Unskilled labor, $/hr	$2.50	
Operator wage, $/hr	$5.00	
Supervisor wage, $/hr	$10.00	
Federal Tax Rate, %	34%	
State tax rate, %	4.55%	
Inflation rate, %	10.0%	
Total annual costs, $/yr. (amortization, interest, taxes, operating costs)	$2,692,000	
Credits:		
Electricity value, $/kWh	$0.06	
Annual excess electricity generated, kWh/yr.	23,000,000	
Annual electricity sales, $/yr.	$1,388,000	
Compost value, $/tonne	$20.00	
Annual compost production, tonnes/yr.	3,900	
Annual compost sales, $/yr.	$78,000	
Total annual electricity and compost credits	$1,466,000	
Net annual costs/annual tipping fee income, $/yr. (Total annual costs - annual electricity and compost credits)	$1,226,000	
Annual solid waste, tonnes/yr.	73,000	
Break-even solid waste tipping fee, $/tonne	$16.80	

EXHIBIT 5-2

SUMMARY OF CAPITAL AND OPERATING COSTS, AND CREDITS - 6,000 TONNES/DAY UTILIZING 30 DIGESTION MODULES @ 200 TONNES/MODULE

Capital cost, $	$159,000,000
Total annual costs, $/yr. (amortization, interest, taxes, operating costs)	$80,760,000
Total annual credits:	
Annual excess electricity sales, $/yr.	$41,640,000
Annual compost sales, $/yr.	$2,340,000
Total compost and electricity credits, $/yr.	$43,980,000
Net annual costs/annual tipping fee income, $/yr. (Total annual costs - annual electricity and compost credits)	$36,780,000
Annual solid waste, tonnes/yr.	2,190,000
Break-even solid waste tipping fee, $/tonne	$16.80

5.1.2 Czech Republic

The total daily input of solid waste for the Kladno District is estimated to be 105 metric tons (tonnes) per day; the paper fraction makes up 14 tonnes, the organic kitchen wastes is 16 tonnes and sewage sludge is 75 tonnes per day. These three organic fractions will be anaerobically digested in a system as described in Exhibit 5-3, with Figure 2 showing the system block design with energy and mass flows. As shown, the wet organic kitchen waste is combined with the dry paper and shredded prior to being mixed and pumped into the digester. This influent mixture has the desired solids content, about 35%, for being anaerobically digested by the bacteria in the bioreactor. The volume of the daily influent is approximately 130 cubic meters; since a 17-day retention time is required for the bacteria to digest the solid waste, the bioreactor must have at least 17 times the volume of the daily influent - approximately 2300 cubic meters - in order to maximize biogas production. The daily biogas production of 14,100 cubic meters contains 51% methane which fuels a large internal combustion engine-generator set producing 940 KW, and providing the hot water needed to keep the bioreactor at 55 degrees C. The digested sludge is then dewatered by a screw press and these solids are composted to produce 4.8 tonnes/day of compost soil amendment. The liquid fraction is then available as a liquid fertilizer for agricultural crops.

Exhibit 5-3 lists the functional specifications and cost analysis of the digestion system for Kladno. As shown, the estimated capital cost of the system is US$2,400,000, and with the electricity and compost credits, the required tipping fee would be $38.56 per tonne for the system to break even.

2

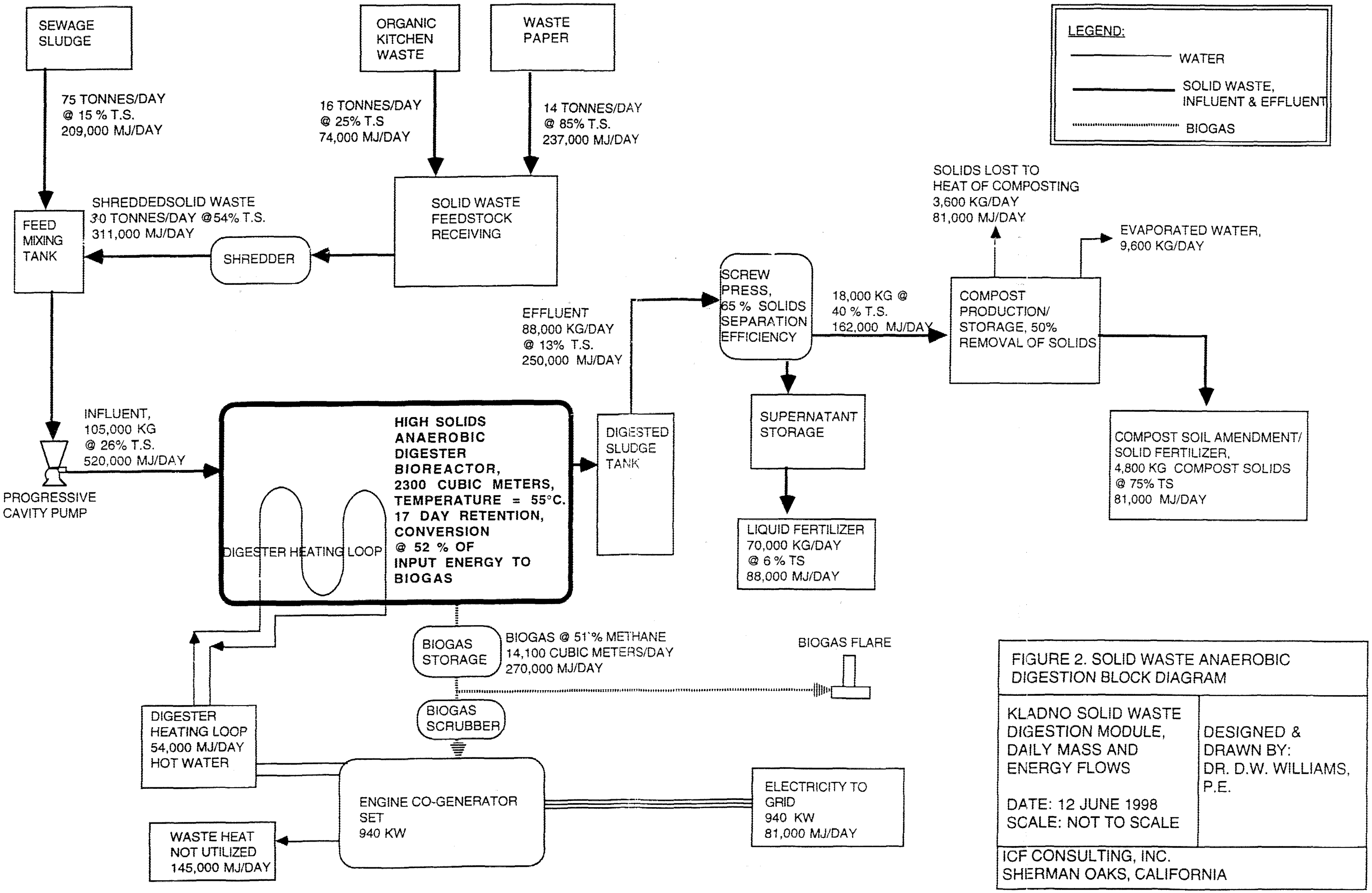


FIGURE 2. SOLID WASTE ANAEROBIC DIGESTION BLOCK DIAGRAM

KLADNO SOLID WASTE DIGESTION MODULE, DAILY MASS AND ENERGY FLOWS

DATE: 12 JUNE 1998
SCALE: NOT TO SCALE

DESIGNED & DRAWN BY:
DR. D.W. WILLIAMS, P.E.

ICF CONSULTING, INC.
SHERMAN OAKS, CALIFORNIA

EXHIBIT 5-3

FUNCTIONAL SPECIFICATION: 105 TONNES PER DAY FOR KLADNO SOLID WASTE

A. Solid Waste Input Specification:Sewage Sludge	Sewage Sludge	Paper	Organic Kitchen Waste
Tonnes per day	75	14	16
Mass percent total solids (TS)	15%	85%	25%
Mass percent volatile solids(VS)	10%	72%	20%
Bulk density, kg/cubic meter	1000	450	850

B. Digester Specifications:	
Total solids percent in digester influent	26%
Digester residence time, days	17
Percent volatile solids converted to biogas	75%
Biogas production, cubic meters/day	14,100
Methane production, cubic meters/day	7,100
Gross methane yield, cubic meters/kg VS	0.35
Volume methane /volume digester	3.0
VS loading rate, kg VS/cubic meter digester/day	9.0

C. Cost Analysis	
Costs:	
Total capital cost, $	$2,400,000
Annual interest rate, %	10%
Facility life, years	20
Labor costs:	
Unskilled labor, $/hr	$5.00
Operator wage, $/hr	$10.00
Supervisor wage, $/hr	$20.00
Federal Tax Rate, %	34%
State tax rate, %	4.55%
Inflation rate, %	8.0%
Total annual costs, $/yr. (amortization, interest, taxes, operating costs)	$1,992,000
Credits:	
Electricity value, $/kWh	$0.06
Annual excess electricity generated, kWh/yr.	8,000,000
Annual electricity sales, $/yr.	$480,000
Compost value, $/tonne	$20.00
Annual compost production, tonnes/yr.	1,700
Annual compost sales, $/yr.	$34,000
Total annual electricity and compost credits	$514,000
Net annual costs/annual tipping fee income, $/yr. (Total annual costs - annual electricity and compost credits)	$1,478,000
Annual solid waste, tonnes/yr.	38,325
Break-even solid waste tipping fee, $/tonne	$38.56

5.2 Overview of Landfill Gas Collection Systems

Landfill gas is generated naturally through the bacterial decomposition of organic matter deposited in a sanitary landfill. Gas collection systems pull the gas from a series of wells to a central processing facility. Landfill gas is typically a medium Btu gas that has a number of energy applications. The most prevalent use is production of electricity for sale to the local utility. The gas may also be employed directly for use as a boiler fuel and industrial process heat.

As shown below in Figure 3, a typical landfill gas collection system has the following components:

- gas collection wells
- a condensate collection and treatment system
- a compressor or blower, and
- a gas flare.

Gas Collection Wells

Gas collection typically begins after a portion of a landfill (or cell) is closed. There are two collection system configurations: vertical wells and horizontal trenches. Vertical wells are by far the most common type of well used for gas collection. Trenches are more appropriate for deeper landfills, and may be used in areas of active filling. Regardless of whether wells or trenches are used, each wellhead is connected to lateral piping, which transports the gas to a main collection header. The collection system should be designed so that the operator can monitor and adjust the gas flow as necessary. Figure 4 presents a schematic diagram of a typical landfill gas extraction well. Figure 5 presents an illustration of a typical landfill gas extraction site plan.

Condensate Collection and Treatment

The condensate collection and treatment system is used to remove the condensate that forms when warm gas from the landfill cools as it moves through the collection system. If the condensate is not removed, it can block the collection system and disrupt the energy recovery process. Condensate control typically begins in the field collection system, where sloping pipes and headers are used to allow drainage into collecting tanks or traps ("knockouts"). The collected condensate can either be discharged to a public sewer system, treated onsite, or recirculated to the landfill (especially in drier climates).

Blower/Compressor

A blower is necessary to pull the gas from the collection wells into the collection header, and a compressor may be required to compress the gas before it can enter the energy recovery system. The size, type, and number of blowers and compressors needed depends on the gas flow rate and the desired level of compression, which is typically determined by the energy conversion equipment.

FIGURE 3

LANDFILL GAS RECOVERY SYSTEM BLOCK SCHEMATIC

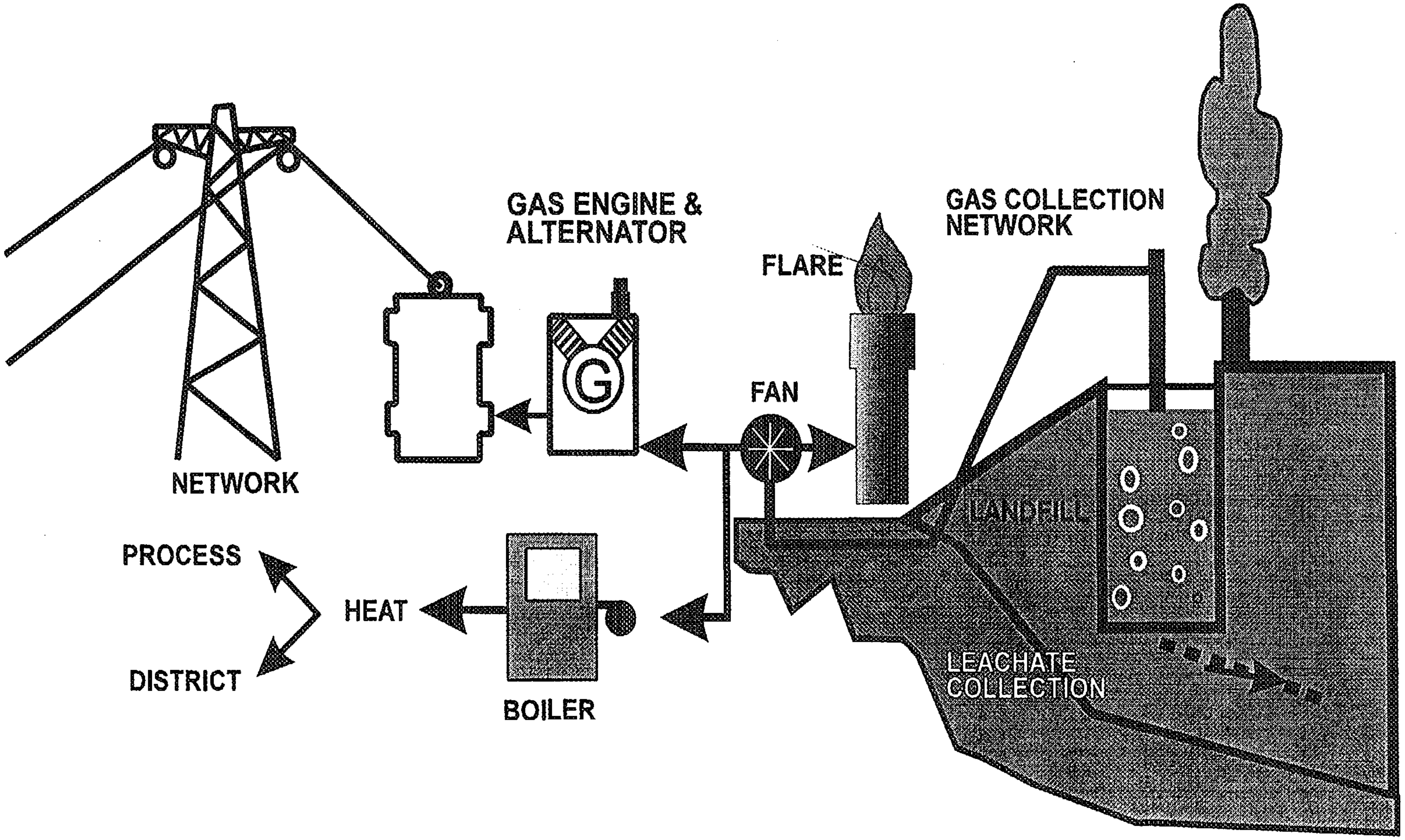


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FIGURE 4

A SCHEMATIC ILLUSTRATION OF A TYPICAL LANDFILL GAS EXTRACTION WELL

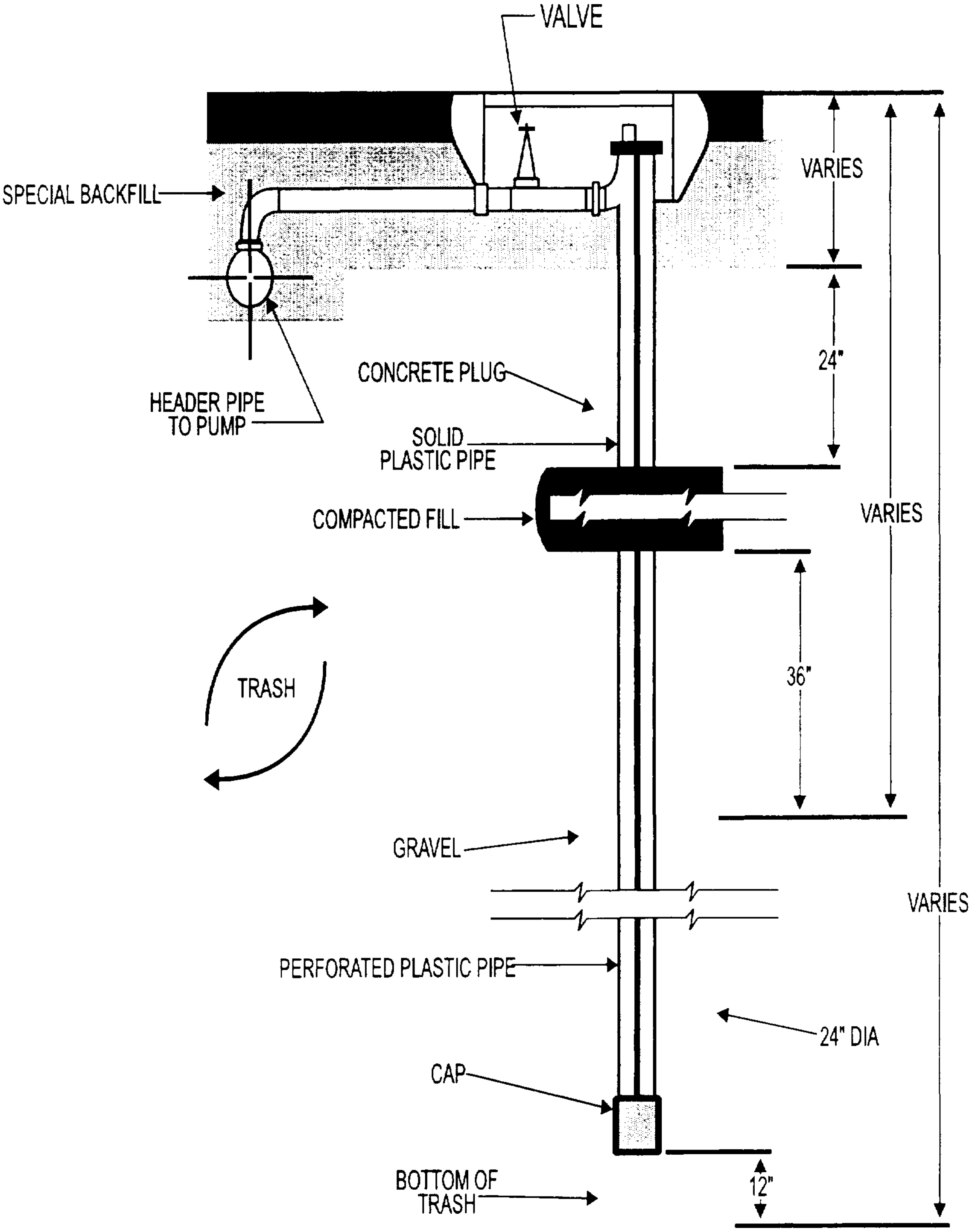

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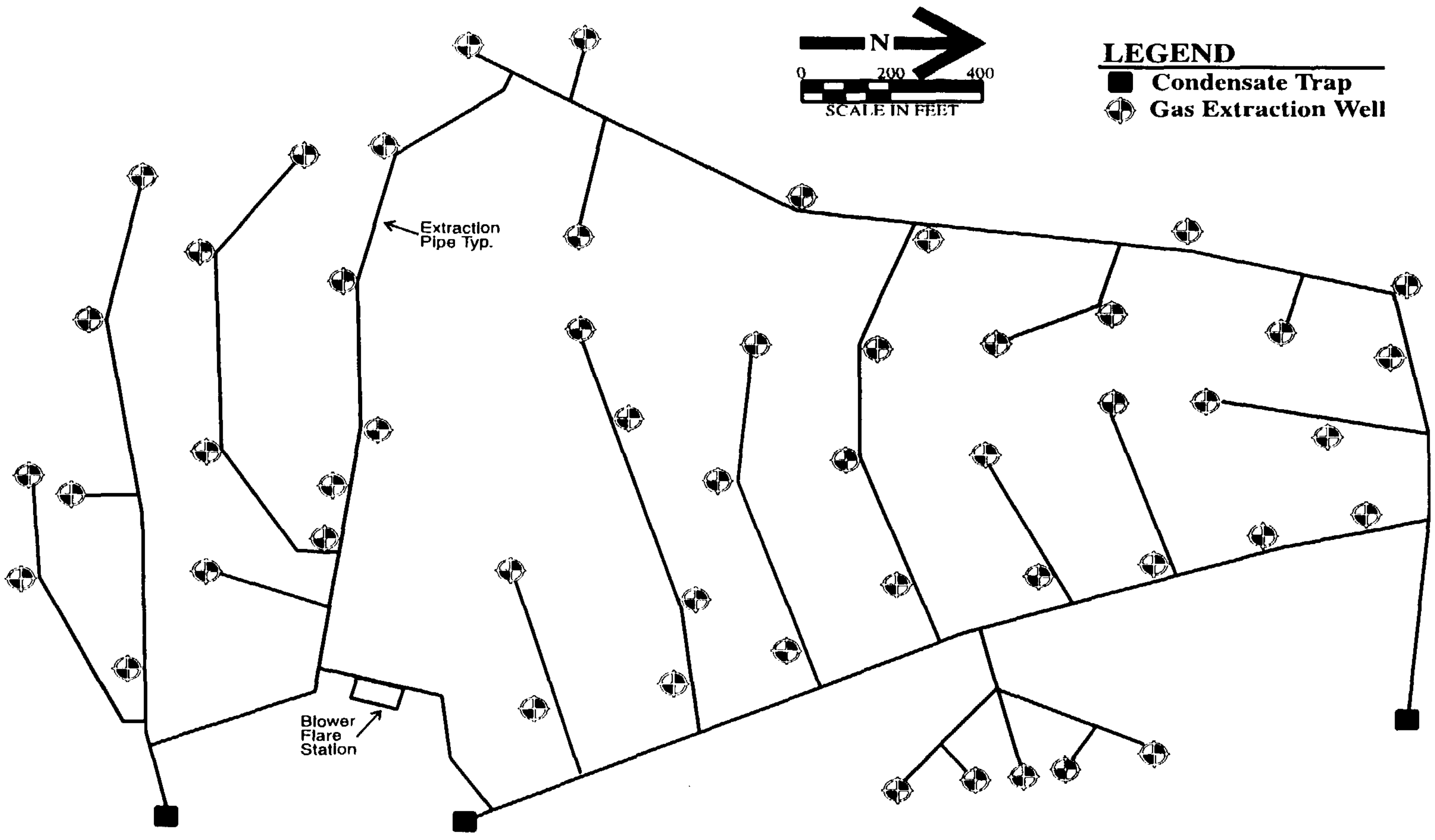
FIGURE 5

ILLUSTRATION OF A TYPICAL LANDFILL GAS EXTRACTION SITE PLAN



c7d041-2

Flare

A gas flare is a device used to ignite and burn the landfill gas. Flares are considered a component of each energy recovery option because they may be needed during energy recovery system startup and downtime. In addition, it may be more cost effective to gradually increase the size of the energy recovery system and to flare excess gas between system upgrades. Flare designs included open (or candle) flares and enclosed flares. Enclosed flares are more expensive but may be preferable because they allow for stack testing and can achieve slightly higher combustion efficiencies. They also reduce noise and light nuisances.

Gas Treatment Systems

Once the landfill gas has been collected, it must be treated to remove any condensate that was not captured in the knockout tanks, as well as particulates and other impurities. Treatment requirements depend on the end use application. Minimal treatment is required for direct use of gas in boilers, while extensive treatment is necessary to remove CO_2 for injection into a natural gas pipeline. Power production applications typically include a series of filters to remove impurities that could damage engine components and reduce system efficiency.

Energy Recovery Systems

The goal of a landfill gas-to-energy project is to convert landfill gas into a useful energy form such as electricity, steam, boiler fuel, vehicle fuel, or pipeline quality gas. There are several technologies that can be used to maximize the value of landfill gas when producing these energy forms, the most prevalent of which are:

- direct medium-Btu gas use, and
- power production/cogeneration.

The simplest and often most cost-effective use of landfill gas is as a medium-Btu fuel for boiler or industrial process use (e.g., drying operations, kiln operations, and cement and asphalt production). In these projects, the gas is piped directly to a nearby customer where it is used in new or existing combustion equipment as a replacement or supplementary fuel. Only limited condensate removal and filtration treatment is required, but some modification of existing equipment may be necessary. However, before the gas can be used by a customer, a pipeline must first be constructed to access the supply. Pipeline construction costs range from US$250,000 to $500,000 per mile, depending on the terrain, right-of-way costs, and other site-specific factors.

The most prevalent use for landfill gas is as a fuel for power generation, with the electricity sold to a utility and/or a nearby power customer. Power generation is advantageous because it produces a valuable end product--electricity--from waste gas. Cogeneration, on the other hand, is an alternative to producing electricity only. Cogeneration systems produce electricity and thermal energy (steam or hot water) from one fuel source. Whereas the thermal efficiencies of electricity-only generation range from 20% to 50%, cogeneration systems can achieve substantially higher efficiencies by putting to use the "waste" heat that is a by-product of most power generation cycles. Thermal energy cogenerated by the landfill gas projects can be used onsite for heating, cooling, and/or process needs, or piped to a nearby industrial or commercial user to provide a second revenue stream to the project. (EPA96.)

The reciprocating internal combustion (IC) engine is the most commonly used conversion technology in landfill gas applications; almost 80 percent of all existing landfill gas projects use them. The reason for such widespread use is their relatively low cost, high efficiency, and good size match with the gas output of many landfills. In fact, IC engines running on landfill gas are capable of achieving efficiencies in the range of 25 to 35 percent. (EPA96.)

5.2.1 Landfill Gas Recovery Project - Brazil

Section 5.2.2 presents the summary evaluation of the landfill gas generation and recovery potential for four Sao Paulo, Brazil landfills:

- Vila Albertina
- Santo Amaro
- Sâo Joâo
- Bandeirantes.

The basic input data were taken from a U.S. Environmental Protection Agency (EPA) study released in January, 1997, titled: "Feasibility Assessment for Gas-To-Energy at Selected Landfills in Sao Paulo, Brazil. ICF analyzed these data using EPA's Energy Project Landfill Gas Utilization Software (E-PLUS) version 1.0a. This software, which was developed by EPA, estimates the profitability and environmental benefits of landfill gas utilization projects. Section 5.2.3 presents a similar analysis for the Libusin landfill in the Czech Republic. The detailed E-PLUS manual, containing information on default values and instructions for use, and the E-PLUS installation disk are attached.

5.2.2 Summary of Evaluation Methodology

E-PLUS (and many other programs) estimates landfill gas generation using a first order decay model, in which the quantity of methane (Q) generated in a given year (T) attributable to waste disposed of in year (x) can be calculated as follows:

$$Q_{Tx} = kR_xL_oe^{-k(T-x)}$$

Where k = rate of methane generation (1/year)
L_o = lifetime methane generation potential (ft^3/lb)
R_x = the amount of waste disposed of in year x
x = the year of waste input
T = current year
Q_{Tx} = the methane generated in the current year by the waste R_x

The total amount of methane generated in a year (Q_T) is the sum of the methane generation contributions in that year for each year that waste was deposited:

$$Q_T = \sum Q_{Tx}$$

For example, if a landfill accepted waste from 1985 to 1995, the above equation could be used to calculate the total methane generation in 1998 by calculating the individual contributions of methane from the waste disposed of in 1985, 1986, 1987... 1995, and adding these generation rates together.

Based on this equation, landfill gas (LFG) generation typically peaks several years after the waste is added to the landfill, and then declines until the gas is no longer detectable. Two variables in the equation, L_0 and k, are important in predicting the intensity and timing of the peak. L_0 is the lifetime total of methane that will be generated by a unit of waste, and the coefficient k represents the rate of methane generation (or how quickly the methane will be available for utilization). Higher values of L_0 result in more methane generated, and hence a higher peak for a given k, while higher k values result in earlier and more intense peaks for a given L_0.

EPA examined gas generation rate and quality at the Bandeirantes Landfill. Based on the analysis of the data collected during the pump test, which assumed a lifetime methane generation (L_0) of 2.0 ft^3/lb, the range of the apparent methane generation rate coefficient (k) is from 0.04, which is a typical value used in modeling landfills in the Unites States, to 0.125, which would be considered to be fairly high in the U.S. Several factors were identified that would contribute to a high generation rate, including:

- The waste deposited in the landfill has a high organic content (particularly food waste) as observed visually at the working face at both Bandeirantes and Sao Joao Landfills, as well as their transfer operation at Santo Amaro. Waste composition data provided by the municipality also support these observations.

- The rainfall in this area is greater than 80 inches per year, thereby raising the moisture content and increasing the generation rate accordingly. High liquid levels measured in the landfill along with high leachate flows reported by the municipality support this observation.

- Passive vent flares installed during waste filling operations are ignitable within two or three months after waste placement indicating a rapid anaerobic decomposition of the waste. These same vents at the older sites (i.e., landfills which were closed several years ago) were no longer able to support combustion, which is due at least in part to the depletion of the organic waste mass through rapid decomposition.

Simply put, the Sao Paulo sites tend to produce more LFG more rapidly than U.S. landfills, followed by a sharp decrease in LFG flow.

Modeling Assumptions

Despite the potential for high LFG generation at Brazil landfills, we used the lower of the two k values (0.040) in the E-PLUS simulation to prepare LFG generation profiles for each site. As a result, lower peak methane generation and longer sustained methane generation are modeled. This k value is more conservative for sites that are still accepting waste (Bandeirantes and Sao Joao), because the peak of LFG generation occurs during the project period. Conversely, this k value may slightly overestimate LFG generation at the two sites that no longer accept waste (Santo Amaro and Vila Albertina). The value used for lifetime gas generation (L_0) was 2.0 ft^3/lb. We used the information on landfill characteristics in Exhibit 5-4 to create a methane generation profile for each landfill. These profiles are presented in Exhibits 5-5 through 5-8. By assuming that the LFG was 50 percent methane, we were also able to estimate LFG generation profiles. The Btu value of the gas was assumed to be 1,000 Btu/ft^3 methane.

Both gas to electricity and direct gas use projects are assumed to collect gas at approximately equal efficiencies, 75 percent, which is lower than the typical US collection efficiency of 85 percent. This is in part, due to the fact that most landfills in Brazil are not built with liners, and there is nothing to keep the gas from escaping by seeping into the ground. We note that one simple way to increase the efficiency of any project that is adopted is to install a liner in any cells that have not already received waste.

Exhibit 5-4
Landfill Characteristics

	Vila Albertina	Santo Amaro	Bandeirantes	Sâo Joâo
Date Landfill Opened	1977	1976	1979	1992
Date Landfill Stopped Accepting Waste	1993	1993	2001	2011
Waste in Place (tons)	10,200,000	16,800,000	28,470,000	7,220,000
Annual Acceptance Rate (tons/yr - Calculated)	--	--	1,674,706	1,805,000

Exhibit 5-5
Methane Production Estimates - Vila Albertina Landfill

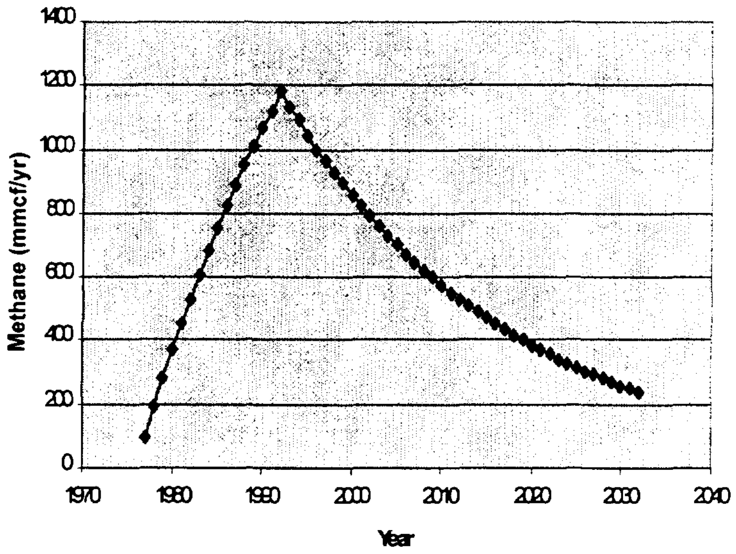


Exhibit 5-6
Methane Production Estimates - Santo Amaro Landfill

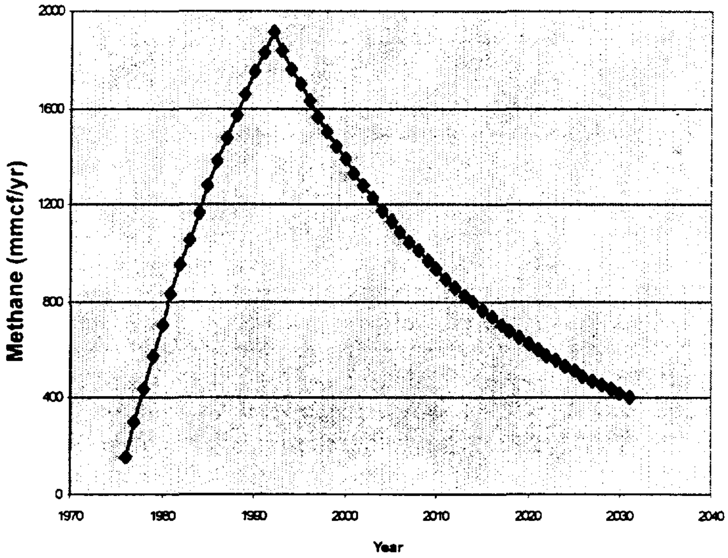


Exhibit 5-7
Methane Production Estimates - Bandeirantes Landfill

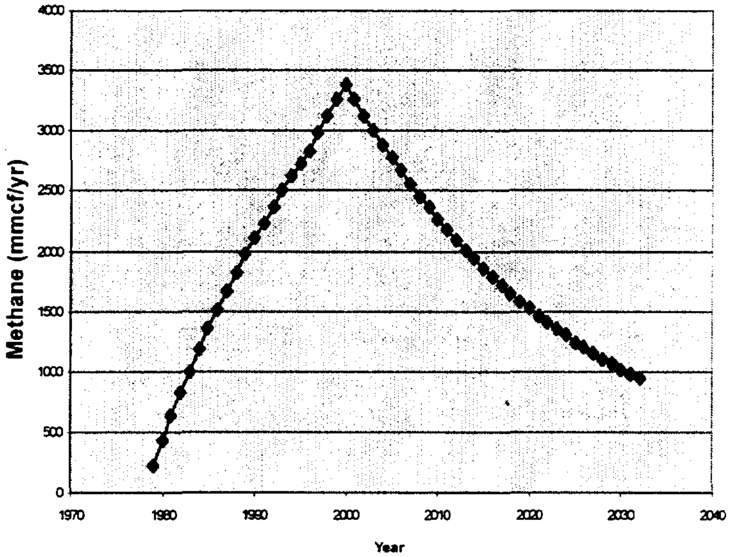
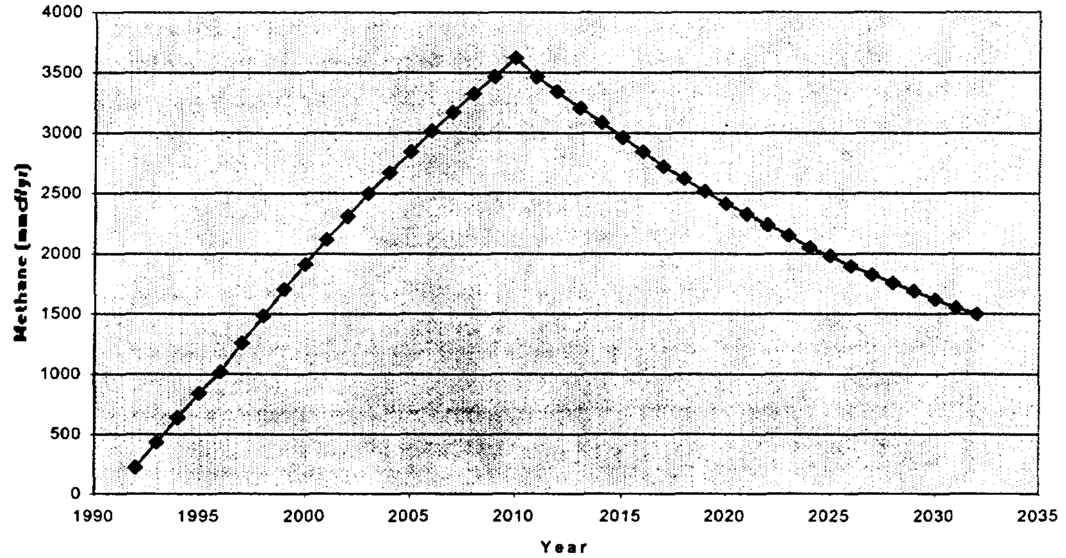


Exhibit 5-8
Methane Production Estimates - Sao Joao Landfill



In addition to gas collection efficiency, plant availability and energy consumption will affect the amount of gas sold. We assume that both the gas to electricity and gas cleaning plants are available 90 percent of the time (that is, 90 percent of the collected gas is converted to an energy product). In addition, we assume that customers demand 85 percent of these energy products. Thus the amount of gas sold is effectively 77 percent of the gas collected for both direct use projects and gas to electricity projects.

Economic Feasibility Analysis

An economic analysis was performed over a 15-year life. All projects were assumed to commence engineering and construction during 1997 and be operational by 1998. Two types of economic feasibility analysis were conducted for each landfill: 1) direct use as a medium Btu fuel and 2) gas to electricity. These two alternatives were selected because they represent the most common technologies. The preferred technology for each site will be dependent on a number of factors, including the supply and demand for gas and electricity and impacts of government regulation. A more critical analysis must be performed to identify energy demand within the proximity of each landfill. Exhibit 5-9 lists the economic assumptions that were used during the analysis for each site. These assumptions are discussed in more detail below.

Several of these assumptions used in the financial analysis, including discount and interest rates, are representative of typical U.S. conditions. However, the inflation rate and revenue escalation rates were adjusted to the 1996 Brazilian inflation rate of 10 percent, and the tax rate was adjusted to reflect the Brazilian tax rate of 25 percent.

Revenues

Revenues are generated from the sale of either gas or electricity. For this analysis, all revenue estimates were developed in 1997 U.S. dollars. Natural gas is relatively inexpensive in Brazil (in fact, supply exceeds demand in many areas of the country). As is typical in the U.S., it was assumed that a LFG project will have to offer gas to consumers at a competitive price (given the less stable nature of the supply and lower energy value of the gas). Based on U.S. experience, it was therefore assumed that LFG developers for the Sao Paulo projects could market the gas at $2.25 per mmBtu, approximately 80 percent of the prevalent rate paid by Comgas to Petrobras.

Exhibit 5-9
Economic Assumptions

Assumptions	**Value**	**Units**
Economic		
Inflation Rate	10	percent per year
Financial		
Interest Rate	10	Percent
Discount Rate	14	Percent
Loan Pay-Off Period	15	Years
Down Payment	20	Percent of capital costs
Tax Rate	25	Percent of profit
Revenues		
Direct Gas Usage	2.25	U.S. $ per MMBTU (1997 $)
Gas to Electricity	0.060	U.S. $ per kWh (1997 $)
Escalation Rate	10	Percent per year

For electricity, EletroPaulo's user rates range from $0.045 to $0.12 per kW-hr, depending on supply voltage. It was assumed that electricity would be sold at a rate of $0.060 per kW-hr (the lower end of this range). This energy payment assumes the availability of a customer willing to buy at a discounted retail rate. If retail customers are not available, electricity could be sold to EletroPaulo at the wholesale rate of $0.035/kW-hr, per a letter from the utility's president to SVMA, dated July 29, 1996. The project, however, would not be economical at this rate to EletroPaulo.

It must be recognized that prices paid for energy are speculative. If one of the projects discussed in this report is to move forward in the development process, it will be critical to ascertain the local demand for direct gas use and electricity at each of the landfills.

Costs

E-PLUS estimates costs for capital, and operations and maintenance (O&M) items. The default values for the individual components of these costs can be found in Appendix A of the E-PLUS manual. Loans on capital expenses were assumed to have a 15-year payback period, with annual payments being made at the end of each period. It was assumed that 80 percent of the project capital costs would be financed (i.e., 20 percent of these costs would be met up front). The interest rate was assumed to be 10 percent. This estimate is based on the project being implemented by a large, established company. If the project were implemented by a public entity or smaller private firm, the interest rate for financing may range from 7 to 12 percent.

Annual operation and maintenance costs (O & M) costs were estimated when E-PLUS did not provide default values. The pipeline O&M cost was assumed to be 10 percent of the pipeline capital cost.

Measures of Profitability

The net present value (NPV) is calculated by returning a series of annual cash flows over time (revenues minus costs) to their present value (1998 $) using a discount rate. A discount rate of 14 percent was selected. This value is higher than the cost of financing by 4 percent. A positive NPV indicates a financially viable project. The internal rate of return (IRR) is the discount rate which makes the NPV of an income stream equal to zero. Project IRR can be compared to select the more financially attractive project. Project developers and investors often require a project to have a minimum IRR for them to invest in, such as 20 percent IRR.

ICF presents a summary of the economic costs and benefits of these projects in Exhibit 5-10. The environmental benefits associated with the four potential recovery projects are shown in Exhibit 5-11. Lastly, the detailed E-PLUS report for each site is included in Attachment A, along with a list of non-default options used in this analysis.

EXHIBIT 5-10
Project Summary of LFGTE Site Evaluations - Brazil

PROJECT SUMMARIES:	Vila Albertina	Santo Amaro	Bandeirantes	Sâo Joâo
Gas to Energy				
Project Size (MW)	4.0	6.5	15.8	15.5
Capital Costs	$7,350,000	$11,900,000	$22,800,000	$22,200,000
Project Life (yrs)	15	15	15	15
Internal Rate of Return	17%	25%	47%	22%
Net Present Value	$410,000	$1,370,000	$10,800,000	$6,000,000
Direct Use as Med. Btu Fuel				
Project Size (MMBTU/yr)	277,000	449,000	1,010,000	1,070,000
Capital Costs	$2,860,000	$4,560,00	$4,610,000	$4,340,000
Project Life	15	15	15	15
Internal Rate of Return	88%	104%	286%	114%
Net Present Value	$3,480,000	$6,110,000	$22,200,000	$18,500,000

EXHIBIT 5-11
Environmental Benefits of LFGTE Projects - Brazil

Environmental Benefit	Vila Albertina	Santo Amaro	Bandeirantes	Sâo Joâo
Gas Collection				
CH_4 Avoided (tons/yr)	1,030,000	1,670,000	4,400,000	4,180,00
CO_2 equivalent (tons/yr)	21,700,000	35,100,00	92,400,000	87,700,000
Use of Electricity				
CO_2 Emissions Avoided (tons/yr)	9,150	14,900	38,600	35,100
SO_2 Emissions Avoided (tons/yr)	270	440	1,130	1,030
Direct Use as Med. Btu Fuel				
CO_2 Emissions Avoided (tons/yr)	37,800	61,400	161,000	153,000

5.2.3 Landfill Gas Recovery Project - Czech Republic

The Kladno district is situated about 20 km northwest of Prague and the city of Kladno has a population of approximately 92,000 (page 17 of the case study report). Household and municipal wastes reportedly are hauled to a central landfill in Libušin. Approximately 60,000 metric tons/yr (or 66,150 tons) of waste is landfilled (page 20 of the case study report).

Using this information and following the same methodology used in the LFGTE calculations for the Brazilian landfills, ICF ran EPA's Energy Project Landfill Gas Utilization Software (E-PLUS) and replicated the analysis for the central landfill in Libušin. ICF assumed that the landfill opened in 1980 and will close in 2013, and that the energy recovery project will operate for 15 years starting in 1998. ICF also assumed that the efficiency of collecting landfill gas in the Czech Republic is 85 percent (the average in the United States) rather than 75 percent (assumed for landfills in Brazil). Finally, we assumed the Czech inflation and energy escalation rates are 7.5 percent (based on 1996 data). All other default values and assumptions were the same as those used in the analysis of the Brazilian landfills. Exhibit 5-12 shows estimated methane production, while Exhibit 5-13 presents a summary of the economic costs and benefits and Exhibit 5-14 presents the environmental benefits associated with the potential gas to energy project.

Exhibit 5-12
Methane Production Estimates - Libusin Landfill

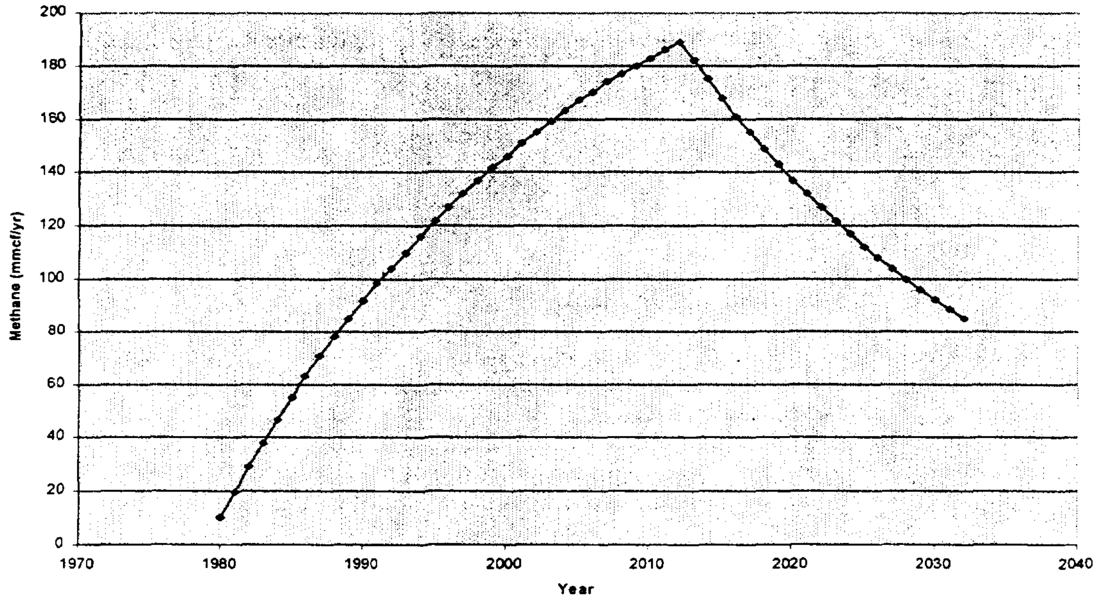


EXHIBIT 5-13
Project Summary of LFGTE Site Evaluations - Czech Republic

PROJECT SUMMARIES:	Libusin
Gas to Energy	
Project Size (MW)	0.92
Capital Costs	$1,740,000
Project Life (yrs)	15
Internal Rate of Return	16%
Net Present Value	$57,700
Direct Use as Med. Btu Fuel	
Project Size (MMBTU/yr)	64,000
Capital Costs	$825,000
Project Life	15
Internal Rate of Return	42%
Net Present Value	$506,000

EXHIBIT 5-14
Environmental Benefits of LFGTE Projects - Czech Republic

Environmental Benefit	Libusin
Gas Collection	
CH_4 Avoided (tons/yr)	281,000
CO_2 equivalent (tons/yr)	5,910,000
Use of Electricity	
CO_2 Emissions Avoided (tons/yr)	2,410
SO_2 Emissions Avoided (tons/yr)	70
Direct Use as Med. Btu Fuel	
CO_2 Emissions Avoided (tons/yr)	9,100

ATTACHMENT A
E-PLUS DETAILED REPORTS

E-Plus Analysis

Summary Report

Landfill: Libusin
Design Scenario: Electricity
Author: ICF Incorporated
Date: June 19, 1998

nalyses performed using E-Plus Version 1.0 are considered preliminary and are to be used for guidance only. It is mperative that a detailed final feasibility assessment be conducted by qualified landfill gas recovery and utilization rofessionals prior to preparing a design, initiating construction, purchasing materials, or entering into agreements to rovide or purchase energy from a landfill gas project.

Summary Results

Based on the project definition, landfill characteristics, and financial assumptions provided, the following summary results are estimated:

Project Start Year: 1998
Project Lifetime: 15
Electricity Capacity: 923 kW for electricity sales
Average Electricity Price: $0.1075 per kWh, averaged over the life of the project
Gas Sales Capacity: 0 MMBTU/year for gas sales
Average Gas Price: $0.00 per MMBTU, averaged over the life of the project
Financial Results:
  Net Present Value: $ 57,746
  IRR: 16
  Simple Payback: 14.3 years
  Capital Costs: $ 1,744,596
  O&M Costs: $ 321,463 per year, averaged over the life of the project

These financial results include the costs associated with the gas collection and flaring system. As defined, the landfill does not trigger the recently promulgated NSPS/EG emissions control requirements using the Tier 1 calculation method.

Landfill Characteristics

Open Year: 1980
Close Year: 2013
Current Year: 1997
Waste in Place: 1,120,000 tons, in 1997
Waste Acceptance Rate: 66,150 tons per year, from current year onward
Depth: 50 feet, maximum during landfill lifetime
Area: 45 acres, maximum during landfill lifetime

Gas Generation and Collection

Gas Generation from 1980 to 2033:
  Annual Average: 122 mmcf/year of methane
  243 mmcf/year of landfill gas
  Maximum: 190 mmcf/year of methane
  380 mmcf/year of landfill gas
Gas Generation During the Project: 1998 to 2013:
  Annual Average: 157 mmcf/year of methane
  314 mmcf/year of landfill gas
  Maximum: 190 mmcf/year of methane
  380 mmcf/year of landfill gas
Gas Collection Efficiency: 85 percent

Financial Assumptions

Project Start Year:	1998
Project End Year:	2013
Base Year for NPV Estimate:	1998

Downpayment Percent:	20 percent of total capital costs (remainder is borrowed)
Loan Rate:	10 percent
Loan Period:	15 years
Project Discount Rate:	14 percent
Marginal Tax Rate:	25 percent
Depreciation Method:	Straight Line
Inflation Rate for Costs:	7.5 percent per year
Collect and Flare Costs:	The costs associated with the gas collection and flaring system are included from the financial analysis.

Project Configuration Summary

Collection:	Included
Flare:	Included
Gas Treatment:	Included
Compression:	Included
Gas Enrichment:	Not Included
Electricity Production:	
Generation:	Included
Intertie:	Included
Sales	Included
Gas Production:	
Pipeline:	Not Included
Sales:	Not Included

Electricity Production and Sales Summary

Total Capacity:	923 kW
Average Generation:	6,359,374 kWh/year over the life of the project
Engine Load Factor:	78.69 percent over the life of the project
Average Electricity Price:	$0.1075 per kWh, averaged over the life of the project

Gas Production and Sales Summary

Gas Sales Capacity:	0 MMBTU/year for gas sales
Average Gas Price:	$0.00 per MMBTU, averaged over the life of the project
Average Production:	0 MMBTU/year over the life of the project

Price Analysis

Electricity Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average electricity price of $0.0586 per kWh is needed, average over the life of the project (assuming that the price for gas sales, if any, remains as defined in the project specification).

Gas Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average gas price of $0.00 per MMBTU is needed, average over the life of the project (assuming that the price for electricity sales, if any, remains as defined in the project specification).

Environmental Benefits Analysis

Annual Average Environmental Benefits From Recovering the Landfill Gas:

Methane Emissions:	281.42 thousand tons avoided/year, averaged over the life of the project
	4,221.33 thousand tons avoided total during the project
CO2 Equivalent:	5,909.86 thousand tons avoided/year, averaged over the life of the project
	88,647.95 thousand tons avoided total during the project

Annual Average Environmental Benefits From Generating Electricity from Landfill Gas:

CO2 Emissions:	2.41 thousand tons avoided/year, averaged over the life of the project
	36.21 thousand tons avoided total during the project
SO2 Emissions:	0.07 thousand tons avoided/year, averaged over the life of the project
	1.06 thousand tons avoided total during the project

Annual Average Environmental Benefits From Using Landfill Gas Directly:

CO2 Emissions:	9.10 thousand tons avoided/year, averaged over the life of the project
	136.57 thousand tons avoided total during the project

E-Plus Analysis

Summary Report

Landfill: Libusin
Design Scenario: Direct Gas Use
Author: ICF Incorporated
Date: June 19, 1998

Analyses performed using E-Plus Version 1.0 are considered preliminary and are to be used for guidance only. It is imperative that a detailed final feasibility assessment be conducted by qualified landfill gas recovery and utilization professionals prior to preparing a design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Based on the project definition, landfill characteristics, and financial assumptions provided, the following summary results are estimated:

Project Start Year: 1998

Project Lifetime: 15

Electricity Capacity: 0 kW for electricity sales

Average Electricity Price: $0.0000 per kWh, averaged over the life of the project

Gas Sales Capacity: 64,030 MMBTU/year for gas sales

Average Gas Price: $4.03 per MMBTU, averaged over the life of the project

Financial Results:

Net Present Value: $ 505,881

IRR: 42

Simple Payback: 7.2 years

Capital Costs: $ 824,660

O&M Costs: $ 136,946 per year, averaged over the life of the project

These financial results include the costs associated with the gas collection and flaring system. As defined, the landfill does not trigger the recently promulgated NSPS/EG emissions control requirements using the Tier 1 calculation method.

Landfill Characteristics

Open Year: 1980

Close Year: 2013

Current Year: 1997

Waste in Place: 1,120,000 tons, in 1997

Waste Acceptance Rate: 66,150 tons per year, from current year onward

Depth: 50 feet, maximum during landfill lifetime

Area: 45 acres, maximum during landfill lifetime

Gas Generation and Collection

Gas Generation from 1980 to 2033:

Annual Average: 122 mmcf/year of methane
243 mmcf/year of landfill gas

Maximum: 190 mmcf/year of methane
380 mmcf/year of landfill gas

Gas Generation During the Project: 1998 to 2013:

Annual Average: 157 mmcf/year of methane
314 mmcf/year of landfill gas

Maximum: 190 mmcf/year of methane
380 mmcf/year of landfill gas

Gas Collection Efficiency: 85 percent

Financial Assumptions

Project Start Year: 1998
Project End Year: 2013
Base Year for NPV Estimate: 1998

Downpayment Percent: 20 percent of total capital costs (remainder is borrowed)
Loan Rate: 10 percent
Loan Period: 15 years
Project Discount Rate: 14 percent
Marginal Tax Rate: 25 percent
Depreciation Method: Straight Line
Inflation Rate for Costs: 7.5 percent per year
Collect and Flare Costs: The costs associated with the gas collection and flaring system are included from the financial analysis.

Project Configuration Summary

Collection: Included
Flare: Included
Gas Treatment: Included
Compression: Included
Gas Enrichment: Not Included
Electricity Production:
  Generation: Not Included
  Intertie: Not Included
  Sales Not Included
Gas Production:
  Pipeline: Included
  Sales: Included

Electricity Production and Sales Summary

Total Capacity: 0 kW
Average Generation: 0 kWh/year over the life of the project
Engine Load Factor: 0.00 percent over the life of the project
Average Electricity Price: $0.0000 per kWh, averaged over the life of the project

Gas Production and Sales Summary

Gas Sales Capacity: 64,030 MMBTU/year for gas sales
Average Gas Price: $4.03 per MMBTU, averaged over the life of the project
Average Production: 55,982 MMBTU/year over the life of the project

Price Analysis

Electricity Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average electricity price of $0.0000 per kWh is needed, average over the life of the project (assuming that the price for gas sales, if any, remains as defined in the project specification).

Gas Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average gas price of $1.54 per MMBTU is needed, average over the life of the project (assuming that the price for electricity sales, if any, remains as defined in the project specification).

Environmental Benefits Analysis

Annual Average Environmental Benefits From Recovering the Landfill Gas:

Methane Emissions:	281.42 thousand tons avoided/year, averaged over the life of the project
	4,221.33 thousand tons avoided total during the project
CO2 Equivalent:	5,909.86 thousand tons avoided/year, averaged over the life of the project
	88,647.95 thousand tons avoided total during the project

Annual Average Environmental Benefits From Generating Electricity from Landfill Gas:

CO2 Emissions:	0.00 thousand tons avoided/year, averaged over the life of the project
	0.00 thousand tons avoided total during the project
SO2 Emissions:	0.00 thousand tons avoided/year, averaged over the life of the project
	0.00 thousand tons avoided total during the project

Annual Average Environmental Benefits From Using Landfill Gas Directly:

CO2 Emissions:	9.10 thousand tons avoided/year, averaged over the life of the project
	136.57 thousand tons avoided total during the project

E-Plus Analysis

Summary Report

Landfill: Sao Joao
Design Scenario: Electricity
Author: ICF Incorporated
Date: June 19, 1998

Analyses performed using E-Plus Version 1.0 are considered preliminary and are to be used for guidance only. It is imperative that a detailed final feasibility assessment be conducted by qualified landfill gas recovery and utilization professionals prior to preparing a design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Based on the project definition, landfill characteristics, and financial assumptions provided, the following summary results are estimated:

Project Start Year: 1998

Project Lifetime: 15

Electricity Capacity: 15,529 kW for electricity sales

Average Electricity Price: $0.1386 per kWh, averaged over the life of the project

Gas Sales Capacity: 0 MMBTU/year for gas sales

Average Gas Price: $0.00 per MMBTU, averaged over the life of the project

Financial Results:

Net Present Value: $ 6,004,120

IRR: 22

Simple Payback: 36.0 years

Capital Costs: $ 22,210,812

O&M Costs: $ 5,430,272 per year, averaged over the life of the project

These financial results include the costs associated with the gas collection and flaring system. As defined, the landfill triggers the recently promulgated NSPS/EG emissions control requirements using the Tier 1 calculation method.

Landfill Characteristics

Open Year: 1992

Close Year: 2011

Current Year: 1997

Waste in Place: 7,220,000 tons, in 1997

Waste Acceptance Rate: 1,805,000 tons per year, from current year onward

Depth: 50 feet, maximum during landfill lifetime

Area: 672 acres, maximum during landfill lifetime

Gas Generation and Collection

Gas Generation from 1992 to 2033:

Annual Average: 2,204 mmcf/year of methane
4,408 mmcf/year of landfill gas

Maximum: 3,621 mmcf/year of methane
7,241 mmcf/year of landfill gas

Gas Generation During the Project: 1998 to 2013:

Annual Average: 2,638 mmcf/year of methane
5,276 mmcf/year of landfill gas

Maximum: 3,621 mmcf/year of methane
7,241 mmcf/year of landfill gas

Gas Collection Efficiency: 75 percent

Financial Assumptions

Project Start Year: 1998
Project End Year: 2013
Base Year for NPV Estimate: 1998

Downpayment Percent: 20 percent of total capital costs (remainder is borrowed)
Loan Rate: 10 percent
Loan Period: 15 years
Project Discount Rate: 14 percent
Marginal Tax Rate: 25 percent
Depreciation Method: Straight Line
Inflation Rate for Costs: 10.0 percent per year
Collect and Flare Costs: The costs associated with the gas collection and flaring system are included from the financial analysis.

Project Configuration Summary

Collection: Included
Flare: Included
Gas Treatment: Included
Compression: Included
Gas Enrichment: Not Included
Electricity Production:
  Generation: Included
  Intertie: Included
  Sales Included
Gas Production:
  Pipeline: Not Included
  Sales: Not Included

Electricity Production and Sales Summary

Total Capacity: 15,529 kW
Average Generation: 92,563,041 kWh/year over the life of the project
Engine Load Factor: 68.04 percent over the life of the project
Average Electricity Price: $0.1386 per kWh, averaged over the life of the project

Gas Production and Sales Summary

Gas Sales Capacity: 0 MMBTU/year for gas sales
Average Gas Price: $0.00 per MMBTU, averaged over the life of the project
Average Production: 0 MMBTU/year over the life of the project

Price Analysis

Electricity Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average electricity price of $0.0513 per kWh is needed, average over the life of the project (assuming that the price for gas sales, if any, remains as defined in the project specification).

Gas Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average gas price of $0.00 per MMBTU is needed, average over the life of the project (assuming that the price for electricity sales, if any, remains as defined in the project specification).

Environmental Benefits Analysis

Annual Average Environmental Benefits From Recovering the Landfill Gas:

Methane Emissions: 4,178.37 thousand tons avoided/year, averaged over the life of the project
62,675.60 thousand tons avoided total during the project

CO2 Equivalent: 87,745.84 thousand tons avoided/year, averaged over the life of the project
1,316,187.65 thousand tons avoided total during the project

Annual Average Environmental Benefits From Generating Electricity from Landfill Gas:

CO2 Emissions: 35.14 thousand tons avoided/year, averaged over the life of the project
527.03 thousand tons avoided total during the project

SO2 Emissions: 1.03 thousand tons avoided/year, averaged over the life of the project
15.45 thousand tons avoided total during the project

Annual Average Environmental Benefits From Using Landfill Gas Directly:

CO2 Emissions: 153.21 thousand tons avoided/year, averaged over the life of the project
2,298.11 thousand tons avoided total during the project

E-Plus Analysis

Summary Report

Landfill: Sao Joao
Design Scenario: Direct Gas Use
Author: ICF Incorporated
Date: June 19, 1998

Analyses performed using E-Plus Version 1.0 are considered preliminary and are to be used for guidance only. It is imperative that a detailed final feasibility assessment be conducted by qualified landfill gas recovery and utilization professionals prior to preparing a design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Based on the project definition, landfill characteristics, and financial assumptions provided, the following summary results are estimated:

Project Start Year: 1998

Project Lifetime: 15

Electricity Capacity: 0 kW for electricity sales

Average Electricity Price: $0.0000 per kWh, averaged over the life of the project

Gas Sales Capacity: 1,077,766 MMBTU/year for gas sales

Average Gas Price: $5.20 per MMBTU, averaged over the life of the project

Financial Results:

Net Present Value: $ 18,489,515

IRR: 114

Simple Payback: 3.5 years

Capital Costs: $ 4,337,421

O&M Costs: $ 1,310,475 per year, averaged over the life of the project

These financial results include the costs associated with the gas collection and flaring system. As defined, the landfill triggers the recently promulgated NSPS/EG emissions control requirements using the Tier 1 calculation method.

Landfill Characteristics

Open Year: 1992

Close Year: 2011

Current Year: 1997

Waste in Place: 7,220,000 tons, in 1997

Waste Acceptance Rate: 1,805,000 tons per year, from current year onward

Depth: 50 feet, maximum during landfill lifetime

Area: 672 acres, maximum during landfill lifetime

Gas Generation and Collection

Gas Generation from 1992 to 2033:

Annual Average: 2,204 mmcf/year of methane
4,408 mmcf/year of landfill gas

Maximum: 3,621 mmcf/year of methane
7,241 mmcf/year of landfill gas

Gas Generation During the Project: 1998 to 2013:

Annual Average: 2,638 mmcf/year of methane
5,276 mmcf/year of landfill gas

Maximum: 3,621 mmcf/year of methane
7,241 mmcf/year of landfill gas

Gas Collection Efficiency: 75 percent

Financial Assumptions

Project Start Year: 1998

Project End Year: 2013

Base Year for NPV Estimate: 1998

Downpayment Percent: 20 percent of total capital costs (remainder is borrowed)

Loan Rate: 10 percent

Loan Period: 15 years

Project Discount Rate: 14 percent

Marginal Tax Rate: 25 percent

Depreciation Method: Straight Line

Inflation Rate for Costs: 10.0 percent per year

Collect and Flare Costs: The costs associated with the gas collection and flaring system are included from the financial analysis.

Project Configuration Summary

Collection: Included

Flare: Included

Gas Treatment: Included

Compression: Included

Gas Enrichment: Not Included

Electricity Production:

- Generation: Not Included
- Intertie: Not Included
- Sales Not Included

Gas Production:

- Pipeline: Included
- Sales: Included

Electricity Production and Sales Summary

Total Capacity: 0 kW

Average Generation: 0 kWh/year over the life of the project

Engine Load Factor: 0.00 percent over the life of the project

Average Electricity Price: $0.0000 per kWh, averaged over the life of the project

Gas Production and Sales Summary

Gas Sales Capacity: 1,077,766 MMBTU/year for gas sales

Average Gas Price: $5.20 per MMBTU, averaged over the life of the project

Average Production: 814,837 MMBTU/year over the life of the project

Price Analysis

Electricity Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average electricity price of $0.0000 per kWh is needed, average over the life of the project (assuming that the price for gas sales, if any, remains as defined in the project specification).

Gas Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average gas price of $0.69 per MMBTU is needed, average over the life of the project (assuming that the price for electricity sales, if any, remains as defined in the project specification).

Environmental Benefits Analysis

Annual Average Environmental Benefits From Recovering the Landfill Gas:

Methane Emissions: 4,178.37 thousand tons avoided/year, averaged over the life of the project
62,675.60 thousand tons avoided total during the project

CO2 Equivalent: 87,745.84 thousand tons avoided/year, averaged over the life of the project
1,316,187.65 thousand tons avoided total during the project

Annual Average Environmental Benefits From Generating Electricity from Landfill Gas:

CO2 Emissions: 0.00 thousand tons avoided/year, averaged over the life of the project
0.00 thousand tons avoided total during the project

SO2 Emissions: 0.00 thousand tons avoided/year, averaged over the life of the project
0.00 thousand tons avoided total during the project

Annual Average Environmental Benefits From Using Landfill Gas Directly:

CO2 Emissions: 153.21 thousand tons avoided/year, averaged over the life of the project
2,298.11 thousand tons avoided total during the project

E-Plus Analysis

Summary Report

Landfill: Bandeirantes
Design Scenario: Electricity
Author: ICF Incorporated
Date: June 19, 1998

Analyses performed using E-Plus Version 1.0 are considered preliminary and are to be used for guidance only. It is imperative that a detailed final feasibility assessment be conducted by qualified landfill gas recovery and utilization professionals prior to preparing a design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Based on the project definition, landfill characteristics, and financial assumptions provided, the following summary results are estimated:

Project Start Year: 1998

Project Lifetime: 15

Electricity Capacity: 15,796 kW for electricity sales

Average Electricity Price: $0.1195 per kWh, averaged over the life of the project

Gas Sales Capacity: 0 MMBTU/year for gas sales

Average Gas Price: $0.00 per MMBTU, averaged over the life of the project

Financial Results:

- Net Present Value: $ 10,776,539
- IRR: 47
- Simple Payback: 6.0 years
- Capital Costs: $ 22,788,481
- O&M Costs: $ 5,549,908 per year, averaged over the life of the project

These financial results include the costs associated with the gas collection and flaring system. As defined, the landfill triggers the recently promulgated NSPS/EG emissions control requirements using the Tier 1 calculation method.

Landfill Characteristics

Open Year: 1979

Close Year: 2001

Current Year: 1997

Waste in Place: 28,470,000 tons, in 1997

Waste Acceptance Rate: 1,674,706 tons per year, from current year onward

Depth: 50 feet, maximum during landfill lifetime

Area: 728 acres, maximum during landfill lifetime

Gas Generation and Collection

Gas Generation from 1979 to 2033:

Annual Average: 2,084 mmcf/year of methane
4,168 mmcf/year of landfill gas

Maximum: 3,683 mmcf/year of methane
7,366 mmcf/year of landfill gas

Gas Generation During the Project: 1998 to 2013:

Annual Average: 2,777 mmcf/year of methane
5,553 mmcf/year of landfill gas

Maximum: 3,683 mmcf/year of methane
7,366 mmcf/year of landfill gas

Gas Collection Efficiency: 75 percent

Financial Assumptions

Project Start Year: 1998
Project End Year: 2013
Base Year for NPV Estimate: 1998

Downpayment Percent: 20 percent of total capital costs (remainder is borrowed)
Loan Rate: 10 percent
Loan Period: 15 years
Project Discount Rate: 14 percent
Marginal Tax Rate: 25 percent
Depreciation Method: Straight Line
Inflation Rate for Costs: 10.0 percent per year
Collect and Flare Costs: The costs associated with the gas collection and flaring system are included from the financial analysis.

Project Configuration Summary

Collection: Included
Flare: Included
Gas Treatment: Included
Compression: Included
Gas Enrichment: Not Included
Electricity Production:
  Generation: Included
  Intertie: Included
  Sales Included
Gas Production:
  Pipeline: Not Included
  Sales: Not Included

Electricity Production and Sales Summary

Total Capacity: 15,796 kW
Average Generation: 101,655,528 kWh/year over the life of the project
Engine Load Factor: 73.46 percent over the life of the project
Average Electricity Price: $0.1195 per kWh, averaged over the life of the project

Gas Production and Sales Summary

Gas Sales Capacity: 0 MMBTU/year for gas sales
Average Gas Price: $0.00 per MMBTU, averaged over the life of the project
Average Production: 0 MMBTU/year over the life of the project

Price Analysis

Electricity Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average electricity price of $0.0467 per kWh is needed, average over the life of the project (assuming that the price for gas sales, if any, remains as defined in the project specification).

Gas Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average gas price of $0.00 per MMBTU is needed, average over the life of the project (assuming that the price for electricity sales, if any, remains as defined in the project specification).

Environmental Benefits Analysis

Annual Average Environmental Benefits From Recovering the Landfill Gas:

Methane Emissions: 4,398.22 thousand tons avoided/year, averaged over the life of the project
65,973.34 thousand tons avoided total during the project

CO2 Equivalent: 92,362.68 thousand tons avoided/year, averaged over the life of the project
1,385,440.18 thousand tons avoided total during the project

Annual Average Environmental Benefits From Generating Electricity from Landfill Gas:

CO2 Emissions: 38.59 thousand tons avoided/year, averaged over the life of the project
578.80 thousand tons avoided total during the project

SO2 Emissions: 1.13 thousand tons avoided/year, averaged over the life of the project
16.97 thousand tons avoided total during the project

Annual Average Environmental Benefits From Using Landfill Gas Directly:

CO2 Emissions: 161.27 thousand tons avoided/year, averaged over the life of the project
2,419.02 thousand tons avoided total during the project

E-Plus Analysis

Summary Report

Landfill: Bandeirantes
Design Scenario: Direct Gas Use
Author: ICF Incorporated
Date: June 19, 1998

Analyses performed using E-Plus Version 1.0 are considered preliminary and are to be used for guidance only. It is imperative that a detailed final feasibility assessment be conducted by qualified landfill gas recovery and utilization professionals prior to preparing a design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Based on the project definition, landfill characteristics, and financial assumptions provided, the following summary results are estimated:

Project Start Year: 1998

Project Lifetime: 15

Electricity Capacity: 0 kW for electricity sales

Average Electricity Price: $0.0000 per kWh, averaged over the life of the project

Gas Sales Capacity: 1,096,312 MMBTU/year for gas sales

Average Gas Price: $4.48 per MMBTU, averaged over the life of the project

Financial Results:

- Net Present Value: $ 22,160,668
- IRR: 286
- Simple Payback: 1.2 years
- Capital Costs: $ 4,605,105
- O&M Costs: $ 1,449,229 per year, averaged over the life of the project

These financial results include the costs associated with the gas collection and flaring system. As defined, the landfill triggers the recently promulgated NSPS/EG emissions control requirements using the Tier 1 calculation method.

Landfill Characteristics

Open Year: 1979

Close Year: 2001

Current Year: 1997

Waste in Place: 28,470,000 tons, in 1997

Waste Acceptance Rate: 1,674,706 tons per year, from current year onward

Depth: 50 feet, maximum during landfill lifetime

Area: 728 acres, maximum during landfill lifetime

Gas Generation and Collection

Gas Generation from 1979 to 2033:

- Annual Average: 2,084 mmcf/year of methane
  4,168 mmcf/year of landfill gas
- Maximum: 3,683 mmcf/year of methane
  7,366 mmcf/year of landfill gas

Gas Generation During the Project: 1998 to 2013:

- Annual Average: 2,777 mmcf/year of methane
  5,553 mmcf/year of landfill gas
- Maximum: 3,683 mmcf/year of methane
  7,366 mmcf/year of landfill gas

Gas Collection Efficiency: 75 percent

Financial Assumptions

Project Start Year: 1998
Project End Year: 2013
Base Year for NPV Estimate: 1998

Downpayment Percent: 20 percent of total capital costs (remainder is borrowed)
Loan Rate: 10 percent
Loan Period: 15 years
Project Discount Rate: 14 percent
Marginal Tax Rate: 25 percent
Depreciation Method: Straight Line
Inflation Rate for Costs: 10.0 percent per year
Collect and Flare Costs: The costs associated with the gas collection and flaring system are included from the financial analysis.

Project Configuration Summary

Collection: Included
Flare: Included
Gas Treatment: Included
Compression: Included
Gas Enrichment: Not Included
Electricity Production:
Generation: Not Included
Intertie: Not Included
Sales Not Included
Gas Production:
Pipeline: Included
Sales: Included

Electricity Production and Sales Summary

Total Capacity: 0 kW
Average Generation: 0 kWh/year over the life of the project
Engine Load Factor: 0.00 percent over the life of the project
Average Electricity Price: $0.0000 per kWh, averaged over the life of the project

Gas Production and Sales Summary

Gas Sales Capacity: 1,096,312 MMBTU/year for gas sales
Average Gas Price: $4.48 per MMBTU, averaged over the life of the project
Average Production: 894,878 MMBTU/year over the life of the project

Price Analysis

Electricity Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average electricity price of $0.0000 per kWh is needed, average over the life of the project (assuming that the price for gas sales, if any, remains as defined in the project specification).

Gas Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average gas price of $0.64 per MMBTU is needed, average over the life of the project (assuming that the price for electricity sales, if any, remains as defined in the project specification).

Environmental Benefits Analysis

Annual Average Environmental Benefits From Recovering the Landfill Gas:

Methane Emissions: 4,398.22 thousand tons avoided/year, averaged over the life of the project
65,973.34 thousand tons avoided total during the project

CO2 Equivalent: 92,362.68 thousand tons avoided/year, averaged over the life of the project
1,385,440.18 thousand tons avoided total during the project

Annual Average Environmental Benefits From Generating Electricity from Landfill Gas:

CO2 Emissions: 0.00 thousand tons avoided/year, averaged over the life of the project
0.00 thousand tons avoided total during the project

SO2 Emissions: 0.00 thousand tons avoided/year, averaged over the life of the project
0.00 thousand tons avoided total during the project

Annual Average Environmental Benefits From Using Landfill Gas Directly:

CO2 Emissions: 161.27 thousand tons avoided/year, averaged over the life of the project
2,419.02 thousand tons avoided total during the project

E-Plus Analysis

Summary Report

Landfill: Santo Amaro
Design Scenario: Electricity
Author: ICF Incorporated
Date: June 19, 1998

Analyses performed using E-Plus Version 1.0 are considered preliminary and are to be used for guidance only. It is imperative that a detailed final feasibility assessment be conducted by qualified landfill gas recovery and utilization professionals prior to preparing a design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Based on the project definition, landfill characteristics, and financial assumptions provided, the following summary results are estimated:

Project Start Year: 1998

Project Lifetime: 15

Electricity Capacity: 6,469 kW for electricity sales

Average Electricity Price: $0.1185 per kWh, averaged over the life of the project

Gas Sales Capacity: 0 MMBTU/year for gas sales

Average Gas Price: $0.00 per MMBTU, averaged over the life of the project

Financial Results:

- Net Present Value: $ 1,371,912
- IRR: 25
- Simple Payback: 7.2 years
- Capital Costs: $ 11,925,815
- O&M Costs: $ 2,342,266 per year, averaged over the life of the project

These financial results include the costs associated with the gas collection and flaring system. As defined, the landfill triggers the recently promulgated NSPS/EG emissions control requirements using the Tier 1 calculation method.

Landfill Characteristics

Open Year: 1976

Close Year: 1993

Current Year: 1998

Waste in Place: 16,850,000 tons, in 1998

Waste Acceptance Rate: 0 tons per year, from current year onward

Depth: 50 feet, maximum during landfill lifetime

Area: 349 acres, maximum during landfill lifetime

Gas Generation and Collection

Gas Generation from 1976 to 2033:

- Annual Average: 990 mmcf/year of methane
  1,980 mmcf/year of landfill gas
- Maximum: 1,917 mmcf/year of methane
  3,835 mmcf/year of landfill gas

Gas Generation During the Project: 1998 to 2013:

- Annual Average: 1,056 mmcf/year of methane
  2,113 mmcf/year of landfill gas
- Maximum: 1,508 mmcf/year of methane
  3,016 mmcf/year of landfill gas

Gas Collection Efficiency: 75 percent

Financial Assumptions

Project Start Year:	1998
Project End Year:	2013
Base Year for NPV Estimate:	1998
Downpayment Percent:	20 percent of total capital costs (remainder is borrowed)
Loan Rate:	10 percent
Loan Period:	15 years
Project Discount Rate:	14 percent
Marginal Tax Rate:	25 percent
Depreciation Method:	Straight Line
Inflation Rate for Costs:	10.0 percent per year
Collect and Flare Costs:	The costs associated with the gas collection and flaring system are included from the financial analysis.

Project Configuration Summary

Collection:	Included
Flare:	Included
Gas Treatment:	Included
Compression:	Included
Gas Enrichment:	Not Included
Electricity Production:	
Generation:	Included
Intertie:	Included
Sales	Included
Gas Production:	
Pipeline:	Not Included
Sales:	Not Included

Electricity Production and Sales Summary

Total Capacity:	6,469 kW
Average Generation:	39,122,842 kWh/year over the life of the project
Engine Load Factor:	69.04 percent over the life of the project
Average Electricity Price:	$0.1185 per kWh, averaged over the life of the project

Gas Production and Sales Summary

Gas Sales Capacity:	0 MMBTU/year for gas sales
Average Gas Price:	$0.00 per MMBTU, averaged over the life of the project
Average Production:	0 MMBTU/year over the life of the project

Price Analysis

Electricity Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average electricity price of $0.0556 per kWh is needed, average over the life of the project (assuming that the price for gas sales, if any, remains as defined in the project specification).

Gas Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average gas price of $0.00 per MMBTU is needed, average over the life of the project (assuming that the price for electricity sales, if any, remains as defined in the project specification).

Environmental Benefits Analysis

Annual Average Environmental Benefits From Recovering the Landfill Gas:

Methane Emissions: 1,673.34 thousand tons avoided/year, averaged over the life of the project
25,100.11 thousand tons avoided total during the project

CO2 Equivalent: 35,140.15 thousand tons avoided/year, averaged over the life of the project
527,102.26 thousand tons avoided total during the project

Annual Average Environmental Benefits From Generating Electricity from Landfill Gas:

CO2 Emissions: 14.85 thousand tons avoided/year, averaged over the life of the project
222.75 thousand tons avoided total during the project

SO2 Emissions: 0.44 thousand tons avoided/year, averaged over the life of the project
6.53 thousand tons avoided total during the project

Annual Average Environmental Benefits From Using Landfill Gas Directly:

CO2 Emissions: 61.36 thousand tons avoided/year, averaged over the life of the project
920.34 thousand tons avoided total during the project

E-Plus Analysis

Summary Report

Landfill: Santo Amaro
Design Scenario: Direct Gas Use
Author: ICF Incorporated
Date: June 19, 1998

Analyses performed using E-Plus Version 1.0 are considered preliminary and are to be used for guidance only. It is imperative that a detailed final feasibility assessment be conducted by qualified landfill gas recovery and utilization professionals prior to preparing a design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Based on the project definition, landfill characteristics, and financial assumptions provided, the following summary results are estimated:

Project Start Year: 1998

Project Lifetime: 15

Electricity Capacity: 0 kW for electricity sales

Average Electricity Price: $0.0000 per kWh, averaged over the life of the project

Gas Sales Capacity: 448,952 MMBTU/year for gas sales

Average Gas Price: $4.44 per MMBTU, averaged over the life of the project

Financial Results:

Net Present Value: $ 6,110,092

IRR: 104

Simple Payback: 2.9 years

Capital Costs: $ 4,562,367

O&M Costs: $ 734,802 per year, averaged over the life of the project

These financial results include the costs associated with the gas collection and flaring system. As defined, the landfill triggers the recently promulgated NSPS/EG emissions control requirements using the Tier 1 calculation method.

Landfill Characteristics

Open Year: 1976

Close Year: 1993

Current Year: 1998

Waste in Place: 16,850,000 tons, in 1998

Waste Acceptance Rate: 0 tons per year, from current year onward

Depth: 50 feet, maximum during landfill lifetime

Area: 349 acres, maximum during landfill lifetime

Gas Generation and Collection

Gas Generation from 1976 to 2033:

Annual Average: 990 mmcf/year of methane
1,980 mmcf/year of landfill gas

Maximum: 1,917 mmcf/year of methane
3,835 mmcf/year of landfill gas

Gas Generation During the Project: 1998 to 2013:

Annual Average: 1,056 mmcf/year of methane
2,113 mmcf/year of landfill gas

Maximum: 1,508 mmcf/year of methane
3,016 mmcf/year of landfill gas

Gas Collection Efficiency: 75 percent

Financial Assumptions

Project Start Year: 1998

Project End Year: 2013

Base Year for NPV Estimate: 1998

Downpayment Percent: 20 percent of total capital costs (remainder is borrowed)

Loan Rate: 10 percent

Loan Period: 15 years

Project Discount Rate: 14 percent

Marginal Tax Rate: 25 percent

Depreciation Method: Straight Line

Inflation Rate for Costs: 10.0 percent per year

Collect and Flare Costs: The costs associated with the gas collection and flaring system are included from the financial analysis.

Project Configuration Summary

Collection: Included

Flare: Included

Gas Treatment: Included

Compression: Included

Gas Enrichment: Not Included

Electricity Production:

- Generation: Not Included
- Intertie: Not Included
- Sales Not Included

Gas Production:

- Pipeline: Included
- Sales: Included

Electricity Production and Sales Summary

Total Capacity: 0 kW

Average Generation: 0 kWh/year over the life of the project

Engine Load Factor: 0.00 percent over the life of the project

Average Electricity Price: $0.0000 per kWh, averaged over the life of the project

Gas Production and Sales Summary

Gas Sales Capacity: 448,952 MMBTU/year for gas sales

Average Gas Price: $4.44 per MMBTU, averaged over the life of the project

Average Production: 344,400 MMBTU/year over the life of the project

Price Analysis

Electricity Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average electricity price of $0.0000 per kWh is needed, average over the life of the project (assuming that the price for gas sales, if any, remains as defined in the project specification).

Gas Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average gas price of $1.10 per MMBTU is needed, average over the life of the project (assuming that the price for electricity sales, if any, remains as defined in the project specification).

Environmental Benefits Analysis

Annual Average Environmental Benefits From Recovering the Landfill Gas:

Methane Emissions: 1,673.34 thousand tons avoided/year, averaged over the life of the project
25,100.11 thousand tons avoided total during the project

CO2 Equivalent: 35,140.15 thousand tons avoided/year, averaged over the life of the project
527,102.26 thousand tons avoided total during the project

Annual Average Environmental Benefits From Generating Electricity from Landfill Gas:

CO2 Emissions: 0.00 thousand tons avoided/year, averaged over the life of the project
0.00 thousand tons avoided total during the project

SO2 Emissions: 0.00 thousand tons avoided/year, averaged over the life of the project
0.00 thousand tons avoided total during the project

Annual Average Environmental Benefits From Using Landfill Gas Directly:

CO2 Emissions: 61.36 thousand tons avoided/year, averaged over the life of the project
920.34 thousand tons avoided total during the project

E-Plus Analysis

Summary Report

Landfill: Vila Albertina
Design Scenario: Electricity
Author: ICF Incorporated
Date: June 19, 1998

Analyses performed using E-Plus Version 1.0 are considered preliminary and are to be used for guidance only. It is imperative that a detailed final feasibility assessment be conducted by qualified landfill gas recovery and utilization professionals prior to preparing a design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Based on the project definition, landfill characteristics, and financial assumptions provided, the following summary results are estimated:

Project Start Year: 1998

Project Lifetime: 15

Electricity Capacity: 3,986 kW for electricity sales

Average Electricity Price: $0.1185 per kWh, averaged over the life of the project

Gas Sales Capacity: 0 MMBTU/year for gas sales

Average Gas Price: $0.00 per MMBTU, averaged over the life of the project

Financial Results:

Net Present Value: $ 411,176

IRR: 17

Simple Payback: 7.2 years

Capital Costs: $ 7,347,467

O&M Costs: $ 1,452,960 per year, averaged over the life of the project

These financial results include the costs associated with the gas collection and flaring system. As defined, the landfill triggers the recently promulgated NSPS/EG emissions control requirements using the Tier 1 calculation method.

Landfill Characteristics

Open Year: 1977

Close Year: 1993

Current Year: 1997

Waste in Place: 10,200,000 tons, in 1997

Waste Acceptance Rate: 0 tons per year, from current year onward

Depth: 50 feet, maximum during landfill lifetime

Area: 211 acres, maximum during landfill lifetime

Gas Generation and Collection

Gas Generation from 1977 to 2033:

Annual Average: 608 mmcf/year of methane
1,216 mmcf/year of landfill gas

Maximum: 1,181 mmcf/year of methane
2,363 mmcf/year of landfill gas

Gas Generation During the Project: 1998 to 2013:

Annual Average: 651 mmcf/year of methane
1,302 mmcf/year of landfill gas

Maximum: 929 mmcf/year of methane
1,859 mmcf/year of landfill gas

Gas Collection Efficiency: 75 percent

Financial Assumptions

Project Start Year: 1998

Project End Year: 2013

Base Year for NPV Estimate: 1998

Downpayment Percent: 20 percent of total capital costs (remainder is borrowed)

Loan Rate: 10 percent

Loan Period: 15 years

Project Discount Rate: 14 percent

Marginal Tax Rate: 25 percent

Depreciation Method: Straight Line

Inflation Rate for Costs: 10.0 percent per year

Collect and Flare Costs: The costs associated with the gas collection and flaring system are included from the financial analysis.

Project Configuration Summary

Collection: Included

Flare: Included

Gas Treatment: Included

Compression: Included

Gas Enrichment: Not Included

Electricity Production:

- Generation: Included
- Intertie: Included
- Sales Included

Gas Production:

- Pipeline: Not Included
- Sales: Not Included

Electricity Production and Sales Summary

Total Capacity: 3,986 kW

Average Generation: 24,108,377 kWh/year over the life of the project

Engine Load Factor: 69.04 percent over the life of the project

Average Electricity Price: $0.1185 per kWh, averaged over the life of the project

Gas Production and Sales Summary

Gas Sales Capacity: 0 MMBTU/year for gas sales

Average Gas Price: $0.00 per MMBTU, averaged over the life of the project

Average Production: 0 MMBTU/year over the life of the project

Price Analysis

Electricity Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average electricity price of $0.0579 per kWh is needed, average over the life of the project (assuming that the price for gas sales, if any, remains as defined in the project specification).

Gas Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average gas price of $0.00 per MMBTU is needed, average over the life of the project (assuming that the price for electricity sales, if any, remains as defined in the project specification).

Environmental Benefits Analysis

Annual Average Environmental Benefits From Recovering the Landfill Gas:

Methane Emissions: 1,031.15 thousand tons avoided/year, averaged over the life of the project
15,467.25 thousand tons avoided total during the project

CO2 Equivalent: 21,654.15 thousand tons avoided/year, averaged over the life of the project
324,812.30 thousand tons avoided total during the project

Annual Average Environmental Benefits From Generating Electricity from Landfill Gas:

CO2 Emissions: 9.15 thousand tons avoided/year, averaged over the life of the project
137.27 thousand tons avoided total during the project

SO2 Emissions: 0.27 thousand tons avoided/year, averaged over the life of the project
4.02 thousand tons avoided total during the project

Annual Average Environmental Benefits From Using Landfill Gas Directly:

CO2 Emissions: 37.81 thousand tons avoided/year, averaged over the life of the project
567.13 thousand tons avoided total during the project

E-Plus Analysis

Summary Report

Landfill: Vila Albertina
Design Scenario: Direct Gas Use
Author: ICF Incorporated
Date: June 19, 1998

Analyses performed using E-Plus Version 1.0 are considered preliminary and are to be used for guidance only. It is imperative that a detailed final feasibility assessment be conducted by qualified landfill gas recovery and utilization professionals prior to preparing a design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Based on the project definition, landfill characteristics, and financial assumptions provided, the following summary results are estimated:

Project Start Year: 1998

Project Lifetime: 15

Electricity Capacity: 0 kW for electricity sales

Average Electricity Price: $0.0000 per kWh, averaged over the life of the project

Gas Sales Capacity: 276,654 MMBTU/year for gas sales

Average Gas Price: $4.44 per MMBTU, averaged over the life of the project

Financial Results:

- Net Present Value: $ 3,483,548
- IRR: 88
- Simple Payback: 3.0 years
- Capital Costs: $ 2,863,789
- O&M Costs: $ 475,631 per year, averaged over the life of the project

These financial results include the costs associated with the gas collection and flaring system. As defined, the landfill triggers the recently promulgated NSPS/EG emissions control requirements using the Tier 1 calculation method.

Landfill Characteristics

Open Year: 1977

Close Year: 1993

Current Year: 1997

Waste in Place: 10,200,000 tons, in 1997

Waste Acceptance Rate: 0 tons per year, from current year onward

Depth: 50 feet, maximum during landfill lifetime

Area: 211 acres, maximum during landfill lifetime

Gas Generation and Collection

Gas Generation from 1977 to 2033:

- Annual Average: 608 mmcf/year of methane
  1,216 mmcf/year of landfill gas
- Maximum: 1,181 mmcf/year of methane
  2,363 mmcf/year of landfill gas

Gas Generation During the Project: 1998 to 2013:

- Annual Average: 651 mmcf/year of methane
  1,302 mmcf/year of landfill gas
- Maximum: 929 mmcf/year of methane
  1,859 mmcf/year of landfill gas

Gas Collection Efficiency: 75 percent

Financial Assumptions

Project Start Year: 1998

Project End Year: 2013

Base Year for NPV Estimate: 1998

Downpayment Percent: 20 percent of total capital costs (remainder is borrowed)

Loan Rate: 10 percent

Loan Period: 15 years

Project Discount Rate: 14 percent

Marginal Tax Rate: 25 percent

Depreciation Method: Straight Line

Inflation Rate for Costs: 10.0 percent per year

Collect and Flare Costs: The costs associated with the gas collection and flaring system are included from the financial analysis.

Project Configuration Summary

Collection: Included

Flare: Included

Gas Treatment: Included

Compression: Included

Gas Enrichment: Not Included

Electricity Production:

- Generation: Not Included
- Intertie: Not Included
- Sales Not Included

Gas Production:

- Pipeline: Included
- Sales: Included

Electricity Production and Sales Summary

Total Capacity: 0 kW

Average Generation: 0 kWh/year over the life of the project

Engine Load Factor: 0.00 percent over the life of the project

Average Electricity Price: $0.0000 per kWh, averaged over the life of the project

Gas Production and Sales Summary

Gas Sales Capacity: 276,654 MMBTU/year for gas sales

Average Gas Price: $4.44 per MMBTU, averaged over the life of the project

Average Production: 212,227 MMBTU/year over the life of the project

Price Analysis

Electricity Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average electricity price of $0.0000 per kWh is needed, average over the life of the project (assuming that the price for gas sales, if any, remains as defined in the project specification).

Gas Price: To achieve an IRR equal to the project evaluation discount rate of 14 percent, an average gas price of $1.19 per MMBTU is needed, average over the life of the project (assuming that the price for electricity sales, if any, remains as defined in the project specification).

Environmental Benefits Analysis

Annual Average Environmental Benefits From Recovering the Landfill Gas:

Methane Emissions: 1,031.15 thousand tons avoided/year, averaged over the life of the project
15,467.25 thousand tons avoided total during the project

CO2 Equivalent: 21,654.15 thousand tons avoided/year, averaged over the life of the project
324,812.30 thousand tons avoided total during the project

Annual Average Environmental Benefits From Generating Electricity from Landfill Gas:

CO2 Emissions: 0.00 thousand tons avoided/year, averaged over the life of the project
0.00 thousand tons avoided total during the project

SO2 Emissions: 0.00 thousand tons avoided/year, averaged over the life of the project
0.00 thousand tons avoided total during the project

Annual Average Environmental Benefits From Using Landfill Gas Directly:

CO2 Emissions: 37.81 thousand tons avoided/year, averaged over the life of the project
567.13 thousand tons avoided total during the project

Non-Default Options Used in E-PLUS Modeling

E-PLUS Screen	Variable	Landfills in Brazil	Landfills in Czech Republic
Financial Assumptions	loan rate	10%	10%
	discount rate	14%	14%
	loan period	15 years	15 years
	tax rate	25%	25%
	inflation	10%	7.5%
	exclude collection and flaring costs	off (i.e., include these costs)	off (i.e., include these costs)
Energy Price	Electricity	$0.06/kWh	$0.06/kWh
	Gas	$2.25/mmBtu	$2.25/mmBtu
Design - Collection	Collection Efficiency	75 %	85 %
Design - Splitter	Percent of Inflow	77%	77%
Design - Gas Treatment	Moisture in Outflow	0 %	0 %
	Treatment Components	Refrigeration	Desiccation
Design - Electricity Gen.	Generation Components	Control System	Control System
Design - Electricity Prices	Escalation Rate	10%	7.5%
Design - Gas Rates	Gas Price Growth Rate	10 %	7.5 %
Design - Pipeline Cost	Fixed O & M	$18,480	$18,480

ATTACHMENT B
E-PLUS USER'S MANUAL

United States
Environmental Protection
Agency

Air and Radiation
(6202J)

EPA-430-B-97-006
January 1997

EPA
U.S. Environmental
Protection Agency

**Atmospheric
Pollution
Prevention
Division**

Energy Project Landfill Gas Utilization Software (E-PLUS)

Version 1.0

E-PLUS User's Manual

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User's Manual

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PREPARED FOR:
ATMOSPHERIC POLLUTION PREVENTION DIVISION
U.S. ENVIRONMENTAL PROTECTION AGENCY

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DISCLAIMER

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Introduction

Welcome to E-PLUS - the Energy Project Landfill Gas Utilization Software. E-PLUS is a decision support system designed to analyze the opportunities for installation of a gas recovery system at your landfill.

Installing the E-PLUS Software

Before you begin working with E-PLUS , check the contents of your E-PLUS package, make sure you have the correct equipment to run the program, and read through the rest of this section to be sure you have a clear understanding of the installation procedure.

The E-PLUS Package

Your E-PLUS package includes the following:

- 3½ inch E-PLUS program disk
- E-PLUS manual

Required Equipment

- An IBM compatible computer with a 386SX or better processor with at least 8 MB RAM;
- Microsoft Windows 3.1 or later; and
- Hard disk with at least 4 MB of space available,

Recommended Equipment

- ***Color monitor*** - E-PLUS will operate on a monochrome monitor; however, some screens are difficult to read. We suggest using a minimum resolution of 800 by 600.
- ***Mouse*** - If you do not have a mouse, it is possible (though rather inconvenient) to use E-PLUS using keyboard controls. File menu options may be accessed by clicking the Alt key and the underscored letter in the menu option (e.g., to access the **File** menu, click **Alt+F**).
- ***Printer*** - You may wish to print a hard copy of E-PLUS' results.

Installation Instructions

For Windows 3.1

To install E-PLUS on your computer, follow the instructions below:

1. Insert the E-PLUS disk into your floppy disk drive (A or B).
2. Click on the **File** menu of your **Windows Program Manager** and select **Run**.
3. Type **a:\install** (or **b:\install**) and click OK.
4. Follow the instructions during the installation process, making sure that you select the default directory.
5. Read the message in the instruction screen at the end of the installation process and double click on the upper left hand corner to continue.

To run E-PLUS, double click on the E-PLUS icon, or click on the File menu of the Windows Program Manager, select Run, and type c:\eplus\eplus.exe (or d:\eplus\eplus.exe or e:\eplus\eplus.exe, depending on where you install the E-PLUS program files).

For Windows 95

Although designed for Windows 3.1, you may install E-PLUS on Windows 95 using the directions below:

1. Insert the E-PLUS disk into your floppy disk drive (A or B).
2. Click on the **Start** button and select **Run**.
3. Type **a:\install** (or **b:\install**) and click OK.
4. Follow the instructions during the installation process, making sure that you select the default directory.
5. Read the message in the instruction screen at the end of the installation process and double click on the upper left hand corner to continue.

To run E-PLUS, click on the **Start** button and select **E-PLUS** from the Program group.

After E-PLUS has loaded, it will display the "Welcome to E-PLUS" screen. To begin the program, click on Yes.

If you are a first time user, you may want to continue with the E-PLUS Tutorial section of this manual to go through a quick overview of the E-PLUS software.

If you have any questions regarding the above installation procedure, please call the Energy Star Hotline at 1-888-STAR-YES (toll-free).

Chapter 1. E-PLUS Interview/Quick Start

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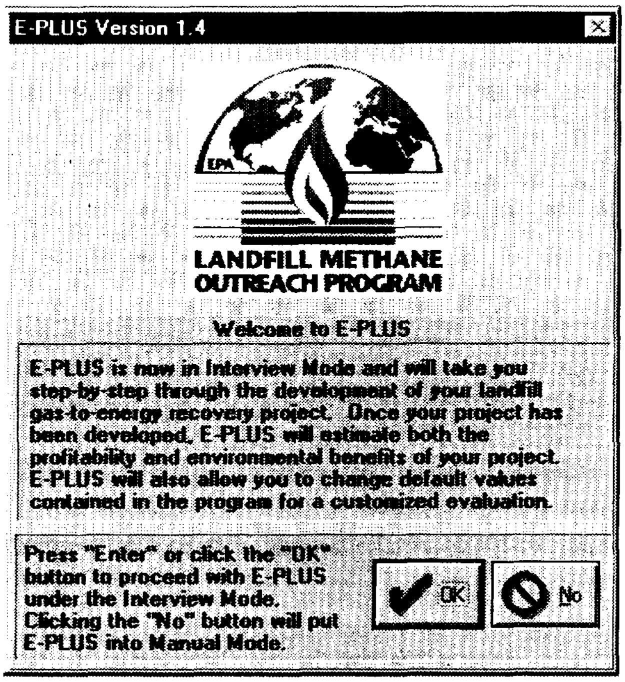
Figure 1: Happy face icon

Users who are not familiar with E-PLUS are advised to use the E-PLUS Interview. The interview may be accessed by clicking on the happy face icon (Figure 1) on the toolbar or by clicking "OK" in the welcome screen (Figure 2).



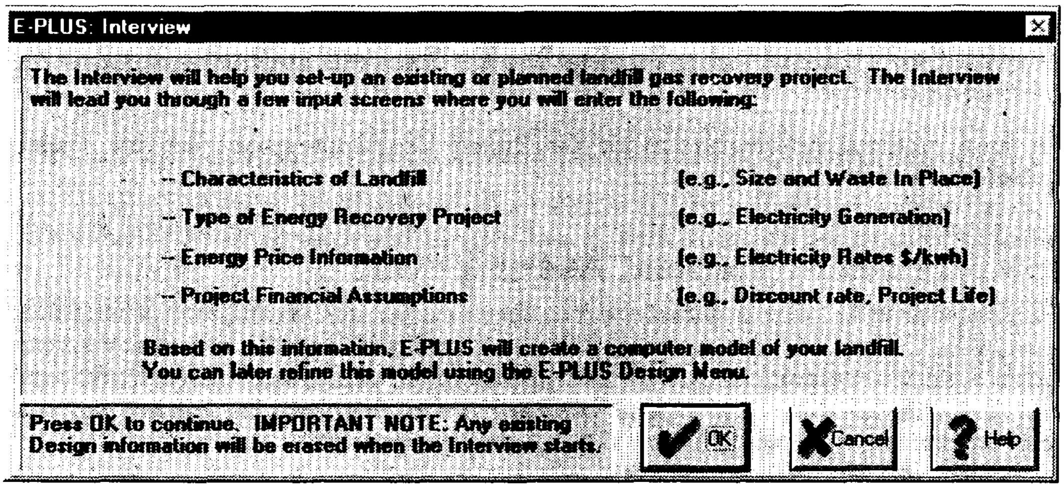
Welcome to E-PLUS

E-PLUS is now in Interview Mode and will take you step-by-step through the development of your landfill gas-to-energy recovery project. Once your project has been developed, E-PLUS will estimate both the profitability and environmental benefits of your project. E-PLUS will also allow you to change default values contained in the program for a customized evaluation.

Press "Enter" or click the "OK" button to proceed with E-PLUS under the Interview Mode. Clicking the "No" button will put E-PLUS into Manual Mode.

Figure 2: E-PLUS Welcome Screen

The first interview screen pops up as shown in Figure 3 below:



The Interview will help you set-up an existing or planned landfill gas recovery project. The Interview will lead you through a few input screens where you will enter the following:

-- Characteristics of Landfill [e.g., Size and Waste In Place]
-- Type of Energy Recovery Project [e.g., Electricity Generation]
-- Energy Price Information [e.g., Electricity Rates $/kwh]
-- Project Financial Assumptions [e.g., Discount rate, Project Life]

Based on this information, E-PLUS will create a computer model of your landfill. You can later refine this model using the E-PLUS Design Menu.

Press OK to continue. IMPORTANT NOTE: Any existing Design information will be erased when the Interview starts.

Figure 3: E-PLUS Interview screen

To continue with the interview, click on the OK button. To cancel, click on the Cancel button. ***Note: Any existing design information will be erased when the interview starts.***

The following sections briefly describe the steps involved with entering the data into the E-PLUS software system.

Step 1. Landfill Characteristics

The first step is to enter the characteristics of your landfill, including the amount and growth of waste at the site. This screen is divided into the following three sections:

- Landfill Chronology - includes the dates corresponding to the opening and closing of the landfill.
- Landfill and Waste Metrics - includes information regarding the dimensions and content of the landfill.
- Landfill Gas Composition - includes information regarding the composition of the landfill gas extracted.

For more detailed information about the Landfill Characteristics screen, see the **Landfill Characteristics** section on page 9.

Step 2. NSPS/EG Tier 1 Evaluation

The second step in the E-PLUS interview is the NSPS/EG Tier 1 Evaluation. Based on the data entered in Step 1 - Landfill Characteristics, the landfill may be subject to the New Source Performance Standards (NSPS) / Emissions Guidelines (EG) Tier 1 calculations[1].

Step 3. Project Templates

The third step is to enter the project template which is used to create the various stages in the landfill gas recovery project. These stages may be defined in the Process Configuration screen.

A template may be chosen by selecting the desired option(s) in the Landfill Gas Recovery Project Template Dialog. Templates for the following project options are available in this version of E-PLUS :

- Electricity Production
- Sale of Gas
- Collect and Flare (the default gas usage if neither Electricity Production or Sale of Gas is selected).

For more detailed information about the Project Templates screen, see the **Project Templates** section on page 11.

Step 4. Project Financial Assumptions

The next step is to edit the default project, financial, tax, and/or inflation assumptions used by E-PLUS to evaluate the profitability of the defined landfill gas recovery system. These financial assumptions include the downpayment percentage, loan rate, discount rate, and inflation rate. These characteristics are very important for the estimation of costs and benefits and should be edited as accurately as possible.

In addition, the exclusion of the collection and flaring costs may be selected in this screen if a collection and flaring system is already in place at the landfill. This option may be selected by clicking the "Exclude Collection and Flaring System Costs".

For more detailed information about the Financial Assumptions screen, see the **Financial Assumptions** section on page 12.

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[1] Federal Register (Vol. 61, # 49) March 12, 1996 or the Code of Federal Regulations (40 CFR parts 51, 52, and 60).

Step 5. Energy Price

The next step is to enter default energy prices for electricity and gas. Detailed energy prices may be entered in the Process Configuration screen by selecting the Electricity Sales and/or Gas Sales stages.

For more detailed information about the **Process Configuration** screen please see page 13. For more information about the energy sales screens please see **Electricity Sales** on page 22 and **Gas Sales** on page 27.

Step 6. Quick Financial Report

The next step is to view the quick financial report. This report is created from the data entered in the first 4 steps of the interview. This following estimates are displayed in this screen:

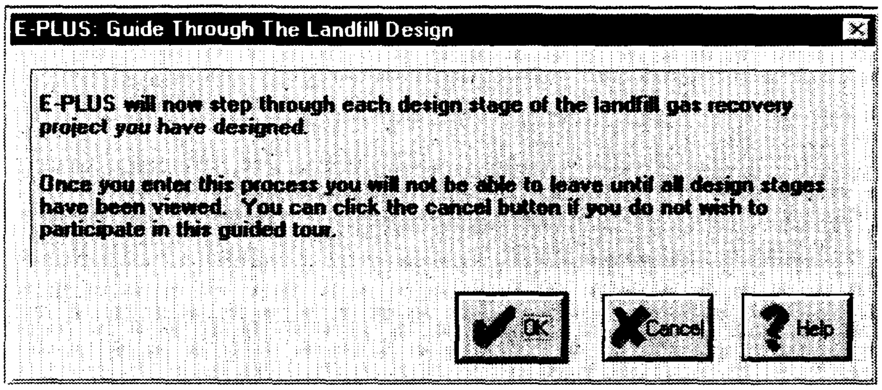
- Total capital costs
- Annual benefits
- Annual operating costs
- NPV
- Simple payback
- NPV payback
- Approximate IRR
- Average Electricity Rate ($/kWh) with inflation
- Average Gas Rate ($/MMBTU) with inflation
- Average Electricity Rate ($/kWh) base year
- Average Gas Rate ($/MMBTU) base year

This screen may not be edited. The **What If Analysis** (page 45) may be selected to see the effects on these estimates when the average electricity or gas prices are changed.

For more detailed information about the Quick Financial Report, see the **Project Evaluation** section on page 44.

Step 7. Optional Step Through Project Configuration/ Detailed Interview

The next step is to optionally step through the various stages of the process configuration. The process configuration is created from the selection made in the **Project Template** screen. The **Guide Through the Landfill Design** dialog (Figure 4) gives you the option to step through the design or skip through the design and complete the interview.


E-PLUS: Guide Through The Landfill Design

E-PLUS will now step through each design stage of the landfill gas recovery project you have designed.

Once you enter this process you will not be able to leave until all design stages have been viewed. You can click the cancel button if you do not wish to participate in this guided tour.

Figure 4: Guide Through the Landfill Design screen

Note: Upon entering, you may not leave the detailed interview until all design stages have been viewed. If you do not wish to participate in this tour you should click on the Cancel button.

If you wish to continue with this tour you should click on the OK button. Detailed descriptions of the Process Configuration screen and the landfill gas recovery stages are covered in the **Process Configuration** section on page 13 and the **Landfill Gas Recovery Stages** Chapter on page 17 .

Chapter 2. E-PLUS Landfill and Landfill Gas Assumptions

E-PLUS uses default data and algorithms to calculate the amount of landfill gas produced and utilized at a landfill gas recovery project. Many of these assumptions may be edited by the user in the Landfill Design screens (see Chapter 3. Landfill Design on page 9).

The general landfill assumptions are used to describe the size and content of the landfill. Table 1 lists these assumptions and, where applicable, the equations used to calculate the values.

The density of the waste and the depth of the landfill both may be edited by the user in the **Landfill Characteristics** screen (see page 9).

Table 1: General Landfill Assumptions

Component	Equation/Default assumption	User can edit
Density of waste	44.44 lbs/ft^3	Y
Volume of landfill	$\text{Volume (ft}^3) = \dfrac{\textit{waste (lbs)}}{\textit{density of waste}}$	N*
Depth of landfill	50 ft	Y
Area of landfill	$\text{Area (acres)} = \dfrac{\textit{volume of landfill (ft}^3)}{\textit{depth of landfill (ft)}} \times \dfrac{\textit{1 acre}}{\textit{43,500 ft}^2}$	N*
Arid environment	Less than 25 inches of precipitation per year	N
Non-arid environment	More than 25 inches of precipitation per year	N

*The equation cannot be edited by the user. The factor(s) that go into the equation may be edited by the user.

E-PLUS also uses default assumptions and data for landfill gas upon extraction and processing. E-PLUS currently assumes constant temperature of landfill gas throughout the process from extraction to consumption. Thus any change in pressure or volume flow rate is adjusted using Boyle's Law:

$P_1V_1 = P_2V_2$ where:

P_1 is initial pressure

V_1 is initial volume

P_2 is final pressure

V_2 is final volume

All reported values of pressure are in terms of gauge pressure. All pressure computations are calculated in terms of absolute pressure where:

Absolute Pressure (psi) = Gauge Pressure (psi)+ 14.7 (psi)

The heating value of landfill gas is directly related to the percentage of methane and the absolute pressure.

Heating value of Methane = 1000 BTU/ft^3 at STP (Standard Pressure and Temperature)

Heating value of Landfill Gas = [percent Methane * 1000 BTU/ft^3] x [Gauge Pressure + 14.7]/14.7

To calculate changes in the composition and flow rate of landfill gas as the result of water vapor/moisture removal E-PLUS estimates the following:

New % CH_4 = [Old % CH_4 / (100 - Reduction in Water Vapor)] x 100

New Flow Rate = Old Flow rate x [(100 - Reduction in Water Vapor) / 100]

Example:

Take landfill gas (composition breakdown in Table 2) flowing at 1,000 mcf per day. Water vapor/moisture content is reduced from 3% to 1% (reduction of 2%). E-PLUS computes the CH_4 content and flow rates as follows:

New % CH_4 = [50 / (100 - 2)] x 100 = 51.020

New Flow Rate = 1000 mcfd x [(100 - 2) / 100] = 980 mcfd

Table 2: Landfill Gas as Extracted

Component	Default assumption	User can edit
Methane	50%	Y
Carbon dioxide	40%	Y
Water vapor/moisture	3%	Y
Other	7% (=100% - sum of percentages H_2O, CH_4, CO_2)	N
Pressure (gauge)	1,0000 mcf	N

Chapter 3. Landfill Design

The **Design** menu (Figure 5) contains options which allow you to describe the characteristics of your landfill and its gas recovery components. These components are designed using the landfill and landfill gas assumptions described in Chapter 2. Not all of the options may be available at one time. An option is available if it is displayed in **BOLD** in the menu. As you enter data required in certain Design screens, additional Design options become available. You should go into each Design screen to ensure that the characteristics of your landfill gas recovery facility are designed accurately.

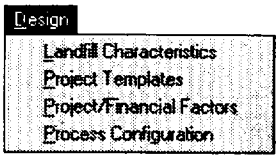


Figure 5: Design menu

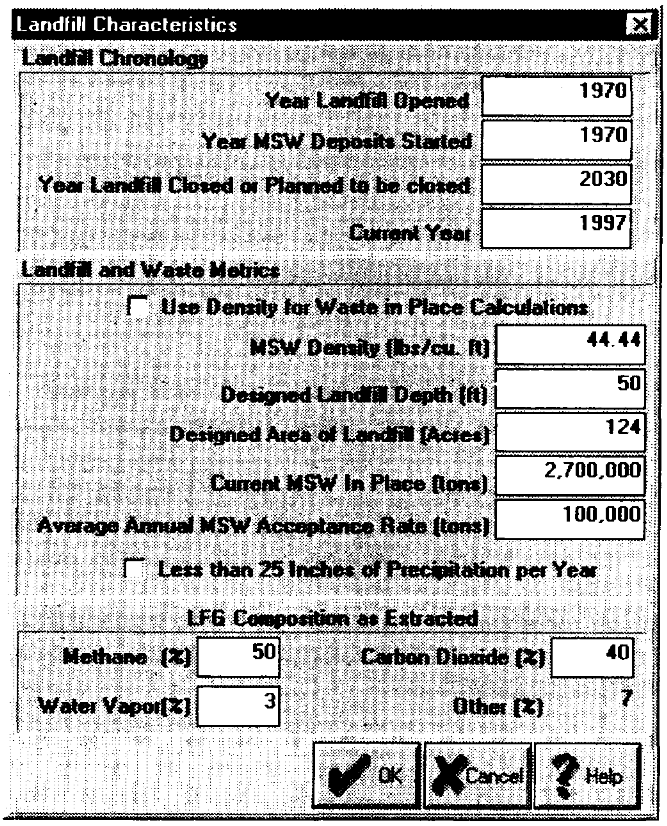
The options contained within the **Design** menu are described in the following sections.

Landfill Characteristics

The purpose of the **Landfill Characteristics** screen is to enter the characteristics of your landfill, including the amount and growth of waste at the site.

Select this screen by clicking the landfill characteristics icon (Figure 6) on the toolbar or by selecting **Landfill Characteristics** from the **Design** menu. Your screen will look like Figure 7 below.

Figure 6: Landfill Characteristics icon



Landfill Characteristics

Landfill Chronology

Year Landfill Opened: 1970
Year MSW Deposits Started: 1970
Year Landfill Closed or Planned to be closed: 2030
Current Year: 1997

Landfill and Waste Metrics

☐ Use Density for Waste in Place Calculations
MSW Density (lbs/cu. ft): 44.44
Designed Landfill Depth (ft): 50
Designed Area of Landfill (Acres): 124
Current MSW In Place (tons): 2,700,000
Average Annual MSW Acceptance Rate (tons): 100,000
☐ Less than 25 Inches of Precipitation per Year

LFG Composition as Extracted

Methane (%): 50
Carbon Dioxide (%): 40
Water Vapor(%): 3
Other (%): 7

Figure 7: Landfill Characteristics screen

Inputs:

The **Landfill Characteristics** screen is divided into three sections requiring inputs from the user. These sections include:

1) Landfill Chronology -The top section of this dialog box contains the dates corresponding to the opening and closing of the landfill. Specifically, the following years should be entered in this section:

- Year the landfill opened
- Year the municipal solid waste (MSW) deposits started
- Year the landfill closed or is planned to close
- Current year

2) Landfill and Waste Metrics - The middle section of this dialog box contains information regarding the dimensions and content of the landfill. The following information is required in this section:

- MSW Density (lbs/ft^3)
- Designed Landfill Depth (ft)
- Designed Area of Landfill (acres)
- Current MSW in Place (tons)
- Average Annual MSW Acceptance Rate (tons/year)

3) Landfill Gas Composition - The third section at the bottom of this dialog contains information regarding the composition of the landfill gas as extracted. The following percentages should be entered:

- Methane
- Carbon Dioxide
- Water Vapor
- Other

Note: The sum of all of these percentages should equal 100%.

Assumptions:

- General landfill assumptions are described in Table 1 in Chapter 2.
- Annual average acceptance rate for years between current year and year MSW deposits started equals:
  Current MSW In Place / (Current Year - Year MSW Deposits Started).
- Annual average acceptance rate for years greater than the current year equals the value entered in the Average annual acceptance rate box in the **Landfill Characteristics** screen.
- Currently E-PLUS does not consider the side slope parameter in calculations for landfill area and volume. Under certain circumstances this assumption could overestimate the total waste volume.

Features:

- If you know the current MSW in place (tons) and the annual MSW acceptance rate (tons), enter these values in the appropriate boxes. Based on these values, the density of the MSW, and the depth of the landfill, E-PLUS calculates the area of the landfill.
- If you know the area of the landfill in acres, check the "Use density for Waste in Place Calculations" box and enter the area in the appropriate box. E-PLUS will calculate the current MSW in place and the annual MSW acceptance rate given the area and the density of the waste.
- E-PLUS uses the current MSW in place and annual MSW acceptance rates to determine the MSW in place for each year over the life of the landfill. You may view and/or edit this information in the Methane Production screen (see page 39).

- In addition, you should indicate whether the landfill receives less than 25 inches of rainfall per year by clicking the appropriate box. This factor is used by the methane generation algorithms (see page 39).

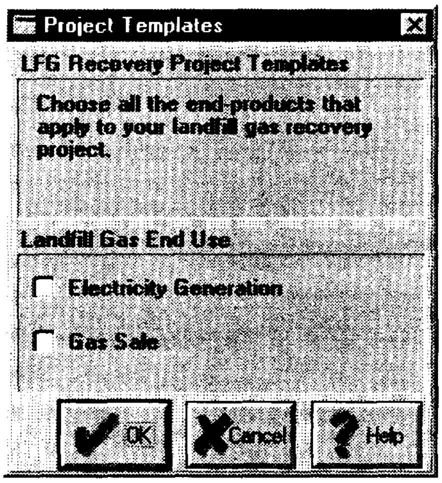
Click on OK to save this information.

Project Templates

The **Project Templates** option allows you to enter the landfill gas recovery configuration template that best fits your landfill project.

Select this screen by clicking the project templates icon (Figure 8) on the toolbar or by selecting **Project Templates** from the **Design** menu. Your screen will look like Figure 9 below.

Figure 8: Project Template icon



Choose all the end-products that apply to your landfill gas recovery project.

☐ Electricity Generation

☐ Gas Sale

Figure 9: Project Template screen

Inputs:

A template may be chosen by selecting the desired option(s) in the **Landfill Gas Recovery Project Template Dialog**. Templates for the following project options are available in this version of E-PLUS :

- Electricity Production
- Sale of Gas
- Collect and Flare (the default gas usage if neither Electricity Production nor Sale of Gas is selected).

Features:

- E-PLUS creates a landfill gas recovery project template (see the Process Configuration section on page 13) based on the selection(s) made by the user. If you do not choose any of the options, E-PLUS assigns a collect and flare template for the landfill gas recovery project.
- The E-PLUS template may contain several splitter stages (see page 32) that distribute the flow of landfill gas. Please note that all splitters distribute the gas equally except for the first splitter immediately following the collection stage. By default, 5% of the landfill gas following the collection stage is sent to the flare stage and the remaining gas is directed for use by the project. The user may choose to modify the amount of gas distributed a splitter stage.

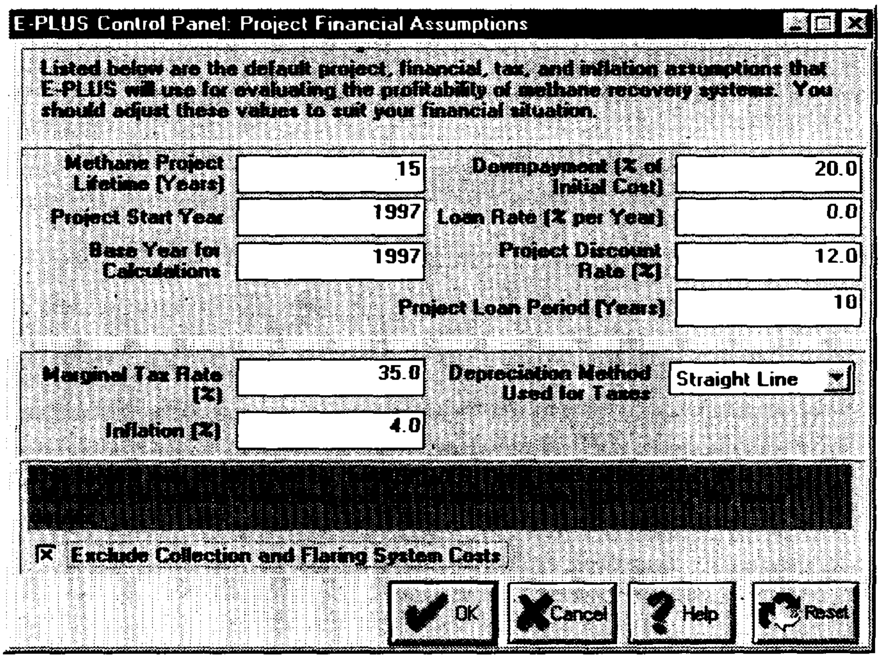
Click on OK to save this information.

Project Financial Assumptions

The purpose of this option is to edit or change the default project, financial, tax, and/or inflation assumptions used by E-PLUS to evaluate the profitability of the defined landfill gas recovery system.

Figure 10: Financial Assumptions icon

Select this screen by clicking on the financial assumptions icon (Figure 10) on the toolbar or by selecting **Financial Assumptions** from the **Design** menu. Your screen will look like Figure 11 below.



E-PLUS Control Panel: Project Financial Assumptions

Listed below are the default project, financial, tax, and inflation assumptions that E-PLUS will use for evaluating the profitability of methane recovery systems. You should adjust these values to suit your financial situation.

Methane Project Lifetime (Years): 15

Downpayment (% of Initial Cost): 20.0

Project Start Year: 1997

Loan Rate (% per Year): 0.0

Base Year for Calculations: 1997

Project Discount Rate (%): 12.0

Project Loan Period (Years): 10

Marginal Tax Rate (%): 35.0

Depreciation Method Used for Taxes: Straight Line

Inflation (%): 4.0

☒ Exclude Collection and Flaring System Costs

Figure 11: Financial Assumptions screen

Inputs:

Input	*Default*
Methane project lifetime	15 years
Downpayment	20% of initial cost
Loan rate	None - user must enter
Loan payback period	10 years
Project discount rate	12%/year[2]
Marginal tax rate	35%
Inflation rate	4%[3] (used for cost escalation over the life of the project)
Depreciation method used	Straight-Line
Inclusion/exclusion of collection and flaring system costs	Varies

These values should be edited if necessary to ensure an accurate reflection of the landfill's financial situation.

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[2] USEPA. 1993. *Opportunities to Reduce Anthropogenic Methane Emissions in the United States. Report to Congress.* EPA Office of Air and Radiation, Washington, D.C. EPA 430-R-93-012, October 1993.

[3] Return on 10 year T-Bill - 2.5%.

Assumptions:

- Loan payback period cannot exceed methane project lifetime.
- Project discount rate is the nominal discount rate (real discount rate + inflation rate).

Features:

- Provides parameters for project financial evaluation.
- Collection and flaring system costs can be excluded from the project financial evaluation if a collection and flare system is already in place. You may wish to also exclude the collect and flare system if your landfill is triggered under the New Source Performance Standards (NSPS) and Emissions Guidelines (EG) under the "Clean Air Act" which require you to install and operate a gas collection and flare system. Since this is an unavoidable cost, you may wish to exclude this from the financial evaluation and evaluate only the new costs for the utilization system.

Click on OK to exit and save.

Process Configuration

Figure 12: Configuration icon

The purpose of the **Process Configuration** screen is to define the characteristics of the components in your landfill gas recovery system.

Select this screen by clicking on the configuration icon (Figure 12) on the toolbar or selecting **Process Configuration** from the **Design** menu. This screen is created based on what was entered in the **Project Templates** Dialog Box (see page 11).

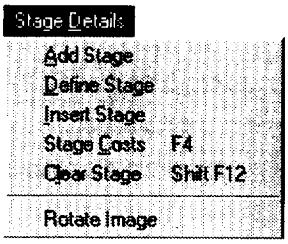


Figure 13: Stage Details menu

Each of the boxes in this screen represent a different component of the landfill gas recovery project. The red colored box indicates the component which is selected. A component may be selected by hitting the tab key as many times as needed to reach the desired component or by clicking on the component box with the mouse. *Note: you may need to use the scroll bars to view some parts of the screen.*

Upon entering this screen you will see a new menu option titled **Stage Details** (Figure 13). The options contained within this menu allow you to edit and view the different landfill gas recovery components and the associated costs. These same options appear when you click with the right mouse button when you are over a selected red component box. Additionally, the options correspond to the buttons in the Process Configuration floating tool bar (Figure 14). These options are described in detail below:

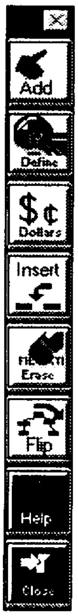


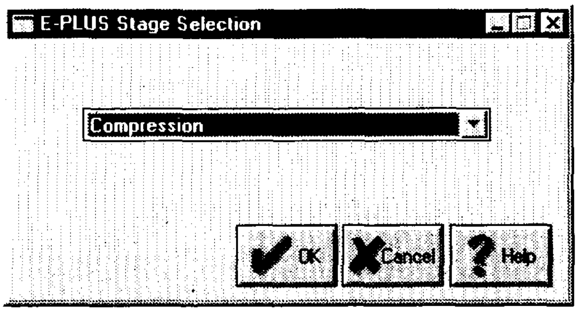
Figure 14: Process Configuration Floating toolbar

Add Stage

The **Add Stage** option allows you to append a stage at the tail end of the process configuration when applicable. E-PLUS is designed with "built in" logic for mapping landfill gas recovery projects. A new stage may only be added if the "built in" logic is satisfied. For example, a compression stage may not be added if a collection stage does not exist. E-PLUS determines the list of possible stages that can follow an existing stage.

If you wish to insert a stage between two existing stages please use the **Insert Stage** option described below.

The **Stage Selection** dialog box (Figure 15) may be accessed by clicking on the stage which is to be followed by the new stage and choosing **Add Stage** from the **Stage Details** menu or clicking on the add button (Figure 16) in the floating toolbar.


E-PLUS Stage Selection

Compression

Figure 15: Stage Selection Dialog box

Figure 16: Add button

Click the arrow button to the right of the selection box to reveal the component choices available in reference to the previous stage. Scroll through these options, click the desired process, and then click the OK button to save and continue. A blue box corresponding to the new stage is created in the process configuration window.

NOTE: E-PLUS issues a warning "Cannot Create Stage" if the desired addition does not conform with "built in" logic.

Define Stage

Figure 17: Define button

The purpose of this option is to enter the characteristics of the different components utilized at the landfill gas recovery system.

You may access this screen for each component of the landfill gas recovery system by highlighting the component you wish to describe and double clicking the left mouse button, clicking on the define button (Figure 17) in the floating toolbar, or selecting **Define Stage** from the **Stage Details** menu.

The component definition screens for the available landfill gas recovery components are described in Chapter 3 on page 17.

Insert Stage

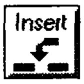
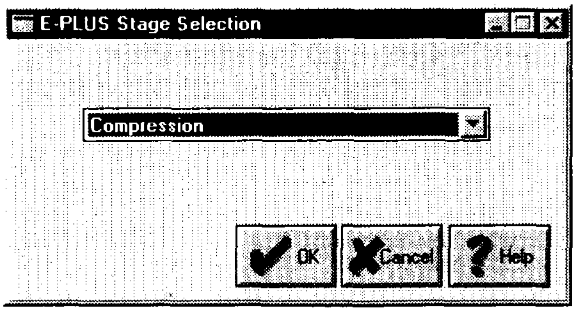


Figure 18: Insert button

The **Insert Stage** option allows you to insert a landfill gas recovery stage between two existing stages when applicable. E-PLUS is designed with "built in" logic for mapping landfill gas recovery projects. A stage may be inserted only if the "built in" logic is satisfied. For example, an electricity generation stage may not be inserted between existing compression and gas enrichment stages. E-PLUS determines the list of possible stages that can follow an existing stage.

The **Stage Selection** dialog box (Figure 19) may be accessed by clicking on the stage which is to be followed by the new stage and choosing **Insert Stage** from the **Stage Details** menu or clicking on the insert button (Figure 18) in the floating toolbar.


E-PLUS Stage Selection

Compression

Figure 19: Stage Selection Dialog box

Click the arrow button to the right of the selection box to reveal the component choices available in reference to the previous stage. Scroll through these options, click the desired process, and then click the OK button to save and continue. A blue box corresponding to the new stage is created in the process configuration window.

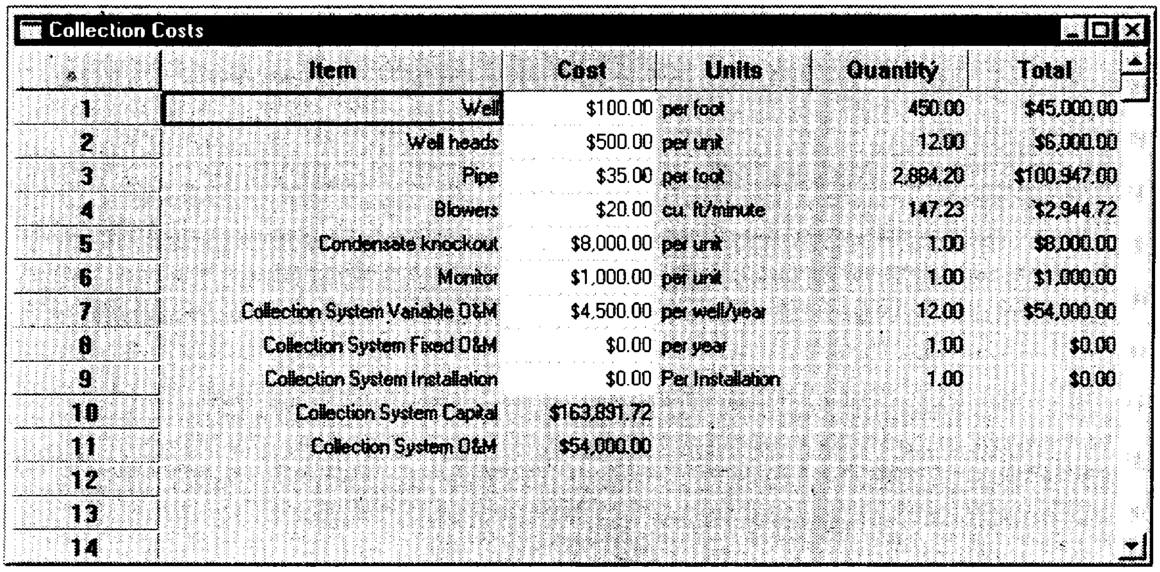
NOTE: E-PLUS issues a warning "Cannot Create Stage" if the desired insertion does not conform with "built in" logic.

Stage Costs

The **Stage Costs** option allows you to enter/edit the capital and operating costs of the components at your landfill gas recovery facility.

Select this option by clicking on the stage which you would like to inspect and pressing F4, clicking on the dollars button (Figure 20) in the floating toolbar, or selecting **Stage Costs** from the **Stage Details** menu. An example of this screen is shown for the Collection component in Figure 21.

Figure 20: Dollars button



Collection Costs

	Item	Cost	Units	Quantity	Total
1	Well	$100.00	per foot	450.00	$45,000.00
2	Well heads	$500.00	per unit	12.00	$6,000.00
3	Pipe	$35.00	per foot	2,884.20	$100,947.00
4	Blowers	$20.00	cu. ft/minute	147.23	$2,944.72
5	Condensate knockout	$8,000.00	per unit	1.00	$8,000.00
6	Monitor	$1,000.00	per unit	1.00	$1,000.00
7	Collection System Variable O&M	$4,500.00	per well/year	12.00	$54,000.00
8	Collection System Fixed O&M	$0.00	per year	1.00	$0.00
9	Collection System Installation	$0.00	Per Installation	1.00	$0.00
10	Collection System Capital	$163,891.72			
11	Collection System O&M	$54,000.00			
12					
13					
14					

Figure 21: Collection Costs Screen

Figure 22: Component Cost floating toolbar

Any of the cream colored boxes may be edited if necessary. If available, default costs are provided. Any user defined costs are shown in red. Similar cost tables are provided for the all components except for Electricity Sales, Gas Sales, and Split Gas.

The Component Cost floating toolbar (Figure 22) is displayed with options allowing you to reset to defaults, access help for the screen, and close the screen.

When you are finished viewing/editing this screen you may save and exit by double clicking on the upper left hand corner of this screen or clicking on the close button in the floating toolbar.

NOTE: Please refer to Chapter 5. Defining ***Stage Costs (page 35) for more details on how to use this feature.***

Clear Stage

The **Clear Stage** option allows you to clear one or more stages from the process configuration. To clear a stage you should select the stage you wish to clear and select **Clear Stage** from the **Stage Details** menu or click on the erase button (Figure 23) in the floating toolbar.

Figure 23: Erase button

NOTE: All stages following the deleted stage are also deleted.

Rotate Image

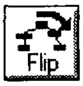


Figure 24: Flip button

The **Rotate Image** option allows you to rotate the process configuration schematic diagram. To rotate the process configuration image, select **Rotate Image** from the **Stage Details** menu or click on the flip button (Figure 24) in the floating toolbar.

Chapter 4. Landfill Gas Recovery Stages

A landfill gas recovery project is comprised of different stages in the landfill gas recovery process. The configuration of these stages is created in E-PLUS after selecting a **Project Template** (see page 11) and the visual display of this configuration is shown by selecting the **Process Configuration** screen (see page 13).

This chapter analyzes the different landfill gas recovery stages and describes in detail the information required in each of the corresponding design screens.

Most landfill gas recovery stages share a common feature of gas inflow and outflow. E-PLUS uses the Ideal Gas Law and the Laws of Conservation of Energy and Mass to calculate the characteristics of landfill gas in different stages.

Common Landfill Gas Recovery Stage Features:

Each stage displays the characteristics of the gas inflow and outflow to and from the stage at the top of the screen. These characteristics include:

- Flow Rate (mmcf/year)
- Methane Content (%)
- Pressure (psig)
- BTU (BTU/cf)
- Moisture (%)
- Carbon Dioxide (%)

Auto Design Vs. User Defined Modes

E-PLUS has an auto design algorithm for each of the landfill gas recovery stages. The auto design algorithm calculates design parameters for a stage as long as the user clicks the "Cancel" button after viewing the stage screen. If the user clicks the "OK" button, E-PLUS treats all values in the input screen as user defined and switches from the auto design to a user design mode. Once the "OK" button has been clicked there is no way to switch back to the auto design mode.

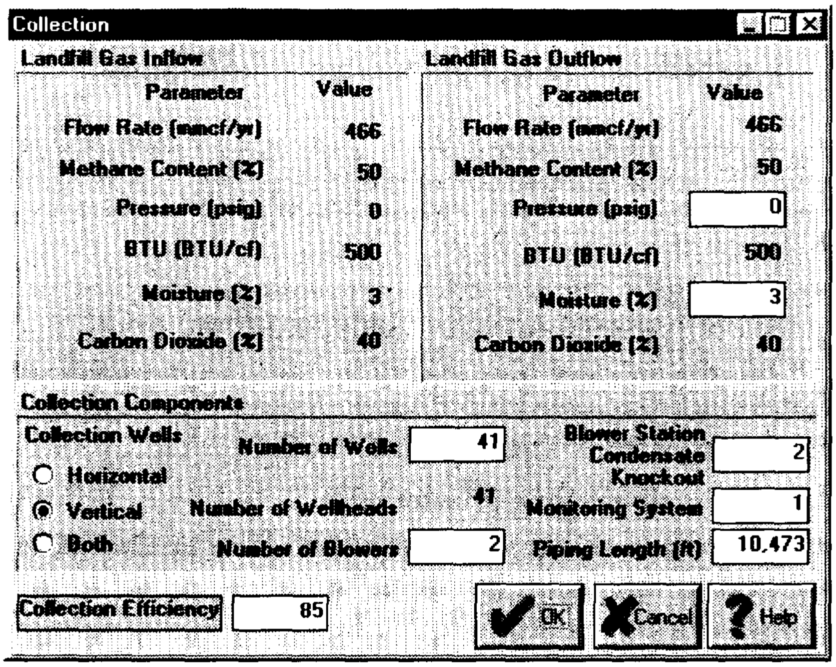
Data Input	**Cancel Button Clicked**	**OK Button Clicked**
No input by user	Auto Design Mode	User Defined Mode
Some input by user	Auto Design Mode	User Defined Mode

Common Assumptions:

- Landfill and landfill gas assumptions are described in Chapter 2.
- The flow rate value displayed is the maximum flow rate assigned to a stage over the life of the landfill gas recovery project. However, all calculations for a specific year are based on the gas flows for that year. Gas flows for each year may be viewed or edited in the **Methane Production** screen (see page 35).

Collection

The collection stage is the stage in which the gas produced at the landfill is collected. This stage is mandatory for all landfill gas recovery systems and is the first component in the process configuration. The **Collection Stage Details** screen (Figure 25) allows you to design the collection stage so it may be specific to your landfill.



Landfill Gas Inflow

Parameter	Value
Flow Rate (mmcf/yr)	466
Methane Content (%)	50
Pressure (psig)	0
BTU (BTU/cf)	500
Moisture (%)	3
Carbon Dioxide (%)	40

Landfill Gas Outflow

Parameter	Value
Flow Rate (mmcf/yr)	466
Methane Content (%)	50
Pressure (psig)	0
BTU (BTU/cf)	500
Moisture (%)	3
Carbon Dioxide (%)	40

Collection Components

Collection Wells
○ Horizontal
● Vertical
○ Both

Number of Wells: 41
Number of Wellheads: 41
Number of Blowers: 2
Blower Station Condensate Knockout: 2
Monitoring System: 1
Piping Length (ft): 10,473

Collection Efficiency: 85

Figure 25: Collection Stage Details Screen

Inputs:

- Outflow pressure
- Outflow moisture content
- Type of wells (horizontal, vertical, or both)
- Number of wells
- Number of blowers
- Number of condensate knockout units
- Number of monitoring systems
- Piping length
- Collection efficiency

Assumptions:

Component	*Default Assumption*	*User can edit*
Well	1 per 1.5 acres	Y
Well length	75% of depth of landfill	N
Wellhead	1 per well	N
Condensate knockout unit	1 per 15 wells (minimum 1)	Y
Monitoring system	1 per system	Y
Blowers	2 per system	Y
Piping length	Square root of well area x number of wells	Y
Collection efficiency	85%	Y

Features:

- Based on inputs and the common gas equations described on page 17, E-PLUS computes changes to the gas flow. In addition, E-PLUS estimates annual costs for the collection system based on annual gas flows.

- Changing the collection efficiency (the actual amount of landfill gas recovered versus the amount of landfill gas produced) changes the annual flow rate for the project in the following manner:

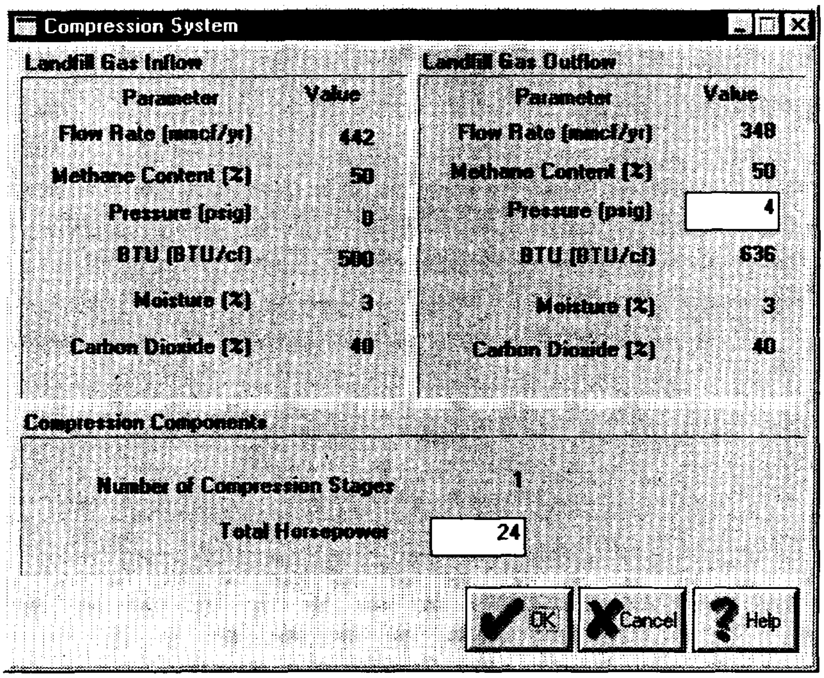
  Project gas flow$_i$ = (gas flow from methane generation algorithms$_i$ X collection efficiency)

  where i is the year of gas flow

Click on the OK button to save and exit.

Compression

The compression stage is the stage in which the landfill gas is compressed. Like the Collection Stage, the **Compression Stage Details** screen (Figure 26) allows you to design the compression stage so it may be specific to your landfill.



Compression System

Landfill Gas Inflow

Parameter	Value
Flow Rate (mmcf/yr)	442
Methane Content (%)	50
Pressure (psig)	0
BTU (BTU/cf)	500
Moisture (%)	3
Carbon Dioxide (%)	40

Landfill Gas Outflow

Parameter	Value
Flow Rate (mmcf/yr)	348
Methane Content (%)	50
Pressure (psig)	4
BTU (BTU/cf)	636
Moisture (%)	3
Carbon Dioxide (%)	40

Compression Components

Number of Compression Stages: 1

Total Horsepower: 24

Figure 26: Compression Stage Details Screen

Inputs:

- Outflow pressure
- Total horsepower

Assumptions:

Component	*Default Assumption*	*User can edit*
Compression ratio (R)	(outlet pressure +14.7)/ (inlet pressure + 14.7)	N
Number of compression stages	n such that $R^{1/n}$ is ≤ 5	N
Compression Ratio for Compressor i (C_i)	$R^{1/n}$	N
Supercompressability factor (J)	{ 0.022 / [(Inlet pressure + 14.7) / 100] }	N
Brake horsepower required per mmcfd (Bhp / mmcfd)	$\sum_{i=1}^{i=n} \frac{C_i}{C_i + C_i J} x \frac{5.16 + 124 \log C_i}{0.97 - 0.03C}$	N
Total horsepower	(Bhp / mmcfd)x gas flow (mmcfd)	Y

*A loss of 5 psia is assumed between two compression stages.

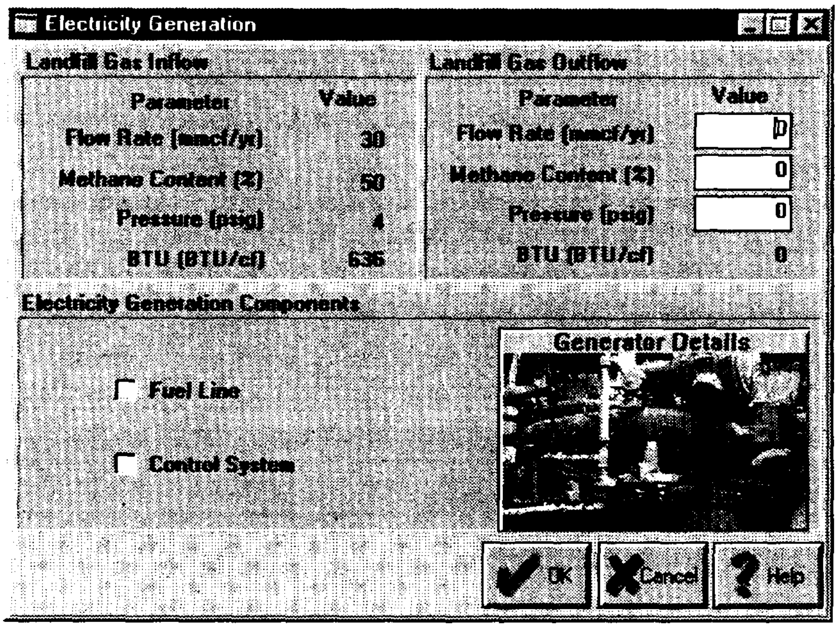
Features:

- Based on inputs E-PLUS computes changes to the gas flow. In addition, E-PLUS estimates annual costs for the compression system based on annual gas flows.

Click on the OK button to save and exit.

Electricity Generation

The electricity generation stage is the stage in which the treated landfill gas is utilized in an IC engine or turbine to produce electricity. The **Electricity Generation Stage Details** screen (Figure 27) allows you to design the electricity generation stage so it may be specific to your landfill.



Landfill Gas Inflow

Parameter	Value
Flow Rate (mmcf/yr)	30
Methane Content (%)	50
Pressure (psig)	4
BTU (BTU/cf)	636

Landfill Gas Outflow

Parameter	Value
Flow Rate (mmcf/yr)	0
Methane Content (%)	0
Pressure (psig)	0
BTU (BTU/cf)	0

Electricity Generation Components

☐ Fuel Line

☐ Control System

Figure 27: Electricity Generation Dialog Box

Inputs:

- Fuel line
- Control system

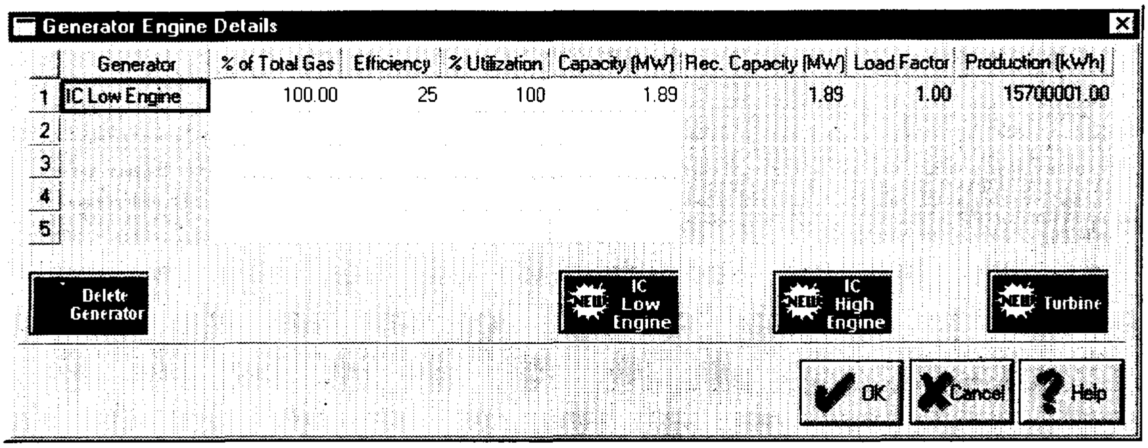
Assumptions:

Component	*Default Assumption*	*User can edit*
Fuel Line	Not selected	Y
Control System	Not selected	Y

Features:

- E-PLUS estimates annual costs for the electricity generation system based on annual gas flows and the selection of additional electricity generation equipment (fuel line and/or control system).

The generator(s) may be designed in the Engine Generator Details screen which may be accessed by clicking on "Generator Details" button.. You should click this button to open up the Engine Generator Details screen as shown in Figure 28.



	Generator	% of Total Gas	Efficiency	% Utilization	Capacity [MW]	Rec. Capacity [MW]	Load Factor	Production [kWh]
1	IC Low Engine	100.00	25	100	1.89	1.89	1.00	15700001.00
2								
3								
4								
5								

Figure 28: Generator Engine Details Dialog Box

Inputs:

- Type of generator(s)
- Percent of total gas for each generator (%)
- Generator efficiency (%)
- Generator utilization (%)
- Generator capacity (MW)

Assumptions

Component	***Default Assumption***	***User can edit***
Efficiency (Heat Rate) IC Low Pressure IC High Pressure Turbine	 25% (13,652 BTU/kWh) 28% (12,189 BTU/kWh) 20% (17,065 BTU/kWh)	Y
LFG Heating value	Calculated from gas characteristics described below	N
Load Factor	[(Electricity Produced kWh/yr)/8760 h/yr]/Engine capacity kW	N
Minimum Engine-generator Capacity (kW)	{[LFG Heating value (BTU/ ft^3) x Fuel consumption (ft^3/h)] / [Heat rate (BTU/kWh)]}/utilization factor	N
Engine-generator Capacity (kW)	Minimum Engine-generator Capacity (kW)	Y (Will issue warnings if less than min. engine capacity)
Utilization Factor	Fraction of hours in a year that the engine runs (i.e. hours used per year (h/yr)/8760 (h/yr))	Y
Electricity Produced	{[LFG Heating value (BTU/ ft^3) x Fuel consumption (ft^3/h)] / [Heat rate (BTU/kWh)]} x 8760 h	N

- The displayed engine capacity is the minimum required. If you enter a value less than the recommended capacity, E-PLUS will issue an unresolved flow warning (see page 55). In this case, the Electricity Generation stage box in the Process Configuration screen will be black in color indicating this unresolved flow. E-PLUS assumes that all gas is either consumed or flared. Therefore, the generator capacity and gas flow to the generator must be consistent.
- Each generator utilizes a certain portion of the gas produced. The total of all of the gas utilized should be 100%.
- Calculations for the minimum engine capacity assume that all the gas that reaches the engine will be consumed. Therefore as the utilization factor is reduced the minimum

engine capacity will increase. To model a smaller engine, the user would reduce gas flow to the engine.

NOTE: The "Production" column displays the average kWh of electricity produced given the engine capacity, utilization factor, efficiency, and fuel. The purpose of this column is for display ONLY. E-PLUS evaluates projects on the basis of annual gas flows and therefore annual electricity production which may vary from the average value displayed above.

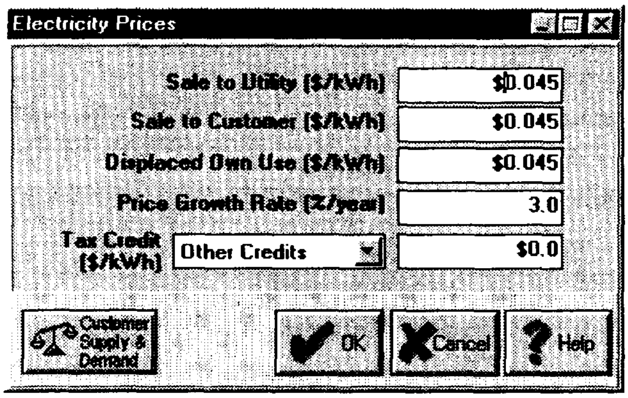
Features:

- Based on inputs and, E-PLUS designs the engine generator(s) at the landfill and estimates annual costs for the engine(s).

Click on OK to save and exit this screen.

Electricity Sales

The electricity sales stage is the stage in which the landfill gas is sold to the utility or to other customers. The **Electricity Prices** screen (Figure 29) allows you to edit the default electricity prices and the electricity demand for the end use consumers.


Electricity Prices

Sale to Utility [$/kWh] $0.045
Sale to Customer [$/kWh] $0.045
Displaced Own Use [$/kWh] $0.045
Price Growth Rate [%/year] 3.0
Tax Credit [$/kWh] Other Credits $0.0

Figure 29: Electricity Prices Dialog Box

Inputs:

- Electricity prices for the utility, a customer, and for displaced landfill use ($/kWh)
- Price growth rate (%/year)
- Tax Credit type and value ($/kWh)

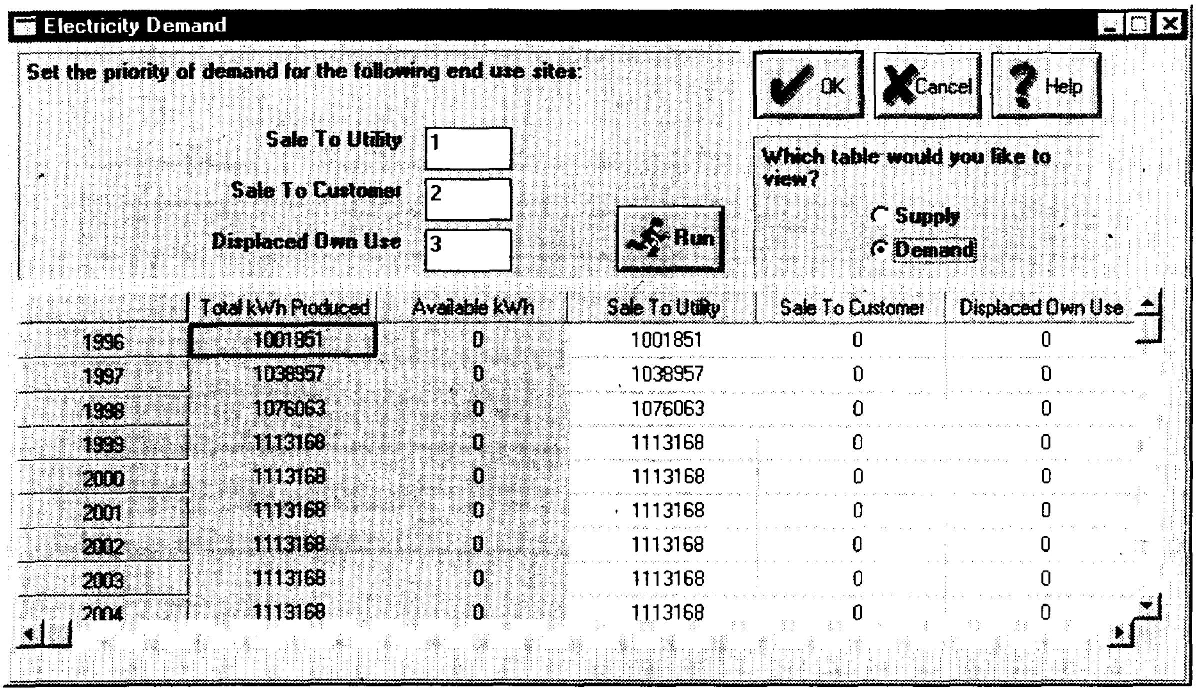
Features:

- E-PLUS calculates the value of the electricity produced and sold to one or more customers.

Figure 30: Supply and Demand Button

The supply and demand of the electricity for each of the end use customers may be edited by clicking on the supply and demand button (Figure 30).

The **Electricity Demand** dialog pops up as shown in Figure 31.



Set the priority of demand for the following end use sites:

Sale To Utility: 1
Sale To Customer: 2
Displaced Own Use: 3

Which table would you like to view?
○ Supply
● Demand

	Total kWh Produced	Available kWh	Sale To Utility	Sale To Customer	Displaced Own Use
1996	1001851	0	1001851	0	0
1997	1038957	0	1038957	0	0
1998	1076063	0	1076063	0	0
1999	1113168	0	1113168	0	0
2000	1113168	0	1113168	0	0
2001	1113168	0	1113168	0	0
2002	1113168	0	1113168	0	0
2003	1113168	0	1113168	0	0
2004	1113168	0	1113168	0	0

Figure 31: Electricity Demand Dialog Box

Inputs:

- Priority of demand for each of the customers
- Electricity (in kWh) to be allocated to each customer

Assumption:

- Electricity supply is allocated to the customers based on the customer priority which is set in the top left portion of the dialog. After changing the priorities, the table may be updated by clicking on the run button (Figure 32). As a result of prioritizing the customers, some customers may not be supplied some or all of their demand. For example, if there is a total supply of 5,000 kWh available, and the utility demands 3,000 kWh, the customer demands 1,000 kWh, and the landfill demands 1,000 kWh to offset its current electricity supply, the total demand equals 5,000 kWh and thus each customer is supplied its demand. If however, the utility demands 3,000 kWh, the customer demands 2,000 kWh and the landfill demands 1,000 kWh for a total demand of 6,000 kWh, supply is allocated based on demand. If the utility has priority 1, the customer has priority 2, and the landfill has priority 3, the utility demand (3,000 kWh) and the customer demand (2,000 kWh) will be supplied while the landfill demand will not as there is no electricity available. If however, the landfill has priority 1, the customer has priority 2, and the utility has priority 3, the landfill demand (1,000 kWh) and the customer demand (2,000 kWh) will be satisfied but the utility will be supplied only 2,000 kWh (versus the 3,000 kWh it demanded) which is remaining after satisfying priorities 1 and 2. These cases are outlined in the table below:

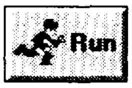


Figure 32: Run Button

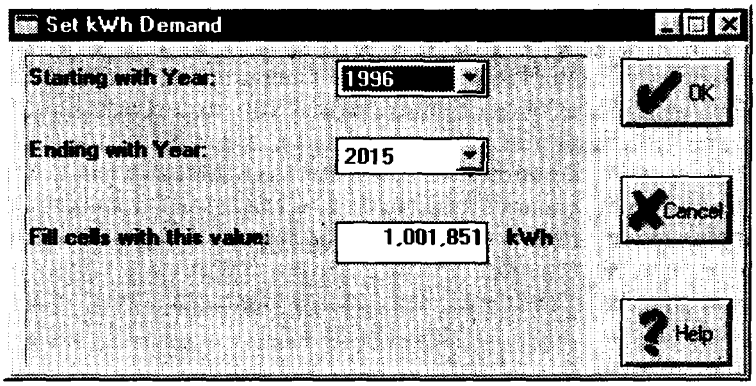
Case 1 - Total Available = 5,000 kWh				
	Utility (1)	Customer (2)	Landfill (3)	
Demanded	3,000	1,000	1,000	Total Demanded = 5,000
Supplied	3,000	1,000	1,000	Total Supplied = 5,000

Case 2 - Total Available = 5,000 kWh				
	Utility (1)	Customer (2)	Landfill (3)	
Demanded	3,000	2,000	1,000	Total Demanded = 6,000
Supplied	3,000	2,000	0	Total Supplied = 5,000

Case 3 - Total Available = 5,000 kWh				
	Landfill (1)	Customer (2)	Utility (3)	
Demanded	1,000	2,000	3,000	Total Demanded = 6,000
Supplied	1,000	2,000	2,000	Total Supplied = 5,000

Features:

- E-PLUS allocates electricity sales to one or more customers based upon the priorities set in the top of the screen..
- Both the supply and the demand for each customer may be displayed. The corresponding tables may be selected by clicking on either the supply or demand button.
- The demand for each customer may be edited if necessary in the demand table. The yellow boxes in the table may be double clicked to open up the Set kWh Demand dialog box as shown in Figure 33. In this screen you may enter the kWh demand for the customer as well as the start and end years for this demand.



Starting with Year: 1996

Ending with Year: 2015

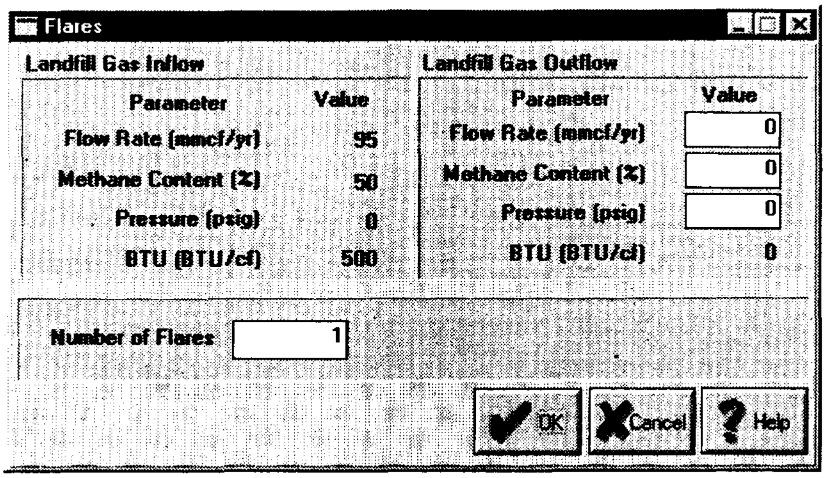
Fill cells with this value: 1,001,851 kWh

Figure 33: Set kWh Demand Dialog Box

When you are finished viewing the supply and demand table, click on OK to save and continue.

Flare

The flare stage is the stage in which the landfill gas is flared. The **Flare Stage Details** screen (Figure 34) allows you to design the flare stage so it may be specific to your landfill.



Landfill Gas Inflow

Parameter	Value
Flow Rate (mmcf/yr)	95
Methane Content (%)	50
Pressure (psig)	0
BTU (BTU/cf)	500

Landfill Gas Outflow

Parameter	Value
Flow Rate (mmcf/yr)	0
Methane Content (%)	0
Pressure (psig)	0
BTU (BTU/cf)	0

Number of Flares: 1

Figure 34: Flare Stage Details Screen

Inputs:

- Outflow flow rate
- Outflow methane content
- Outflow pressure
- Number of flares

Assumptions:

Component	*Default Assumption*	*User can edit*
Flares	1 per system	Y

Features:

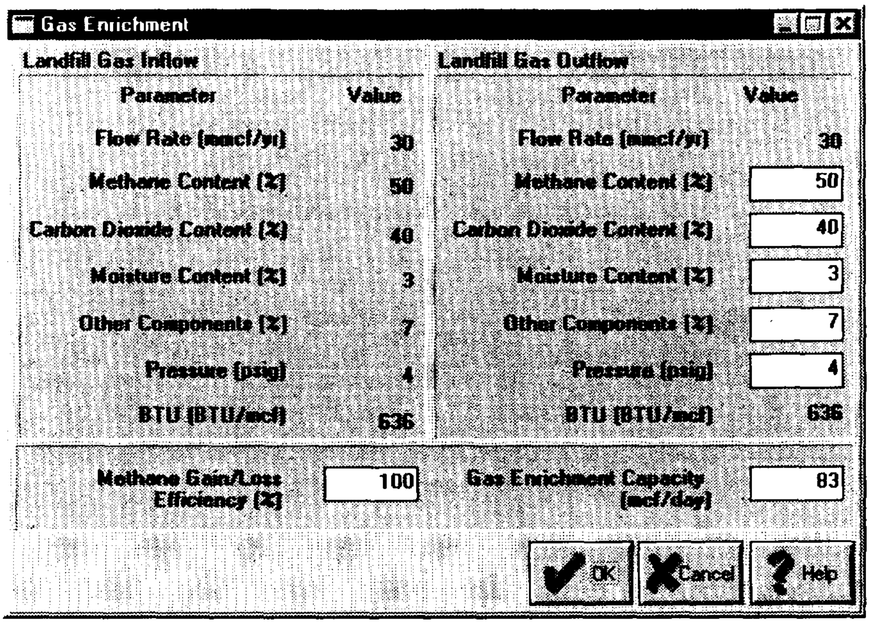
- Based on inputs and the common gas equations described on page 17, E-PLUS computes changes to the gas flow. In addition, E-PLUS estimates annual costs for the flare system based on annual gas flows.

Click on the OK button to save and exit.

Gas Enrichment (User Defined)

The gas enrichment stage is the stage in which the landfill gas is further purified after treatment. In this stage, carbon dioxide and other impurities are removed or pure methane is added to increase the total percentage of methane in the landfill gas. The **Gas Enrichment Stage Details** screen (Figure 35) allows you to design the gas enrichment stage so it may be specific to your landfill.

The gas enrichment stage may also be used as a "user defined" stage. The gas composition, pressure, and flow may be modified to reflect some form of landfill gas processing by the user. E-PLUS assumes the user is aware of the changes being made. E-PLUS computes the cost of processing based on the gas enrichment capacity flow rate.



Landfill Gas Inflow

Parameter	Value
Flow Rate (mmcf/yr)	30
Methane Content (%)	50
Carbon Dioxide Content (%)	40
Moisture Content (%)	3
Other Components (%)	7
Pressure (psig)	4
BTU (BTU/mcf)	636

Landfill Gas Outflow

Parameter	Value
Flow Rate (mmcf/yr)	30
Methane Content (%)	50
Carbon Dioxide Content (%)	40
Moisture Content (%)	3
Other Components (%)	7
Pressure (psig)	4
BTU (BTU/mcf)	636

Methane Gain/Loss Efficiency (%): 100

Gas Enrichment Capacity (mcf/day): 83

Figure 35: Gas Enrichment Stage Details Dialog Box

Inputs:

- Outflow methane content
- Outflow carbon dioxide content
- Outflow moisture content
- Outflow other components
- Outflow pressure
- Methane gain/loss efficiency
- Gas Enrichment capacity

Assumptions:

Component	*Default Assumption*	*User can edit*
Methane Gain/Loss Efficiency	100%	Y
Gas Enrichment Capacity	Capacity = inflow/day. A capacity less than the daily inflow may not be entered.	Y

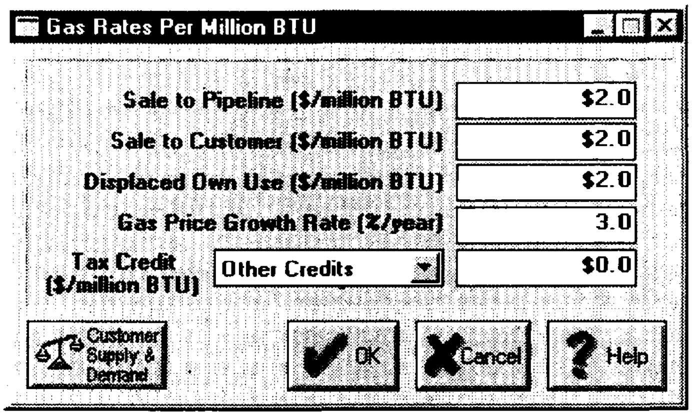
Features:

- Based on the pressure and the methane gain/loss percentage, E-PLUS computes changes to the gas flow. In addition, E-PLUS estimates annual costs for the gas enrichment system based on annual gas flows and system capacity.

Click on the OK button to save and exit.

Gas Sales

The gas sales stage is the stage in which the landfill gas is sold to the pipeline or to other customers. The **Gas Rates** screen (Figure 36) allows you to edit the default gas prices and the gas demand for the end use consumers.



Sale to Pipeline ($/million BTU) $2.0
Sale to Customer ($/million BTU) $2.0
Displaced Own Use ($/million BTU) $2.0
Gas Price Growth Rate (%/year) 3.0
Tax Credit ($/million BTU) Other Credits $0.0

Figure 36: Gas Rates Dialog Box

Inputs:

- Gas prices for the pipeline, a customer, and for displaced landfill use ($/million BTU)
- Gas price growth rate (%/year)
- Tax Credit type and value ($/million BTU)

Features:

- E-PLUS calculates the value of the gas generated and sold to one or more customers.

The supply and demand of the gas for each of the end use customers may be edited by clicking on the supply and demand button (Figure 37).

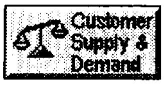
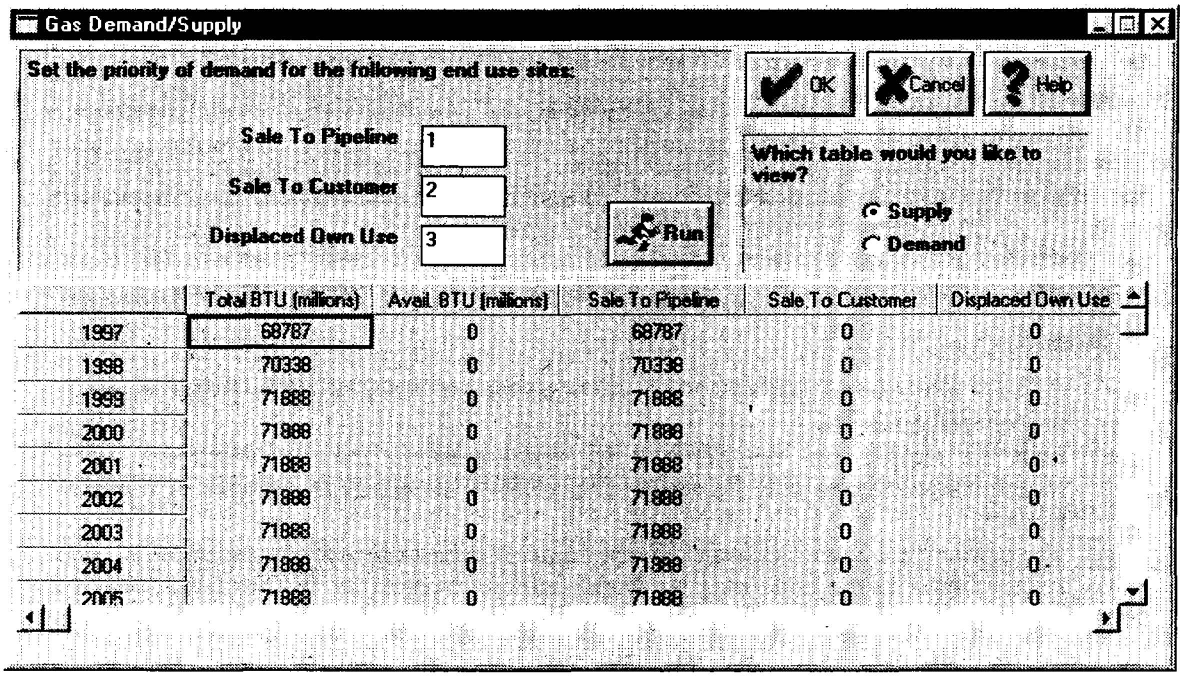


Figure 37: Supply and Demand Button

The **Gas Demand/Supply** dialog pops up as shown in Figure 38.



Set the priority of demand for the following end use sites:

Sale To Pipeline 1
Sale To Customer 2
Displaced Own Use 3

Which table would you like to view?

● Supply
○ Demand

	Total BTU (millions)	Avail. BTU (millions)	Sale To Pipeline	Sale To Customer	Displaced Own Use
1997	68787	0	68787	0	0
1998	70338	0	70338	0	0
1999	71888	0	71888	0	0
2000	71888	0	71888	0	0
2001	71888	0	71888	0	0
2002	71888	0	71888	0	0
2003	71888	0	71888	0	0
2004	71888	0	71888	0	0
2005	71888	0	71888	0	0

Figure 38: Medium BTU Gas Supply and Demand Dialog Box

Inputs:

- Priority of demand for each of the customers
- Gas (in million BTU) to be allocated to each customer

Figure 39: Run Button

Assumption:

- Gas supply is allocated to the customers based on the customer priority which is set in the top left portion of the dialog. After changing the priorities, the table may be updated by clicking on the run button (Figure 39). As a result of prioritizing the customers, some customers may not be supplied some or all of their demand. For example, if there is a total supply of 50 MMBTU available, and the pipeline demands 30 MMBTU, the customer demands 10 MMBTU, and the landfill demands 10 MMBTU to offset its current gas supply, the total demand equals 50 MMBTU and thus each customer is supplied its demand. If however, the pipeline demands 30 MMBTU, the customer demands 20 MMBTU and the landfill demands 10 MMBTU for a total demand of 60 MMBTU, supply is allocated based on demand. If the pipeline has priority 1, the customer has priority 2, and the landfill has priority 3, the pipeline demand (30 MMBTU) and the customer demand (20 MMBTU) will be supplied while the landfill demand will not as there is no gas available. If however, the landfill has priority 1, the customer has priority 2, and the pipeline has priority 3, the landfill demand (10 MMBTU) and the customer demand (20 MMBTU) will be satisfied but the pipeline will be supplied only 20 MMBTU(versus the 30 MMBTU it demanded) which is remaining after satisfying priorities 1 and 2. These cases are outlined in the table below:

Case 1 - Total Available = 50 million BTU

	Pipeline (1)	Customer (2)	Landfill (3)	
Demanded	30	10	10	Total Demanded = 50
Supplied	30	10	10	Total Supplied = 50

Case 2 - Total Available = 50 million BTU

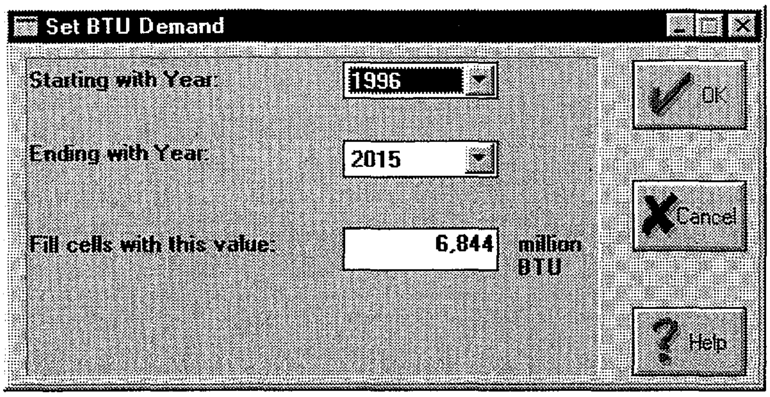
	Pipeline (1)	Customer (2)	Landfill (3)	
Demanded	30	20	10	Total Demanded = 60
Supplied	30	20	0	Total Supplied = 50

Case 3 - Total Available = 50 million BTU

	Landfill (1)	Customer (2)	Pipeline (3)	
Demanded	10	20	30	Total Demanded = 60
Supplied	10	20	20	Total Supplied = 50

Features:

- E-PLUS allocates gas sales to one or more customers based upon the priorities set in the top of the screen..
- Both the supply and the demand for each customer may be displayed. The corresponding tables may be selected by clicking on either the supply or demand button.
- The demand for each customer may be edited if necessary in the demand table. The yellow boxes in the table may be double clicked to open up the Set BTU Demand dialog box as shown in Figure 40. In this screen you may enter the BTU demand for the customer as well as the start and end years for this demand. In this screen you may enter the BTU demand for the customer as well as the start and end years for this demand.



Starting with Year: 1996

Ending with Year: 2015

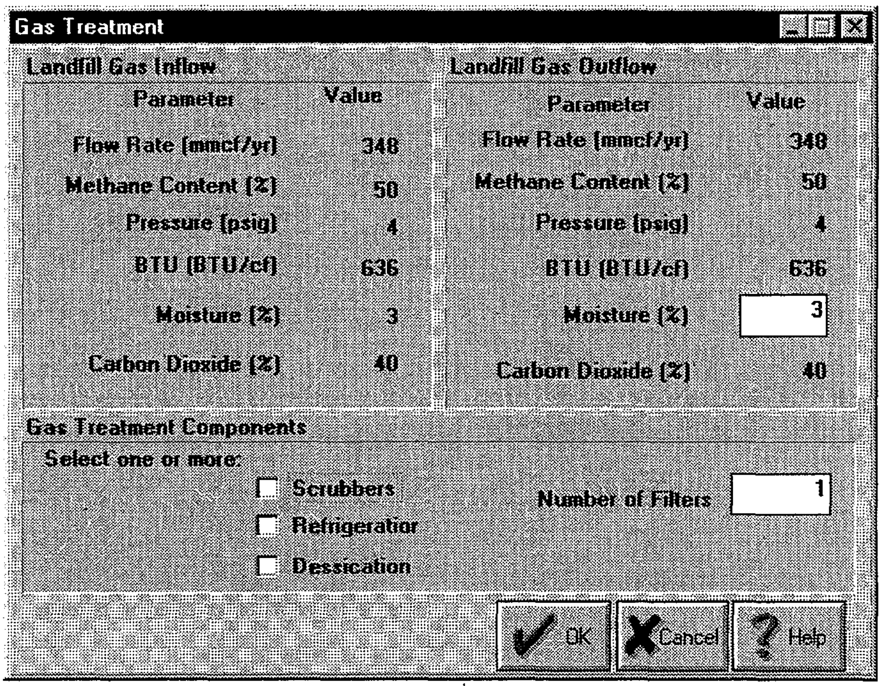
Fill cells with this value: 6,844 million BTU

Figure 40: Set BTU Dialog Box

When you are finished viewing the supply and demand table, click on OK to save and continue.

Gas Treatment

The gas treatment stage is the stage in which the landfill gas is treated prior to electricity generation or gas delivery. The **Gas Treatment Stage Details** screen (Figure 41) allows you to design the gas treatment stage so it may be specific to your landfill.



Landfill Gas Inflow

Parameter	Value
Flow Rate (mmcf/yr)	348
Methane Content (%)	50
Pressure (psig)	4
BTU (BTU/cf)	636
Moisture (%)	3
Carbon Dioxide (%)	40

Landfill Gas Outflow

Parameter	Value
Flow Rate (mmcf/yr)	348
Methane Content (%)	50
Pressure (psig)	4
BTU (BTU/cf)	636
Moisture (%)	3
Carbon Dioxide (%)	40

Gas Treatment Components

Select one or more:

☐ Scrubbers

☐ Refrigeration

☐ Dessication

Number of Filters: 1

Figure 41: Gas Treatment Dialog Box

Inputs:

- Outflow moisture
- Scrubbers
- Refrigeration (dehydration process)
- Dessication (dehydration process)
- Number of filters

Assumptions:

Component	*Default Assumption*	*User can edit*
Filters	2 filters/mmcfd (min = 1)	Y
Scrubber	Not selected	Y*
Dessicator	Not selected	Y*
Refrigeration	Not selected	Y*

*The user can toggle whether or not this component is a part of treatment system. The number of units cannot be changed.

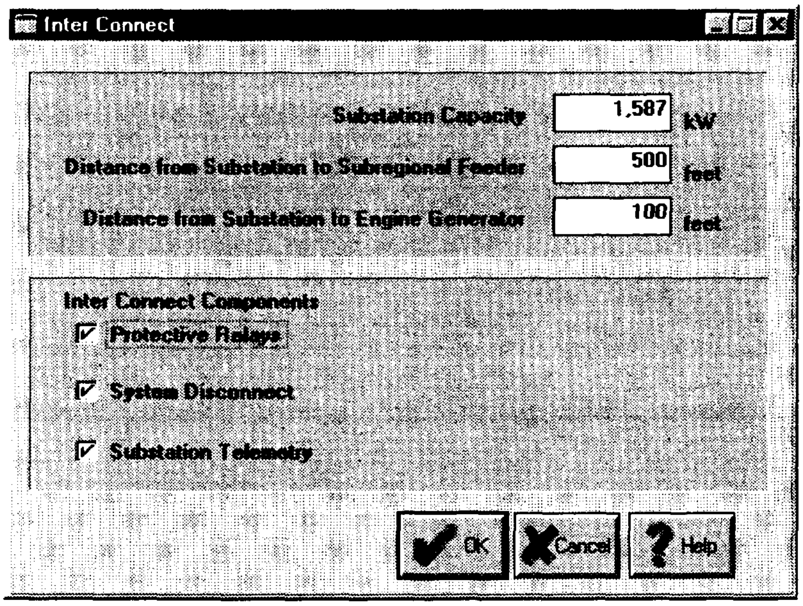
Features:

- Based on inputs and the common gas equations described on page 17, E-PLUS computes changes to the gas flow. In addition, E-PLUS estimates annual costs for the treatment system based on annual gas flows and the additional equipment selected.

Click on the OK button to save and exit.

Interconnect

The interconnect stage is the stage in which the electricity is connected to the utility power lines. The **Interconnect Stage Details** dialog box (Figure 42) does not have a gas inflow and outflow section as only electricity enters the stage.



Inter Connect

Substation Capacity 1,587 kW

Distance from Substation to Subregional Feeder 500 feet

Distance from Substation to Engine Generator 100 feet

Inter Connect Components

☑ Protective Relays

☑ System Disconnect

☑ Substation Telemetry

Figure 42: Interconnect Stage Details Dialog Box

Inputs:

- Substation capacity (kW)
- Distance from substation to subregional feeder (ft)
- Distance from substation to engine generator (ft)
- Protective relays, system disconnect, and substation telemetry components

Assumptions:

Component	*Default Assumption*	*User can edit*
Substation capacity (kW)	Set to engine-generator capacity	Y
Distance from substation to subregional feeder	500 ft	Y
Distance from substation to engine generator	100 ft	Y
Protective relays	Unit installed	Y*
System disconnect	Unit installed	Y*
Substation telemetry	Unit installed	Y*

*The user can toggle whether or not this component is a part of the interconnect system. The number of units cannot be changed

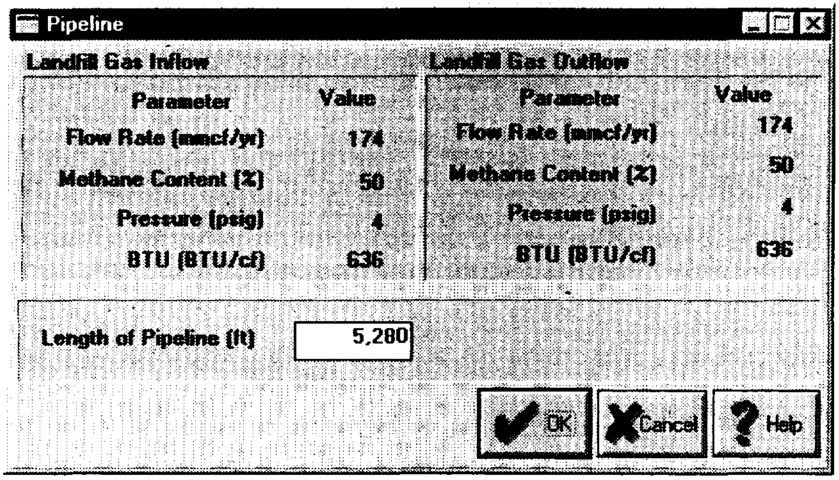
Features:

- E-PLUS estimates annual costs for the interconnect system based on the substation capacity and the additional equipment selected.

Click on the OK button to save and exit.

Pipeline

The pipeline stage is the stage in which gas is hooked into the pipelines. The **Pipeline Stage Details** screen (Figure 43) allows you to design the pipeline stage so it may be specific to your landfill.



Pipeline

Landfill Gas Inflow

Parameter	Value
Flow Rate (mmcf/yr)	174
Methane Content (%)	50
Pressure (psig)	4
BTU (BTU/cf)	636

Landfill Gas Outflow

Parameter	Value
Flow Rate (mmcf/yr)	174
Methane Content (%)	50
Pressure (psig)	4
BTU (BTU/cf)	636

Length of Pipeline (ft) 5,280

Figure 43: Pipeline Stage Details Dialog Box

Inputs:

- Length of pipeline (ft)

Assumptions

Component	*Default Assumption*	*User can edit*
Length of Pipeline	5,280 feet	Y

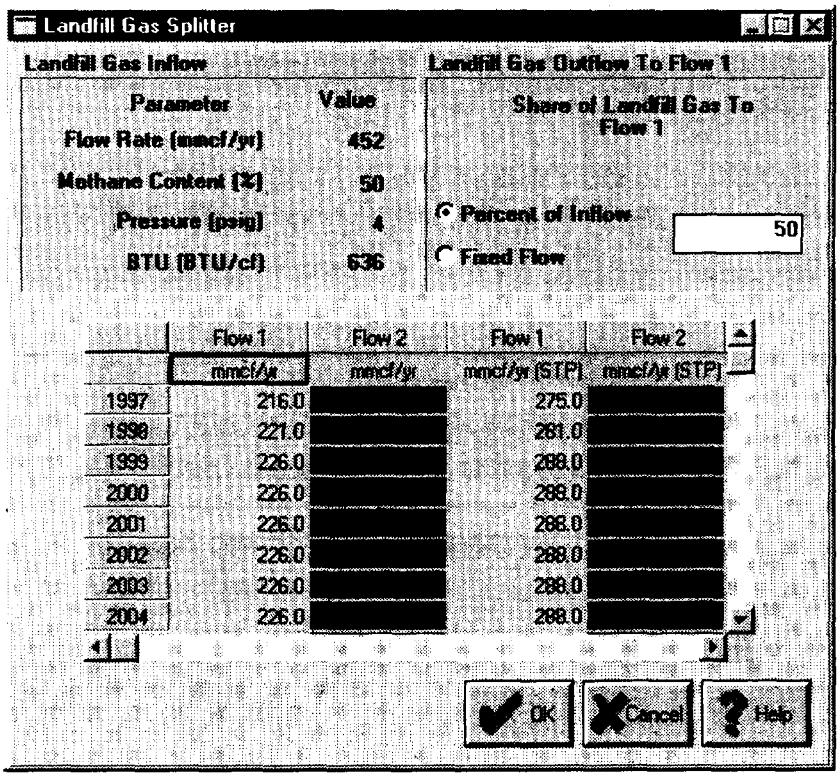
Features

- E-PLUS estimates annual costs for the pipeline system based on the number of feet of pipeline required.

Click on the OK button to save and exit.

Split Gas

The split gas stage is the stage in which gas is split from one component into two components. For example, after gas treatment 50% of the gas may hook into the pipelines and 50% of the gas may be run through an engine generator to generate electricity. The split stage may be selected at any point in the configuration and may split in any combination of percentages. The **Landfill Gas Splitter** dialog box (Figure 44) allows you to design the split gas stage so it may be specific to your landfill.



Landfill Gas Inflow

Parameter	Value
Flow Rate (mmcf/yr)	452
Methane Content (%)	50
Pressure (psig)	4
BTU (BTU/cf)	636

Landfill Gas Outflow To Flow 1

Share of Landfill Gas To Flow 1

● Percent of Inflow 50

○ Fixed Flow

	Flow 1	Flow 2	Flow 1	Flow 2
	mmcf/yr	mmcf/yr	mmcf/yr (STP)	mmcf/yr (STP)
1997	216.0		275.0	
1998	221.0		281.0	
1999	226.0		288.0	
2000	226.0		288.0	
2001	226.0		288.0	
2002	226.0		288.0	
2003	226.0		288.0	
2004	226.0		288.0	

Figure 44: Split Gas Stage Details Dialog Box

Inputs:

- The method of splitting the gas (either percent or fixed)
- The share of landfill gas to Flow 1

Assumptions:

- Flow 1 is the gas which flows to the component in the Process Configuration screen which is on the same line as the Split Gas component (Figure 45) or directly underneath the Split Gas component (Figure 46). Flow 2 is the gas which flows to the component in the row of components below the Split Gas component (Figure 45) or to the lower right of the Split Gas component (Figure 46). For example, in Figure 45 and Figure 46, Flow 1 is the flow to the Flare component and Flow 2 is the flow to the Compression component.

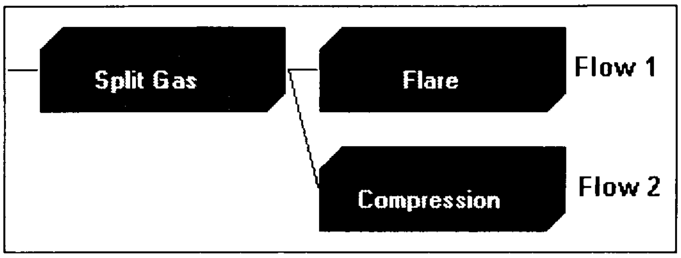


Figure 45: Split Gas Horizontal Configuration

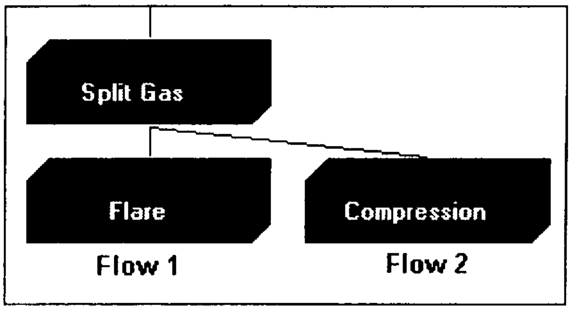


Figure 46: Split Gas Vertical Configuration

Features

- E-PLUS allocates gas to the different components based on the inputs to this screen.
- The "Percent of Inflow" option sets the percent of the inflow that goes to Flow 1. The "Fixed Flow" option sets the maximum flow that goes to Flow 1, the remainder, if any, goes to Flow 2.
- E-PLUS displays the flow to the two components based on current pressure (as shown in the upper left hand corner of the screen) and STP (standard temperature and pressure).
- If the Flow 1 component is deleted, the Flow 2 component becomes the Flow 1 component.

Click on the OK button to save and exit.

Chapter 5. Defining Stage Costs

The cost of each landfill gas recovery stage is considered in the financial evaluation of the costs and benefits of the defined landfill gas recovery project. As such, it is imperative that the costs be defined as accurately as possible to ensure a reliable project financial evaluation.

This chapter is divided into two sections. The first section describes how to enter and edit the cost characteristics for each and the second section describes entering Rule of Thumb costs values versus detailed component cost values.

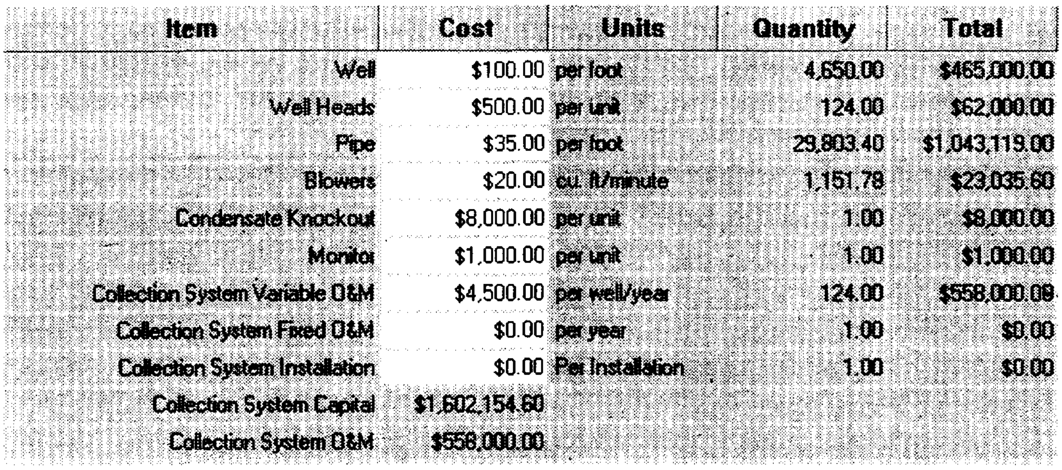
Entering/Editing Stage Cost Components

As described on page 15 in Chapter 3, stage costs may be viewed and edited in the Process Configuration screen by selecting a stage and then clicking on the dollars icon in the floating toolbar or by selecting **Stage Costs** from the **Stage Details** menu.

Each stage cost is broken into different components in the Stage Costs screen. Where possible, default values are used for the items that make up the stage, operation and maintenance (O&M) costs, and installation costs. Any of the costs in the cream colored cells may be edited if necessary. The unit for the cost is displayed under the "Units" column and the number of units requested is displayed under the "Quantity" column. The total for each subcost is displayed in the "Total" column.

NOTE: The value in the "Total" column is the product of the value in the "Cost" column and the value in the "Quantity" column. The value displayed in the "Quantity" column is the maximum over the life of the project and is for display ONLY. The actual values used for the financial evaluation may vary year to year over the life of the project.

A sample cost table for the Collection stage is displayed in Figure 47 below:



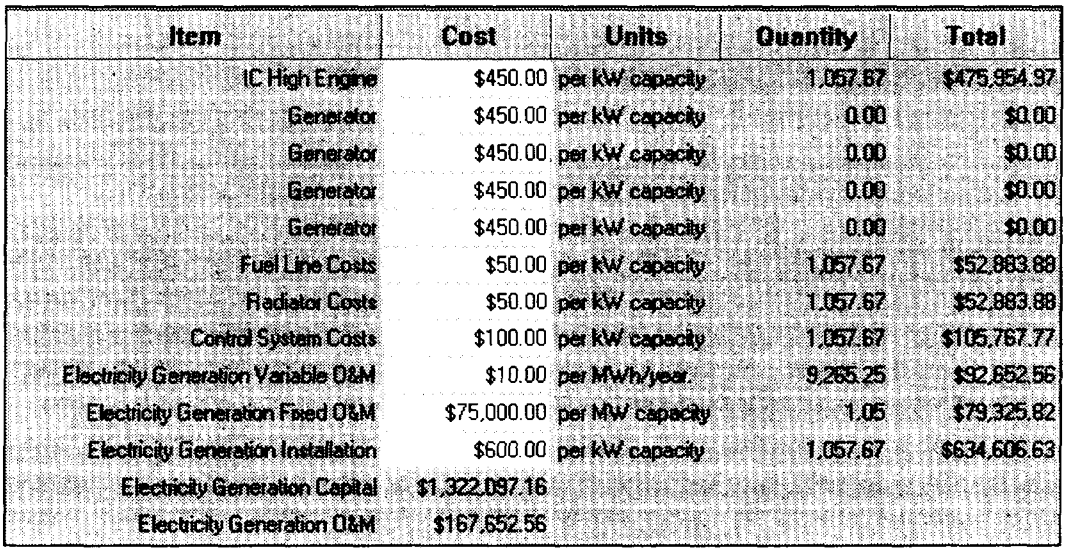
Item	Cost	Units	Quantity	Total
Well	$100.00	per foot	4,650.00	$465,000.00
Well Heads	$500.00	per unit	124.00	$62,000.00
Pipe	$35.00	per foot	29,803.40	$1,043,119.00
Blowers	$20.00	cu. ft/minute	1,151.78	$23,035.60
Condensate Knockout	$8,000.00	per unit	1.00	$8,000.00
Monitor	$1,000.00	per unit	1.00	$1,000.00
Collection System Variable O&M	$4,500.00	per well/year	124.00	$558,000.00
Collection System Fixed O&M	$0.00	per year	1.00	$0.00
Collection System Installation	$0.00	Per Installation	1.00	$0.00
Collection System Capital	$1,602,154.60			
Collection System O&M	$558,000.00			

Figure 47: Sample Collection Costs

In this example, the Collection stage cost is broken into different collection component costs including the costs of wells, wellheads, piping, blowers, condensate knockout, and monitors. In addition, variable and fixed O&M costs are included as well as an installation fee. By default, wells cost $100.00 per foot and, in this example, 4,650 wells are needed for a total ***wells*** cost of $465,000. The other subcosts are similarly calculated. Where possible, these subcosts should be edited to more accurately reflect the capital costs for the defined landfill gas recovery system. The total collection system capital cost is shown in the second to the last row and the total collection system O&M costs are shown in the last row.

Rule of Thumb Versus Detailed Component Costs

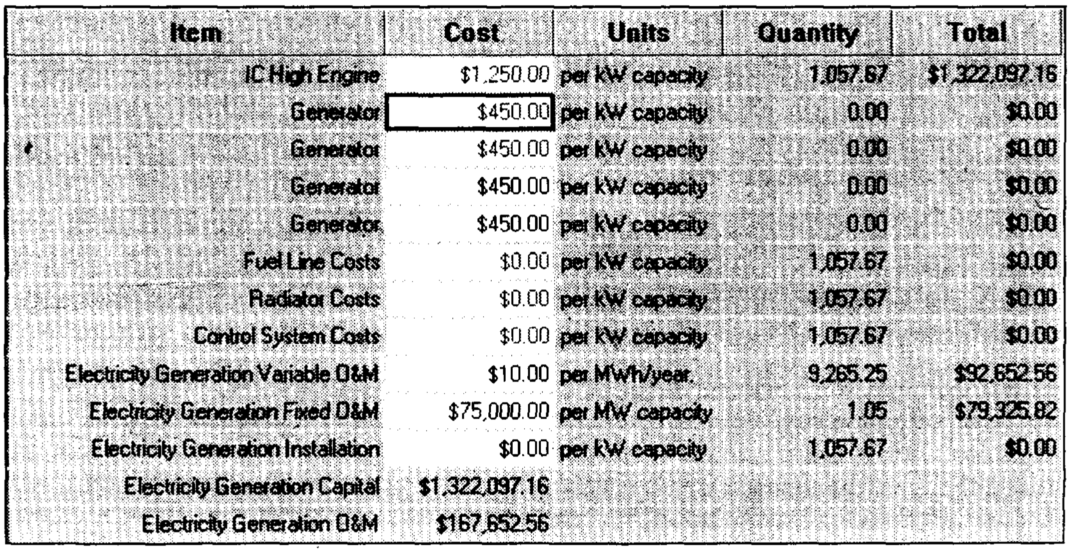
If the detailed component costs for a stage are unknown, but the total cost per unit (Rule of Thumb) is known, the Stage Costs table may be edited to reflect this. For example, if you know that on average the total cost of an engine generator system is $1,250/kW capacity but you do not know how this total breaks into the component costs for the engine, fuel line, radiator, control system, and installation costs, you may alter the table to input only the $1,250 value. The default Stage Costs table for Electricity Generation is shown in Figure 48. In this table, the total cost per kW capacity for Electricity Generation is $450 (IC High Engine) + $50 (fuel line) + $50 (radiator) $100 (control system) + $600 (installation) for a total of $1,250.



Item	Cost	Units	Quantity	Total
IC High Engine	$450.00	per kW capacity	1,057.67	$475,954.97
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Fuel Line Costs	$50.00	per kW capacity	1,057.67	$52,883.88
Radiator Costs	$50.00	per kW capacity	1,057.67	$52,883.88
Control System Costs	$100.00	per kW capacity	1,057.67	$105,767.77
Electricity Generation Variable O&M	$10.00	per MWh/year.	9,265.25	$92,652.56
Electricity Generation Fixed O&M	$75,000.00	per MW capacity	1.05	$79,325.82
Electricity Generation Installation	$600.00	per kW capacity	1,057.67	$634,606.63
Electricity Generation Capital	$1,322,097.16			
Electicity Generation O&M	$167,652.56			

Figure 48: Sample Electricity Generation Costs

To enter the Rule of Thumb total cost of $1,250 you should first zero out all of the costs per kW capacity that are used to calculate the total Electricity Generation costs (in this case, the IC High (pressure) Engine, fuel line, radiator, control system, and installation costs). Then, in any one of the cream colored cells with a per kW capacity unit, you should enter 1,250. An altered cost table may look like Figure 49 below:



Item	Cost	Units	Quantity	Total
IC High Engine	$1,250.00	per kW capacity	1,057.67	$1,322,097.16
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Fuel Line Costs	$0.00	per kW capacity	1,057.67	$0.00
Radiator Costs	$0.00	per kW capacity	1,057.67	$0.00
Control System Costs	$0.00	per kW capacity	1,057.67	$0.00
Electricity Generation Variable O&M	$10.00	per MWh/year.	9,265.25	$92,652.56
Electricity Generation Fixed O&M	$75,000.00	per MW capacity	1.05	$79,325.82
Electricity Generation Installation	$0.00	per kW capacity	1,057.67	$0.00
Electricity Generation Capital	$1,322,097.16			
Electricity Generation O&M	$167,652.56			

Figure 49: Altered Electricity Generation Costs Table

Note that in this example the total cost of $1,250/kW capacity was entered in the IC High Engine row. Note that all of the cells which have been changed from the default values are shown with red text. All of the costs may be reset to the default by clicking on the reset button (Figure 50) in the Stage Costs floating toolbar.

Figure 50: Reset button

Chapter 6. Methane Production

The amount of methane generated from a landfill may be estimated using several different algorithms. Because methane production affects the costs and benefits of the proposed project it is important to generate these estimates accurately. This chapter describes the algorithms used in E-PLUS to estimate methane production and the associated features accompanying editing and viewing the methane production table.

Figure 51: Methane icon

The **Methane Production** table may be viewed by clicking on the methane icon (Figure 51) on the toolbar or by selecting **Methane Production Estimates** from the **Methane** menu. In addition, this table may be viewed after entering the **Landfill Characteristics** (see page 9) if the landfill is triggered by the New Source Performance Standards (NSPS)/Emissions Guidelines (EG) Tier 1 Calculations. In this case you receive a dialog box with a message stating that the landfill may be subject to the NSPS/EG Tier 1 Calculations and a show me button (Figure 52) which opens the Methane Production table.

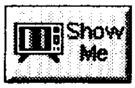
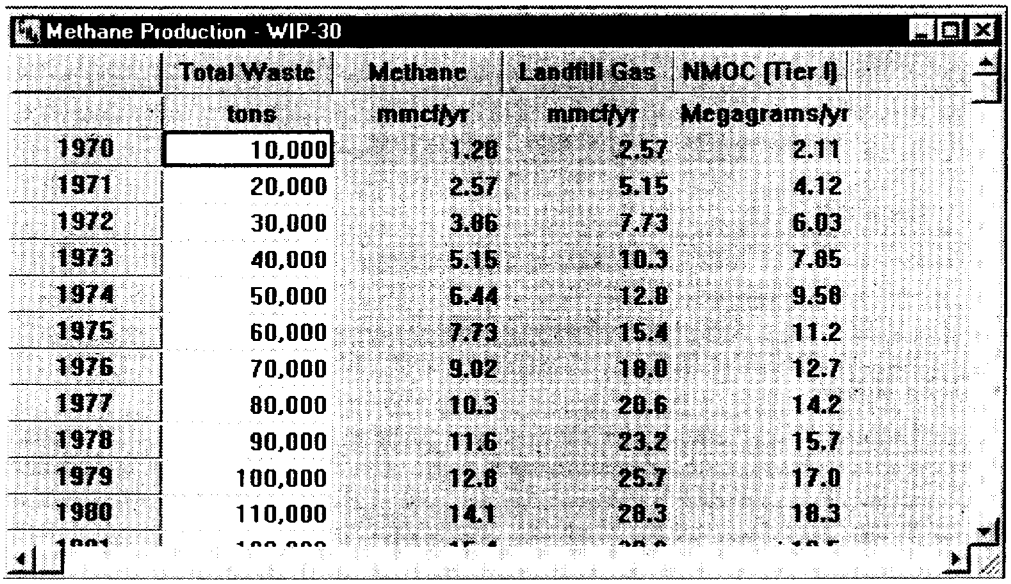


Figure 52: Show Me Button

The **Methane Production** table will look similar to Figure 53 below.



Methane Production - WIP-30

	Total Waste	Methane	Landfill Gas	NMOC (Tier I)
	tons	mmcf/yr	mmcf/yr	Megagrams/yr
1970	10,000	1.28	2.57	2.11
1971	20,000	2.57	5.15	4.12
1972	30,000	3.86	7.73	6.03
1973	40,000	5.15	10.3	7.85
1974	50,000	6.44	12.8	9.58
1975	60,000	7.73	15.4	11.2
1976	70,000	9.02	18.0	12.7
1977	80,000	10.3	20.6	14.2
1978	90,000	11.6	23.2	15.7
1979	100,000	12.8	25.7	17.0
1980	110,000	14.1	28.3	18.3

Figure 53: Methane Production Table

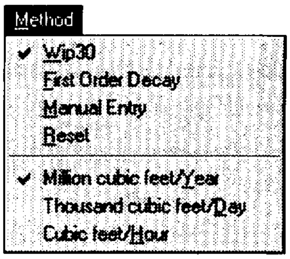


Figure 54: Method menu

In order from left to right, the columns in this screen display total waste, methane production, landfill gas production, and the Tier 1 NMOC emissions estimate. These values are displayed each year from the year the landfill opened until 20 years after either the year the landfill closed or the year the project ended, whichever period is longer. The total waste may be edited if necessary. Editing the total waste will change the methane, landfill gas, and NMOC emissions based on the algorithm used.

NOTE: A lesser amount of total waste cannot be entered for a year than the amount estimated for the previous year.

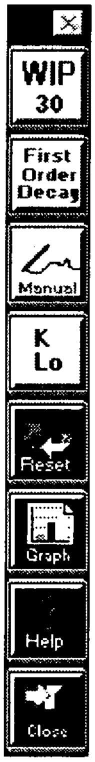


Figure 55: Method floating toolbar

Upon entering this screen, you should notice a new menu item called **Method** (Figure 54) and a corresponding Method floating tool bar (Figure 55). The top three items in this menu and tool bar show the three algorithms available for methane production analysis in E-PLUS . The algorithm with the checkmark next to it in the menu indicates the current method being used. The bottom three menu items show the three units available for analysis (million ft^3/year, 1,000 ft^3/day, ft^3/hr). Again, the checkmark indicates the current units displayed in the **Methane Production** screen. You may select a different algorithm and/or different units from this menu by clicking on the desired method. You may reset to the original algorithm and default units by selecting **Reset**. Additionally, you may graph the methane production by clicking on the graph button in the floating toolbar.

The three methods used to analyze methane production are WIP-30, First Order Decay, and Manual. These algorithms are described below:

WIP-30

The **WIP-30** method uses the amount of waste in place over the past 30 years to estimate methane emissions. The equations for small landfills ($\leq$ 907,000 tons of waste in place) and large landfills (>907.000 tons of waste in place) in arid and non-arid regions are outlined in the table below. Default characteristics for arid and non-arid regions are described in Chapter 2. If this method is selected, the amount of waste in place for each year may be edited in the first column of the **Methane Production** table.

WIP 30[4]
Equation
where W = waste in place that is less than 30 years old (10^6 tons), Arid Regions *Small Landfills ($\leq$ 907,000 tons of waste in place)* LFG = 18.56025 x (5.3253×10^{-6} x W) *Large Landfills(> 907,000 tons of waste in place* LFG = 18.56025 x [8.22+(3.1298×10^{-6} x W)] Non-arid Regions *Small Landfills* LFG = 18.56025 x (6.9492×10^{-6} x W) *Large Landfills* LFG = 18.56025 x [8.22+(5.0259×10^{-6} x W)]

First Order Decay

The **First Order Decay** method uses the waste in place as well as factors accounting for the emission of methane from this waste over time. The first order decay is outlined in the table below. If this method is selected, the amount of waste in place for each year may be edited in the first column of the **Methane Production** table.

---

[4] USEPA. 1993. *Anthropogenic Methane Emissions in the United States: Estimates for 1990. Report to Congress.* EPA Office of Air and Radiation, Washington, D.C. EPA 430-R-93-003, April 1993.

First Order Decay[5]

Equation

$Q_{T,x} = kR_xL_oe^{-k(T-x)}$

where: $Q_{T,x}$ = CH_4 generated in the current year (T) by the waste R_x
x = the year of waste input
R_x = the amount of waste disposed in year x (Mg)
T = current year

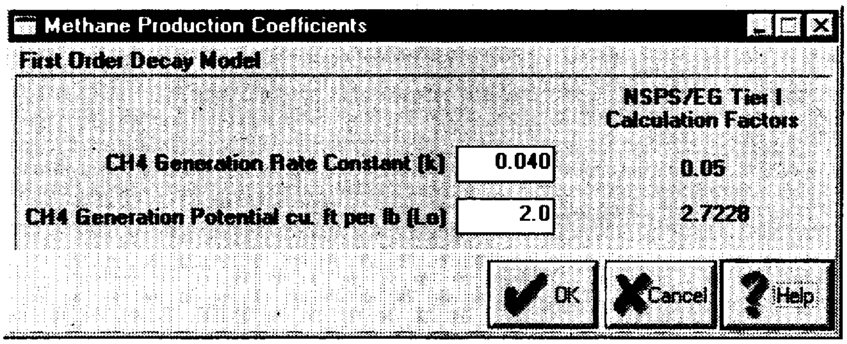
$Q_T = SQ_{T,x}$, for x = initial year to T

where Q_T = total CH_4 generated to the year (T) by the waste R_x

Assumptions

Component	*Units*	*Default Value*	*User can edit*
Waste CH_4 generation potential (L_o)	m^3/Mg of refuse	2.0	Y
Rate of methane generation (k)	1/yr	Dry: 0.02 Wet: 0.04	Y

If you choose to use the First Order Decay method you may wish to edit the two coefficients used in this equation. The **Methane Production Coefficients** (Figure 56) dialog box may be accessed by clicking on the K and Lo button in the floating toolbar.



Methane Production Coefficients

First Order Decay Model

NSPS/EG Tier I Calculation Factors

CH4 Generation Rate Constant (k) 0.040 0.05

CH4 Generation Potential cu. ft per lb (Lo) 2.0 2.7228

Figure 56: Methane Production Coefficients Dialog Box

The methane generation rate constant (k) and the methane generation potential (Lo) may be edited in this screen if necessary. In addition, this dialog also displays the default EPA coefficients used for the NMOC calculations. These coefficients are not editable.

NOTE: Revisiting the Landfill Characteristics dialog (page 9) and clicking the OK button will reset the k values to the defaults depending on whether the landfill is located in an arid or non-arid region.

You may exit the **Methane Production Coefficients Dialog** by clicking on the OK button.

Manual Method

The **Manual** method allows you to edit the amount of methane generated from the landfill based on previous estimates that have been made. Both the annual waste in place and methane emissions may be edited in the **Methane Production** table.

NOTE: This method should only be selected if you know the amount of methane being produced.

---

[5] USEPA. 1991. *Air Emissions from Municipal Solid Waste Landfills - Background Information for Standards and Guidelines.* EPA Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA 450/3-90-011a, March 1991.

You may exit the **Methane Production** Table double clicking in the upper left hand corner or clicking on the close button in the floating toolbar.

Chapter 7. Analyzing the Costs and Benefits

After entering all of the information required under the **Design** menu and selecting the methane production algorithm you may analyze the costs and benefits of the proposed landfill gas recovery system. This chapter describes the analysis screens presented in E-PLUS. These features may be accessed through the options under the **Analysis** menu (Figure 57).

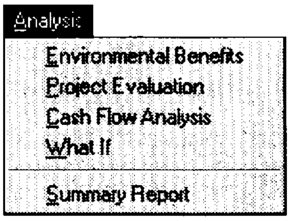


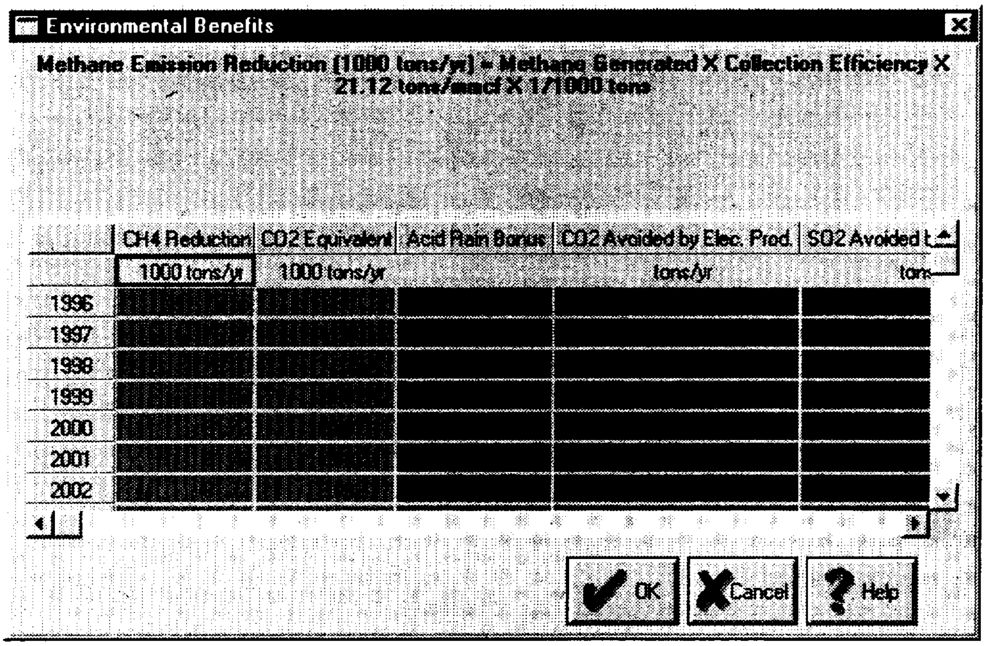
Figure 57: Analysis menu

Environmental Benefits

The recovery of landfill gas results in reduced greenhouse gas emissions to the atmosphere. The Environmental Benefits table categorizes these benefits for each year over the lifetime of the project. The Environmental Benefits table may be viewed by clicking the environment icon (Figure 58) or selecting **Environmental Benefits** from the **Analysis** menu.

Figure 58: Environment icon

The **Environmental Benefits** dialog should look similar to Figure 59 below:



Methane Emission Reduction (1000 tons/yr) = Methane Generated X Collection Efficiency X 21.12 tons/mmcf X 1/1000 tons

Figure 59: Environmental Benefits Dialog Box

This table is read-only – it may not be edited. The following values are displayed for each year:

- Methane reduction (1,000 tons/yr)
- Carbon dioxide reduction (1,000 tons/yr)
- Acid rain bonus
- Carbon dioxide emissions avoided by electricity production (tons/yr)
- Sulfur dioxide emissions avoided by electricity production (tons/yr)
- Carbon dioxide emissions avoided by gas sale (1,000 tons/yr)

The top part of the dialog box displays the equation used to calculate the values in each of the columns in the table. For instance, if you click in the CH4 Reduction column, the equation at the top of the dialog reads "Methane Emission Reduction (1,000 tons/yr) = Methane Generated X Collection Efficiency X 21.12 tons/mmcf X 1/1,000 tons". Similar equations are presented for each of the additional columns.

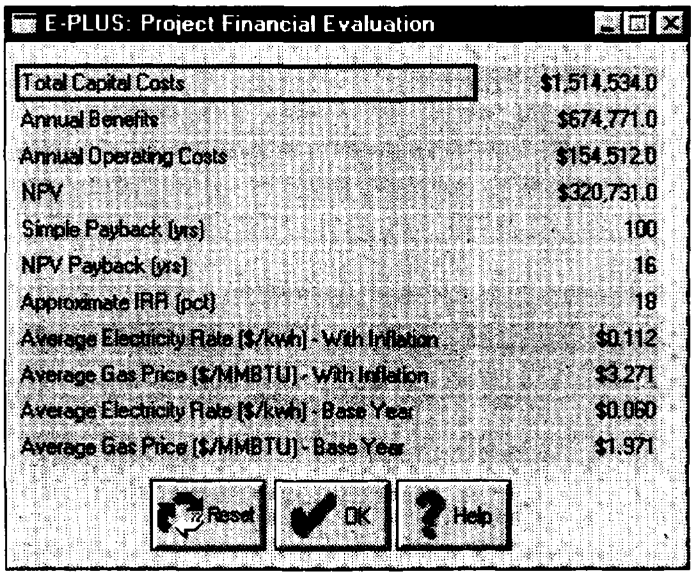
Click on the OK button to exit this screen.

Project Evaluation

Figure 60: Magnifying Glass icon

The **Project Evaluation** screen shows a quick look at the financial benefits of landfill gas recovery. This screen may be viewed by clicking on the magnifying glass icon (Figure 60) or selecting **Project Evaluation** from the **Analysis** menu.

The **Project Financial Evaluation** screen should look similar to Figure 61.



Total Capital Costs	$1,514,534.0
Annual Benefits	$674,771.0
Annual Operating Costs	$154,512.0
NPV	$320,731.0
Simple Payback (yrs)	100
NPV Payback (yrs)	16
Approximate IRR (pct)	18
Average Electricity Rate [$/kwh] - With Inflation	$0.112
Average Gas Price [$/MMBTU] - With Inflation	$3.271
Average Electricity Rate [$/kwh] - Base Year	$0.060
Average Gas Price [$/MMBTU] - Base Year	$1.971

Figure 61: Project Financial Evaluation Dialog Box

The following estimates are displayed in this screen:

- Total capital costs
- Annual benefits
- Annual operating costs
- NPV
- Simple payback
- NPV payback
- Approximate IRR
- Average Electricity Price ($/kWh) with inflation
- Average Gas Rate ($/MMBTU) with inflation
- Average Electricity Rate ($/kWh) base year
- Average Gas Rate ($/MMBTU) base year

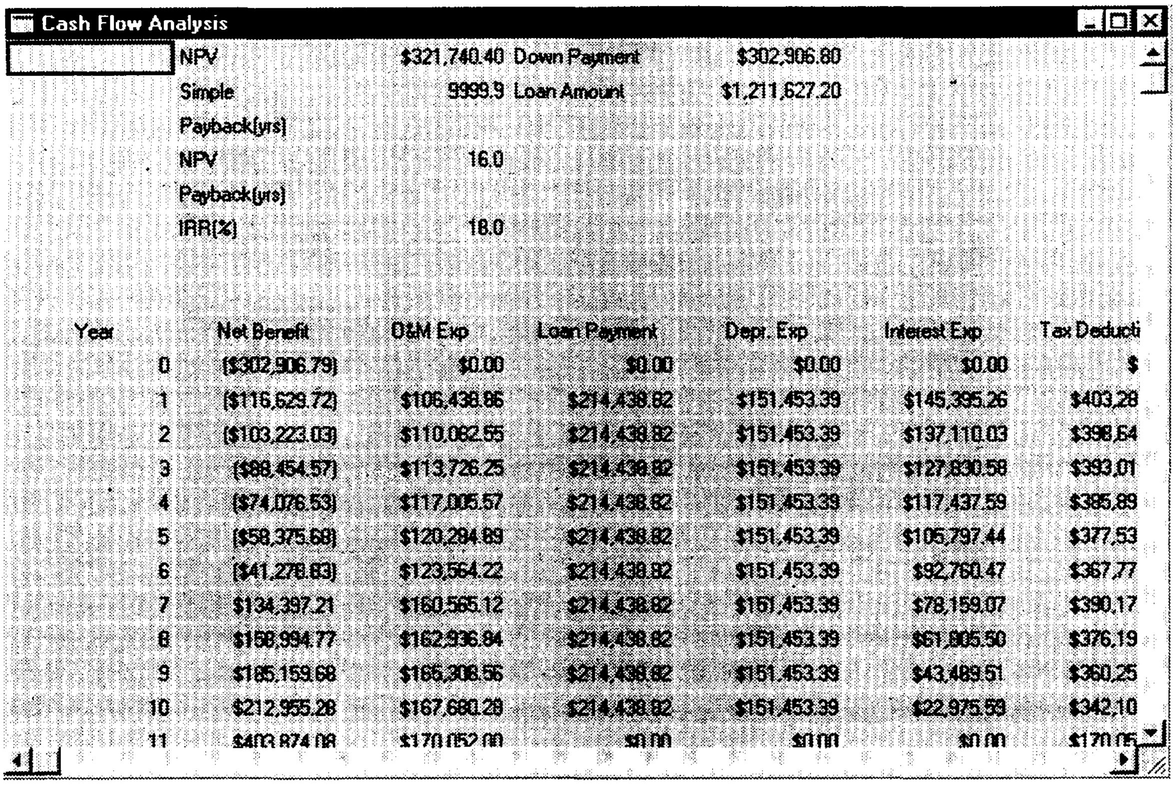
Click on the OK button to exit this screen.

Cashflow Analysis

Figure 62: Cashflow Report icon

The **Cash Flow Analysis** shows the cost breakdown and cash flow associated with the landfill gas recovery project. To view this analysis, click on the cashflow report icon (Figure 62) on the tool bar or select **Cash Flow Analysis** from the **Analysis** menu.

A screen similar to Figure 63 is displayed.



NPV	$321,740.40	Down Payment	$302,906.80
Simple Payback(yrs)	9999.9	Loan Amount	$1,211,627.20
NPV Payback(yrs)	16.0		
IRR(%)	18.0		

Year	Net Benefit	O&M Exp	Loan Payment	Depr. Exp	Interest Exp	Tax Deducti
0	($302,906.79)	$0.00	$0.00	$0.00	$0.00	$
1	($116,629.72)	$106,438.86	$214,438.82	$151,453.39	$145,395.26	$403,28
2	($103,223.03)	$110,082.55	$214,438.82	$151,453.39	$137,110.03	$398,64
3	($88,454.57)	$113,726.25	$214,438.82	$151,453.39	$127,830.58	$393,01
4	($74,076.53)	$117,005.57	$214,438.82	$151,453.39	$117,437.59	$385,89
5	($58,375.68)	$120,284.89	$214,438.82	$151,453.39	$105,797.44	$377,53
6	($41,278.83)	$123,564.22	$214,438.82	$151,453.39	$92,760.47	$367,77
7	$134,397.21	$160,565.12	$214,438.82	$161,453.39	$78,159.07	$390,17
8	$158,994.77	$162,936.84	$214,438.82	$151,453.39	$61,805.50	$376,19
9	$185,159.68	$165,308.56	$214,438.82	$151,453.39	$43,489.51	$360,25
10	$212,955.28	$167,680.28	$214,438.82	$151,453.39	$22,975.59	$342,10
11	$403,874.08	$170,052.00	$0.00	$0.00	$0.00	$170,05

Figure 63: Cashflow Analysis Table

This screen shows a year by year financial expense and benefit breakdown. The top part of the screen shows a simple economic summary including the NPV, IRR, and yearly loan payment. The most important value shown is the NPV as it is a simple indicator of profitability. Any project with an NPV greater than or equal to zero should be profitable.

The bottom part of the screen shows the following expenses and benefits for each year over the lifetime of the project:

- Net benefit
- O&M expense
- Loan payment
- Depreciation expense
- Interest expense
- Tax deduction
- Revenue
- Tax credit
- Taxes paid

This screen and these values may not be edited.

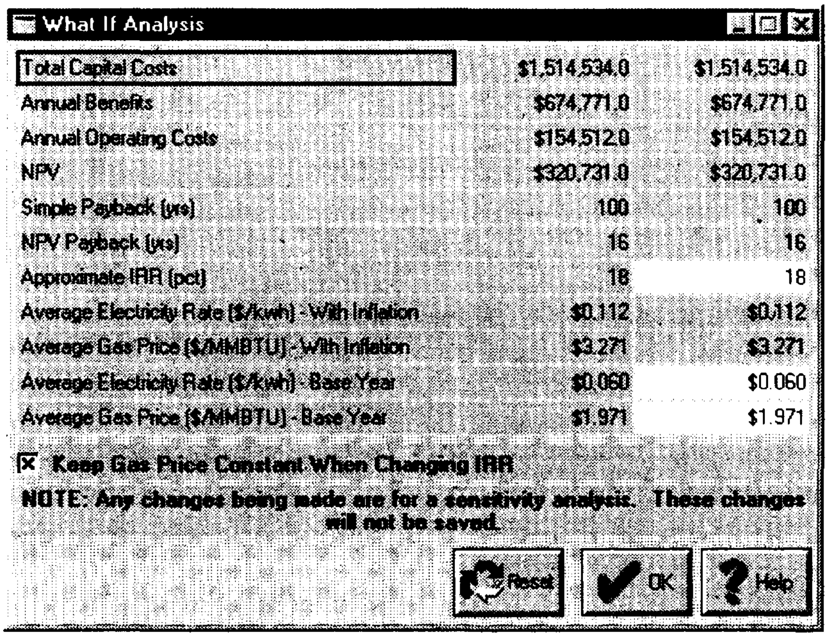
Exit this screen by double clicking in the upper left hand corner.

What If Analysis

The **What If Analysis** allows you to explore the cost and benefit results of changes to the electricity and gas prices. This screen may be viewed by clicking on the what if icon (Figure 64) or selecting **What If** from the **Analysis** menu.

Figure 64: What If icon

The **What If Analysis** dialog pops up as shown in Figure 65 below:



Total Capital Costs	$1,514,534.0	$1,514,534.0
Annual Benefits	$674,771.0	$674,771.0
Annual Operating Costs	$154,512.0	$154,512.0
NPV	$320,731.0	$320,731.0
Simple Payback (yrs)	100	100
NPV Payback (yrs)	16	16
Approximate IRR (pct)	18	18
Average Electricity Rate ($/kwh) - With Inflation	$0.112	$0.112
Average Gas Price ($/MMBTU) - With Inflation	$3.271	$3.271
Average Electricity Rate ($/kwh) - Base Year	$0.060	$0.060
Average Gas Price ($/MMBTU) - Base Year	$1.971	$1.971

☒ Keep Gas Price Constant When Changing IRR

NOTE: Any changes being made are for a sensitivity analysis. These changes will not be saved.

Figure 65: What If Analysis Dialog Box

The following estimates are displayed in this screen:

- Total capital costs
- Annual benefits
- Annual operating costs
- NPV
- Simple payback
- NPV payback
- Approximate IRR
- Average Electricity Rate ($/kWh) with inflation
- Average Gas Rate ($/MMBTU) with inflation
- Average Electricity Rate ($/kWh) base year
- Average Gas Rate ($/MMBTU) base year

There are two columns of estimates in this screen. The first column represents the estimates using the data entered in the Design screens. The second column represents the changed estimates based on any changes made in the cream colored boxes in this screen.

Only the average electricity rate (base year), average gas rate (base year), or IRR may be changed by clicking in the corresponding cream colored boxes, deleting the current value, and entering the new estimate.

If you enter a new IRR value you may select to keep the gas price estimate constant when recalculating the costs and benefits. To keep the gas price constant, click in the box labeled "Keep Gas Price Constant When Changing IRR". If the gas price is kept constant, the electricity rate will change to give the rate needed to achieve the desired IRR. If the gas rate is not kept constant, the electricity rate is kept constant and the gas rate will change to achieve this desired IRR.

To reset the IRR, electricity rate, and gas rate to the default values, click on the reset button.

To exit this screen, click on OK.

NOTE: None of the changes made in this screen are saved in E-PLUS .

Summary Report

Figure 66: Summary Report icon

The E-PLUS Summary Report is a comprehensive report showing the potential results of the defined landfill gas recovery project. The summary report may be accessed by clicking on the summary report icon (Figure 66) in the floating toolbar or selecting **Summary Report** from the **Analysis** menu.

The Summary Report is displayed in the E-PLUS word processor. To save this file, select Save as from the E-PLUS word processor's File menu. The file is saved in rich text format, a format compatible with any word processor.

The E-PLUS word processor may be closed by double clicking on the upper left hand corner.

Note: Analyses performed using* E-PLUS *are considered preliminary and are to be used for guidance only. It is imperative that a detailed final feasibility assessment be conducted by qualified landfill gas recovery and utilization professionals prior to preparing a design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Chapter 8. Adding, Deleting, Editing Landfill Partners

The **Partners** menu (Figure 67) allows you to add, delete, and edit landfill partners. This chapter outlines the options contained within this menu.

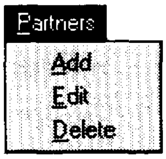


Figure 67: Partners menu

Add Partner

To add a new Partner, select **Add** from the **Partners** menu or click on the add partner icon (Figure 68) on the toolbar. The **Partner Information Sheet** pops up as shown in Figure 69 below.

Figure 68: Add Partner icon

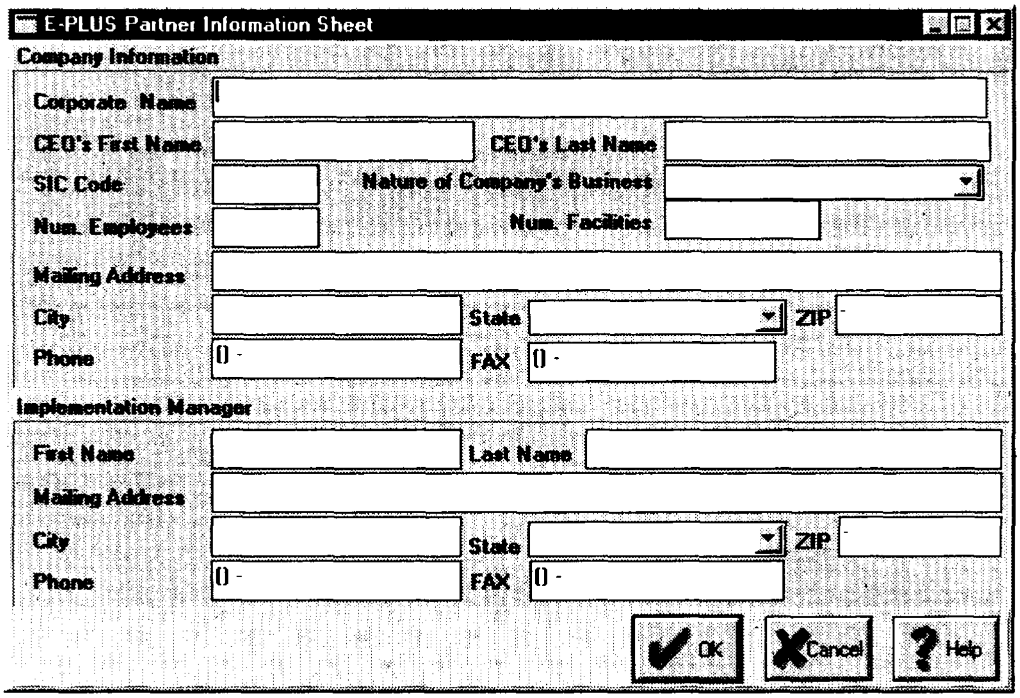


Figure 69: Partner Information Sheet

In this screen, you should enter all of the information requested in the white boxes. You may edit or delete a Partner if any of the information changes in the future (see below).

Click on OK to save and exit this screen.

Edit Partner

To edit an existing Partner Information Sheet, select **Edit** from the **Partners** menu. The first Partner's Information Sheet is displayed. You may navigate through all available Partner Information Sheets by clicking on the down arrow on your keyboard. You may edit any of the information fields. When you are finished editing a Partner Information Sheet, click on OK to exit and save.

Delete Partner

To delete an existing Partner, select **Delete** from the **Partners** menu. The first Partner's Information Sheet is displayed. You may navigate through all available Partner

Information Sheets by clicking on the down arrow on your keyboard. You may delete a Partner Information Sheet by clicking on the OK button.

Chapter 9. Help and Other Features

E-PLUS contains help and other features which may assist you when using the program. These features are described below.

Help

The **Help** menu (Figure 70) provides information about E-PLUS' features and options through E-PLUS' on-line Help system.

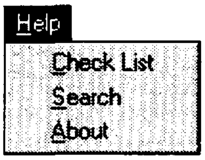
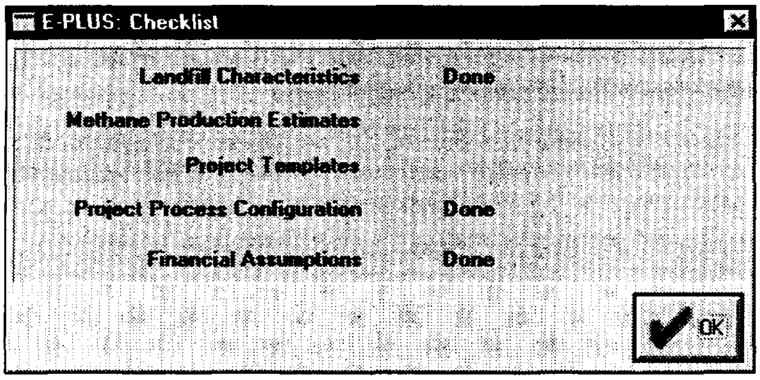


Figure 70: Help menu

Figure 71: Checkmark icon

Checklist

Click on the checkmark icon (Figure 71) or select **Checklist** from the **Help** menu to see a list of the E-PLUS Design screens which should be edited and viewed to ensure an accurate analysis of the potential for landfill gas recovery. The Checklist dialog box looks similar to Figure 72 below.



Landfill Characteristics	Done
Methane Production Estimates	
Project Templates	
Project Process Configuration	Done
Financial Assumptions	Done

Figure 72: Checklist Screen

The critical steps involved in estimating landfill gas production and potential costs and benefits from recovery are listed. Steps which have been completed are identified by the word "Done". Steps without "Done" should be completed before fully analyzing the landfill gas recovery potential.

Click on OK to close this screen.

Search

The **Search** option is available to access the E-PLUS on-line help. The on-line help is outlined in the same manner as this manual and provides basic help for each of the screens in E-PLUS.

About

Select **About** from the **Help** menu to see information about your version of E-PLUS.

Window Options

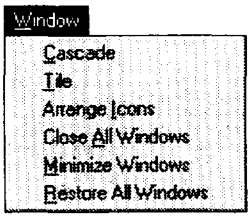


Figure 73: Window menu

The **Window** menu (Figure 73) provides options for you to view the data in the document windows on your screen. The features provided in this menu allow you to open, move, size, and arrange many document windows at one time. The basic controls which allow you to size and arrange the windows include restore, minimize, and maximize. These controls are described below.

When you restore a window, you change it to a previous or medium size which you can then move, size, and close. To restore a maximized document window, click the document Restore button in the upper-left hand corner of a maximized document window or choose Restore from the document Control menu. The document Control menu is the menu containing the commands that will open, close, maximize, minimize, or restore a window. You can display the Control menu by clicking on the small rectangular button in the upper left corner of a window or by pressing Alt+space bar. To restore a minimized document, double-click on the document icon or click on a document icon to open the Control menu and choose Restore. A document window is also restored (unless it is minimized) when you tile or cascade windows.

When you minimize a window the window is reduced to an icon allowing you to keep several documents open at the same time. To minimize a restored document, click the minimize arrow (down arrow) in the upper-right hand corner of the document window or choose minimize from the document Control menu.

When you maximize a document window, the document enlarges to fill up the entire document area. To maximize a restored document, click the maximize arrow (up arrow) in the upper-right corner of the document window or double-click on the title bar. To maximize a minimized document, click on a document icon to open the Control menu and choose Maximize.

The Window menu on the menu bar of E-PLUS contains the following additional controls which allow you to size and arrange the E-PLUS windows:

Cascade

When you have more than one document window open (but not minimized), you can select **Cascade** from the **Window** menu or press Shift+F5 to restore and arrange the open windows. Cascaded windows overlap so that the title bar of each window is displayed. Click on the title bar to view a window's contents.

Tile

When you have more than one document window open (but not minimized), you can select **Tile** from the **Window** menu or press Shift+F4 to restore and arrange the open windows. Tiled windows are arranged on the screen with no overlapping. To work on one of the windows, click on the title bar of the desired window.

Arrange Icons

When you have one or more windows minimized to icons you may wish to arrange the icons so that they are ordered and easy to view. To arrange the icons, select **Arrange Icons** from the **Windows** menu.

Close All

To close all open windows, select **Close All** from the **Window** menu.

Minimize All

To minimize all open windows to icons, select **Minimize All** from the **Window** menu. The minimized icons are displayed on the bottom of the screen.

Restore All

To restore all windows to the maximum size, select **Restore All** from the **Window** menu.

Chapter 10. Frequently Asked Questions

This chapter offers answers to frequently asked questions regarding E-PLUS.

What are the implications of the IRR Error?

An IRR Error may be detected before viewing the **Project Financial Evaluation** or the **What If Analysis**. If you receive this message, E-PLUS has been unable to complete the financial evaluation of your landfill gas recovery project. This could happen for one or more of the following reasons:

1. **No energy sales**. Please make sure that electricity and/or gas is being sold and sold at a non-zero price. For more information, see **Electricity Sales**_or **Gas Sales** (see pages 22 and 27, respectively).
2. **IRR could not be computed**. Under certain conditions the IRR of a cash flow cannot be mathematically computed. Please focus on the NPV of the project rather than the IRR.
3. **You have a negative IRR (displayed as 0).** E-PLUS has calculated your IRR to be negative. Under such conditions, E-PLUS is unable to do a complete financial evaluation. Please focus on the NPV of the project rather than the IRR.

A project should be considered feasible if its NPV is greater than or equal to zero. Under conditions 2 and 3 listed above, a good way to re-evaluate the project is to exclude collection and flaring costs. For most landfills these costs would have to be incurred irrespective of the existence of an energy recovery system. See **Project/Financial Factors** (page 12) for more details.

What is an unresolved energy flow?

Unresolved energy flows occur under two conditions:

1. When a landfill gas stage other than a terminal stage (Flare, Electricity Sales, Gas Sales) is not followed by another landfill gas stage.
2. When a landfill gas stage is receiving more gas than its designed capacity.

Unresolved flows may be marked by a black process stage in the landfill Process Configuration window. All financial calculations will trigger an E-PLUS Messenger window with an error notification. E-PLUS assumes that all gas flows are completely consumed. Therefore, the process configuration for the landfill gas recovery project must be complete (i.e., the project configuration should include energy sales, flaring, or a combination of the previous two).

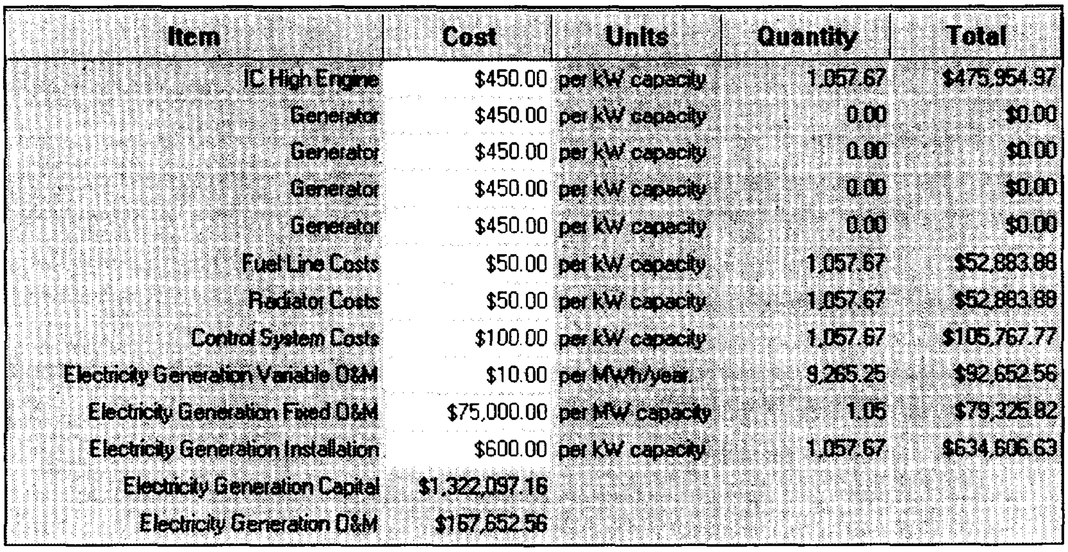
To solve for unresolved energy flows you may attempt one or more of the following:

- If the error occurs due to the absence of a terminal stage, add stages as needed using the **Add Stage** feature in the **Process Configuration** screen (see page 13).
- If the error occurs because a landfill gas stage is receiving more gas than its designed capacity, the following steps may be taken:
  1. Edit the stage(s) with unresolved energy flows to reduce the designed capacity. This may be accomplished using the **Define Stage** option in the **Process Configuration** screen (see page 14).
  2. Edit the Split Gas stage preceding the stage with the unresolved energy flow to reduce the amount of gas assigned to the unresolved stage. If a Split Gas stage does not exist, you will need to insert one before the unresolved stage. Upon insertion you will also need to add a Flare stage (or some other stage) to the Split

Gas stage. For more details, see **Insert Stage** and **Add Stage** on pages 14 and 13, respectively. Following the insertion of the Split Gas stage and the associated stage(s), you should reallocate the gas flows as necessary.

How do I enter Total Costs or Rule of Thumb Costs instead of Detailed Line Item Costs?

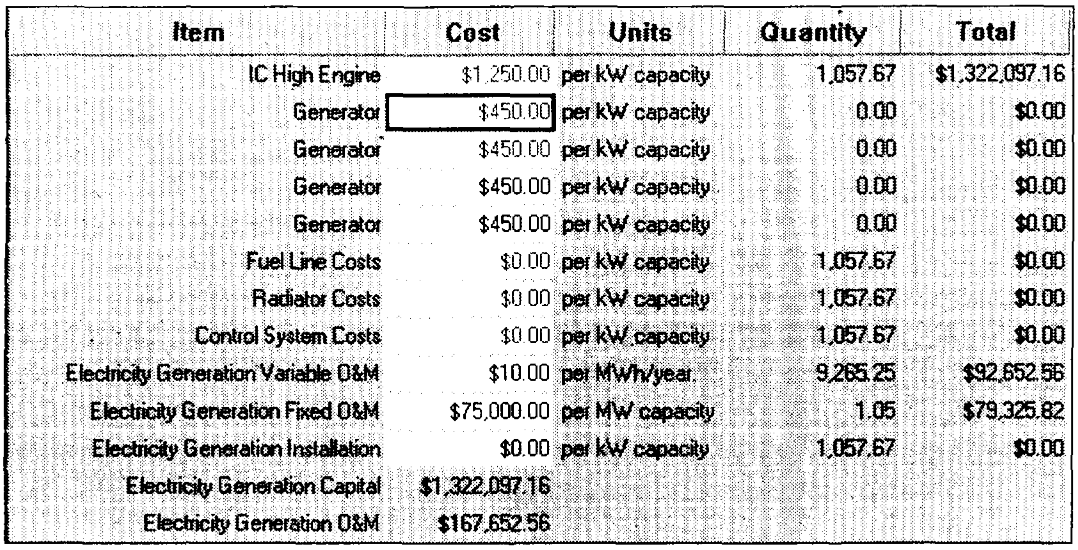
If the detailed component costs for a stage are unknown, but the total cost per unit (Rule of Thumb) is known, the Stage Costs table may be edited to reflect this. For example, if you know that on average the total cost of an engine generator system is $1,250/kW capacity but you do not know how this total breaks into the component costs for the engine, fuel line, radiator, control system, and installation costs, you may alter the table to input only the $1,250 value. The default Stage Costs table for Electricity Generation is shown in Figure 48. In this table, the total cost per kW capacity for Electricity Generation is $450 (IC High Engine) + $50 (fuel line) + $50 (radiator) $100 (control system) + $600 (installation) for a total of $1,250.



Item	Cost	Units	Quantity	Total
IC High Engine	$450.00	per kW capacity	1,057.67	$475,954.97
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Fuel Line Costs	$50.00	per kW capacity	1,057.67	$52,883.88
Radiator Costs	$50.00	per kW capacity	1,057.67	$52,883.88
Control System Costs	$100.00	per kW capacity	1,057.67	$105,767.77
Electricity Generation Variable O&M	$10.00	per MWh/year.	9,265.25	$92,652.56
Electricity Generation Fixed O&M	$75,000.00	per MW capacity	1.05	$79,325.82
Electricity Generation Installation	$600.00	per kW capacity	1,057.67	$634,606.63
Electricity Generation Capital	$1,322,097.16			
Electricity Generation O&M	$167,652.56			

Figure 74: Sample Electricity Generation Costs

To enter the Rule of Thumb total cost of $1,250 you should first zero out all of the costs per kW capacity that are used to calculate the total Electricity Generation costs (in this case, the IC High (pressure) Engine, fuel line, radiator, control system, and installation costs). Then, in any one of the cream colored cells with a per kW capacity unit, you should enter 1,250. An altered cost table may look like Figure 49 below:



Item	Cost	Units	Quantity	Total
IC High Engine	$1,250.00	per kW capacity	1,057.67	$1,322,097.16
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Generator	$450.00	per kW capacity	0.00	$0.00
Fuel Line Costs	$0.00	per kW capacity	1,057.67	$0.00
Radiator Costs	$0.00	per kW capacity	1,057.67	$0.00
Control System Costs	$0.00	per kW capacity	1,057.67	$0.00
Electricity Generation Variable O&M	$10.00	per MWh/year	9,265.25	$92,652.56
Electricity Generation Fixed O&M	$75,000.00	per MW capacity	1.05	$79,325.82
Electricity Generation Installation	$0.00	per kW capacity	1,057.67	$0.00
Electricity Generation Capital	$1,322,097.16			
Electricity Generation O&M	$167,652.56			

Figure 75: Altered Electricity Generation Costs Table

Note that in this example the total cost of $1,250/kW capacity was entered in the IC High Engine row. Note that all of the cells which have been changed from the default values are shown with red text. All of the costs may be reset to the default by clicking on the reset button (Figure 50) in the Stage Costs floating toolbar.

Figure 76: Reset button

Appendix A: Default Landfill Gas Component Costs

Each of the landfill gas recovery stages with the exception of Split Gas, Gas Sales, and Electricity Sales has associated costs which are used in the financial evaluation of the landfill gas recovery project. This appendix lists the default cost values for each of these components.

Collection Costs

CAPITAL COSTS		
Component	*Default Unit Cost*	*User can edit*
Wells	\$80 / foot of depth	Y
Wellheads	\$750 / unit	Y
Piping (main & branch)	\$35 / linear foot	Y
Blowers	\$20 / ft^3 /min	Y
Condensate knockout	\$8,000 / unit	Y
Monitoring system	\$1,000 / unit	Y
Collection system installation and other costs**	\$0	Y
O&M COSTS		
Component	*Default Unit Cost*	*User can edit*
Collection system variable O&M	\$1,000 / well /yr	Y
Collection system fixed O&M	Not yet determined	Y
**Default values listed above include installation costs. You may adjust any of these costs as needed.		

Compression Costs

CAPITAL COSTS		
Component	*Default Unit Cost*	*User can edit*
Compressor	\$1,350 / horsepower	Y
Compressor system installation and other costs**	\$0	Y
O&M COSTS		
Component	*Default Unit Cost*	*User can edit*
Compression system variable O&M	\$12,000 / unit / yr	Y
Compression system fixed O&M	Not yet determined	Y
**Default values listed above include installation costs. You may adjust any of these costs as needed.		

Electricity Generation Costs

CAPITAL COSTS		
Component	*Default Unit Cost*	*User can edit*
IC engine-generator (low & high pressure)	$450 / kW capacity	Y
Turbine-generator	$450 / kW capacity	Y
Fuel line costs	$50 / kW capacity	Y
Radiator costs	$50 / kW capacity	Y
Control system costs	$150 / kW capacity	Y
Electricity generation installation and other costs**	$400 / kW capacity	Y
O&M COSTS		
Component	*Default Unit Cost*	*User can edit*
Electricity generation variable O&M	$10 / MWh - year	Y
Electricity Generation Fixed O&M	$75,000 / MW capacity /year	Y
** Other costs include project soft costs such as development, design, financing, building, and site improvements.		

Flare Costs

CAPITAL COSTS		
Component	*Default Unit Cost*	*User can edit*
Flare	$75,000 / unit	Y
Flare installation and other costs**	$0	Y
O&M COSTS		
Component	*Default Unit Cost*	*User can edit*
Flare system variable O&M	Not yet determined	Y
Flare system fixed O&M	$2,000 / year	Y
** Default values listed above include installation costs. You may adjust any of these costs as needed.		

Gas Enrichment Costs

CAPITAL COSTS		
Component	*Default Unit Cost*	*User can edit*
Gas Enrichment Component	Not yet determined	Y
Gas Enrichment installation and other costs**	Not yet determined	Y
O&M COSTS		
Component	*Default Unit Cost*	*User can edit*
Gas Enrichment system variable O&M	Not yet determined	Y
Gas Enrichment system fixed O&M	Not yet determined	Y
** Other Costs include any other capital expenditures.		

Gas Conditioning/Treatment Costs

CAPITAL COSTS

Component	*Default Unit Cost*	*User can edit*
Scrubber	\$15 / ft^3 / min	Y
Dessicator	\$10 / ft^3 / min	Y
Refrigeration	\$60 / ft^3 / min	Y
Filters	\$3,200 / unit	Y
Gas treatment installation and other costs**	\$15 / ft^3 / min	Y

O&M COSTS

Component	*Default Unit Cost*	*User can edit*
Gas treatment variable O&M	\$2.50 / million ft^3 / yr	Y
Gas treatment fixed O&M	\$10,000 / yr	Y

** Other Costs include any other capital expenditures.

Interconnect Costs

CAPITAL COSTS

Component	*Default Unit Cost*	*User can edit*
Substation cost	\$60 / kW	Y
Engine wiring cost	\$45 / foot	Y
Intertie wiring cost	\$60 / foot	Y
Substation telemetry cost	\$10,000 / unit	Y
Protective relays cost	\$10 / kW	Y
System disconnect cost	\$20 / kW	Y
Interconnect installation and other costs**	\$20 / kW	Y

O&M COSTS

Component	*Default Unit Cost*	*User can edit*
Inter connect variable O&M	\$0.20 / MWh / yr	Y
Inter connect fixed O&M	\$2,000 / yr	Y

** Other Costs include any other capital expenditures.

Pipeline Costs

CAPITAL COSTS

Component	*Default Unit Cost*	*User can edit*
Pipeline Pipe Costs	\$35 / foot	Y
Pipeline installation and other costs**	Not yet determined	Y

O&M COSTS

Component	*Default Unit Cost*	*User can edit*
Pipeline variable O&M	Not yet determined	Y
Pipeline fixed O&M	Not yet determined	Y

**Other Costs include other capital expenditures and user costs (new boiler, modifications, controls, etc.).

Appendix B: Glossary

Acid Rain Bonus: Under Title IV of the Clean Air Act (the EPA Acid Rain Program), the Conservation and Renewable Energy Reserve (CRER) allocates a pool of SO2 allowances for renewable energy technologies. These "Acid Rain Bonus Allowances" are available to utilities for landfill energy recovery projects, at the rate of one for every 500 MWh/yr generated (i.e., one for every 0.5 GWh/yr generated). The bonus allowances can be earned each year between 1994 and 2000 by applying to the CRER.

Annual Acceptance Rate: The amount of waste received and landfilled for a reported year, including all waste types, in short tons (tons).

BTU: British Thermal Unit (BTU) is a measure of the heat content. One BTU is the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit.

Collection Efficiency: The efficiency of the gas collection system, expressed in percent. The efficiency will be less than 100 percent due to a number of potential factors, including: poor well placement and air infiltration through the landfill cover, the wellhead, or lateral pipe connections. Collection efficiency can range from 50 percent or lower at existing landfills to 95 percent at newer, well-designed landfills.

Depreciation Method: The method used to calculate the decreased value of the landfill gas recovery project. The E-PLUS depreciation methods include: DDB, Straight-Line, and SYD.

DDB Depreciation: Double declining balance (DDB) depreciation is an accelerated depreciation method in which first year depreciation is double the amount of straight-line depreciation.

Downpayment: The initial amount paid at the time of purchase or construction expressed as a percent of the total initial cost.

Discount rate: The interest rate used to convert future payments into present values.

EG: Emissions Guidelines.

First Order Decay: A method of estimating methane emissions from landfills based on the fact that methane is emitted over a long period of time rather than instantaneously. The first order decay equation is: $Q = Lo\ R\ (e^{-kc} - e^{-kt})$ where Q = methane generated in current year (m^3/yr); Lo = methane generation potential (m^3/Mg of refuse); R = average annual waste acceptance rate during active life (Mg/yr); k = methane generation constant (yr^{-1}); c = time since landfill closure (yr); and t = time since landfill opened (yr).

Gas Enrichment Capacity: The flow rate in mcf/day of the landfill gas outflow from the gas enrichment stage.

Greenhouse gas: An atmospheric gas which is transparent to incoming solar radiation but absorbs the infrared radiation emitted by the Earth's surface. The principal anthropogenic greenhouse gases are carbon dioxide, methane, nitrous oxide, and CFCs.

Inflation Rate: The annual rate of increase in costs or sales prices in percent.

Internal Rate of Return (IRR): The discount rate which makes the NPV of an income stream equal to zero.

Kilowatt (kW): One kilowatt (kW) is equal to 1,000 watts or the absolute meter kilogram per second unit of power equal to the work done at the rate of one absolute joule per second or to the rate of work represented by a current of one ampere under a pressure of one volt and taken as the standard in the United States.

Kilowatt Hour (kWh): A unit of work or energy equal to that expended by one kilowatt in one hour or to 3.6 million joules.

Loan Rate: The percent of the total loan amount paid per year.

Manual Entry: The Manual option in the Methane Production screen allows you to edit both the total waste and the methane produced for each year during the methane project lifetime. This option should only be selected if you know the actual amount of methane being produced.

Marginal Tax Rate: The percent of the landfill gas recovery project net income to be paid in taxes.

Methane: A colorless, odorless, flammable gaseous hydrocarbon that is a product of the decomposition of organic matter. Methane is a major greenhouse gas.

Methane Gain/Loss Efficiency: The gain or loss in total mass of methane during the gas enrichment stage. 100% gain/loss means that the total mass of methane has remained the same throughout the stage. 80% means that the total mass of methane has decreased by 20%.

MSW: Municipal Solid Waste.

Net Present Value (NPV): The present value of all cash inflows and outflows of a project at a given discount rate over the life of the project.

NMOC: Non Methane Organic Compounds. The amount of NMOC emissions determine whether a landfill triggers the Tier 1 NSPS/EG calculations. If the landfill emits more than 50 megagrams of NMOC per year, the Tier 1 NSPS/EG calculations are triggered.

NPV Payback: The number of years it takes to pay back the capital cost of a project calculated with discounted future revenues and costs. Profitable projects will have an NPV Payback value less than or equal to the lifetime of the project.

NSPS: New Source Performance Standards.

Payback Years: The number of years it takes to pay back the capital cost of a project.

Project Lifetime: The period of time during which the project is installed and operated.

Section 29 Tax Credit: The Section 29 Biomass Gas Credit is a credit of $3.00 per 5.8 million BTUs. This tax credit is applicable to the production and sale of synthetic fuels from coal or gas from biomass (i.e., thermal or combustion type gasifiers, landfill gas facilities, and anaerobic digesters) to an unrelated party.

Simple Payback: The number of years it takes to pay back the capital cost of a project calculated without discounting future revenues or costs.

Straight-Line Depreciation: Depreciation per year equals the total facility cost divided by the years of depreciation (usually the facility lifetime).

SYD Depreciation: Sum of Years Digits (SYD) is a common accelerated depreciation method where the sum of the digits is the total of the numbers representing the years of depreciation (usually the facility lifetime).

WIP: Waste In Place. The total amount of waste that has been landfilled since the landfill opened.

WIP-30: An algorithm for estimating the amount of methane produced based on the amount of waste in place over the past 30 years.

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ATTACHMENT C
E-PLUS INSTALLATION DISK

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APPENDIX A

SUMMARY OF RELEVANT INFORMATION COLLECTED FROM NOYLES

Destruction Technology

This Appendix first introduces the subject of thermal destruction technology, and then describes a number associated processes:

- Introduction
- Central Waste Incinerators
- Waste to Energy Systems
- Air Pollution
- Mass Burn Combustion
- Pyrolysis
- Refuse Derived Fuels

Introduction to Thermal Destruction Technology (Noyes, p. 428-430)

Thermal destruction technologies use processes which "destroy organic materials by the application of heat." (Noyes, p. 428) "All types of wastes can be incinerated including solids, sludges, liquids and gases. There are many types of incineration equipment utilized for municipal waste, medical waste, and hazardous waste." (Noyes, p. 428) "An incinerator is a device in which wastes are burned at a high temperature (typically greater than 1800F) with a proper amount of air, and with adequate time to ensure destruction of the wastes. A state-of-the-art incinerator is equipped with operating controls and monitoring systems which assure good combustion to destroy the waste and an effective method of cleaning the air and the water which are by-products of the process.

How to decide on Incineration

"To determine whether incineration is the best technology for a specific waste consideration must be given to the following issues:

1. Limitations which arise from the quantity or nature of the waste;
2. The environmental impact of incineration including stack and fugitive emissions;
3. The requirements for disposal of residues, i.e., ash and air pollution control (APC) residues;
4. Permitting issues." (Noyes, p. 430)

The functions of incineration

"Incineration is an oxidative process which is used for:

1. Detoxification and sterilization
2. Volume reduction
3. Energy recovery
4. By-product chemical recovery" (Noyes p. 430)

The steps in the incineration process

"The incineration process may be viewed as consisting of four parts:

1. preparation of the feed materials for placement in the incinerator (pretreatment)
2. incineration or combustion of the material in a combustion chamber
3. cleaning of the resultant air stream by air pollution control devices (APCDs) which are suitable for the application at hand
4. disposal of the residues from the application of the process (including ash, and air pollution control system residues).

Considerations concerning the incinerator

"In considering whether an incinerator can combust a specific hazardous waste stream, one must take into account:

1. the waste feed mechanism of the incinerator
2. the size and configuration of the furnace itself
3. the nature of the furnace's refractory material
4. the design of its ash handling mechanism."

The Three Ts of Incineration

Three important factors must be addressed for incineration: (the Three Ts)

Time	"the time during which the combustible material is subject to that temperature"
Temperature	"there are temperatures which the furnace is operated"
Turbulence	"the turbulence required to ensure that all combustible material is exposed to oxygen to ensure complete combustion" (Noyes, p. 429)

Advantages

Incineration processes are often considered an attractive management alternative for hazardous wastes because they possess many advantages over other technologies, including the following:

1. Thermal destruction by incineration provides the ultimate disposal of hazardous wastes, minimizing future liability from land disposal.
2. Toxic components of hazardous wastes can be converted to harmless or less harmful compounds.
3. The volume of waste material may be reduced significantly by incineration; and
4. Resource recovery, i.e., heat value recovery, is possible through combustion." (Noyes, p.429)

Negative factors which affect incinerators

There are some site-specific factors that can negatively affect the efficiency of incinerators. These include:

1. Foreign objects, e.g., rocks, drums, auto bodies, in what was expected to be soil, or liquids, of uniform consistency able to be fed to the incinerator without interruption or special treatment.
2. Styrene tars in a lagoon, seemingly pumpable directly to the incinerator while covered with liquid, but which turn into a stringy stretch non-pumpable "mess" when exposed to air.
3. Metals, e.g., arsenic and lead, in contaminated media that is being incinerated to destroy organic contaminants, with the risk that these metals will volatilize during the incineration process and escape through the incinerator stack to the atmosphere. Even if they do not volatize, the will remain in the incinerator ash, requiring further treatment." (Noyes, p. 429)

Central Waste Incinerators (Noyes, p.439-440)

"Central waste incinerators are those which accept waste from several external sources for destruction in a central facility. They are usually large [in excess of 50t/d (55 t/d)], continuously operated installations equipped with heat recovery equipment. Waste is burned in these incinerators without pre-processing." The distinguishing feature of central waste incinerators is the grate system which transports refuse through the furnace and promotes "combustion by providing adequate agitation without contributing to excessive particulate emissions." (Noyes, p. 439)

"As the waste moves progressively through the furnace, it is dried, burned, and combusted to ash."

Central waste incinerators are a commercially demonstrated technology. The incinerators are usually designed and build to meet specific customer's needs because of their large size and unique features. "Operating temperatures in mass-burning central waste incinerators are normally maintained in the order of 1000 C (1832 F) and refuse residence time on the grate ranges from 20 to 45 minutes. Refractory wall systems normally require 100 to 150% excess air to maintain operating temperatures, whereas waterwall systems require only about 80% excess air. This offers the advantages of a smaller furnace volume and reduced Nox formation with the latter system, due to lower airflow. Waterwalls extract heat from the burning waste." (Noyes, p. 440) Certain large components of the waste stream like stoves and refrigerators, and sometimes tires, must be removed before incinerated.

Air Pollution Control (Noyes, p. 443-444)

"Air pollutants from the incineration of hazardous wastes may arise both as a result of incomplete combustion and from the products of combustion of constituents present in the wastes and combustion air.

The products of incomplete combustion include:

- carbon monoxide
- carbon
- hydrocarbons
- aldehydes
- amines
- organic acids
- polycyclic organic matter
- any other waste constituents or their partially degraded products that escape thermal destruction in the incinerator.

In well designed and operated incinerators, these incomplete combustion products are emitted in insignificant amounts." (Noyes, p. 443)

"Several factors affect the installation of air pollution control equipment on hazardous waste incinerators, including:

1. Federal, state, and local regulations regarding emissions
2. Properties of the waste being incinerated
3. Type of incinerator used
4. Customer preference
5. Equipment cost

Generally, both gaseous and particulate emissions are controlled. Air pollution control equipment is located downstream of the combustion chamber and energy recovery equipment and consists of the ***following components:***

1. Quench chamber

2. Particulate collection device
   (a) Venturi scrubber
   (b) Bag house
   (c) Electrostatic precipitator
   (d) Cyclone
   (e) Ionizing wet scrubber

3. Gas absorbing device
   (a) Packed tower scrubber
   (b) Plate or tray scrubber
   (c) Spray tower scrubber
   (d) Ionizing wet scrubber

4. Mist eliminator

5. Flue gas handling equipment"

(Noyes, p. 443- 444)

Mass Burn Combustion (Noyes, p. 460-461)

"Refuse is burned in the same form as it is delivered with the exception that some large metal items are removed from the waste stream. The technology has been used since the 1970s and has experience the greatest technical and financial operating success. Typical unit size is in the range of 400 - 1,000 tons per day (TPD) with some facilities as large as 3,000 TPD.

Typically, waste is loaded into a feed chute using an overhead crane. Rams or moving gate sections are then used to move the waste through the combustor and promote complete burning by agitating the fuel bed.
Different gate sections provide different functions:

First:	drives off moisture, raises heating value
Second:	primary combustion zone
Third:	"clinker burn-out. Underfire air is provided to support combustion in the bed, and overfire air is added to mix and combust volatile gases evolved from the bed."

There are two variations in the traditional mass burn unit:

Refractory wall units: "combustion zone temperatures are somewhat hotter, and gases exiting the combustion zone are cooled below 1800 F with excess air levels of 100 to 200%. Heat recovery is generally not practiced, so additional cooling prior to entering the control device is usually accomplished with water sprays." (Noyes, p. 460)

Waterwall design: "combustion gas temperatures are moderated by water tubes located in the furnace walls, and additional gas cooling is accomplished in a boiler located at the exit of the furnace. Heat recovery from the combustion process is used in the production of steam and/or electric power. Because of heat recovery, excess air levels are reduced, typically averaging about 80%." (Noyes, p. 461)

"Key **advantages** of mass burn facilities relate to their well established and proven technology, demonstrated long-term reliability, good thermal efficiency and minimal refuse processing requirements.

Disadvantages relate to the long lead times required to design and build plants and their significant capital construction cost." (Noyes, p, 461)

Pyrolysis (Noyes, p. 466-469)

"Pyrolysis is formally defined as chemical decomposition induced in organic materials by heat in the absence of oxygen. In practice, it is not possible to achieve a completely oxygen-free atmosphere actual pyrolytic systems are operated with less than stoichiometric quantities of oxygen." (Noyes, p. 466)

"Pyrolysis is a thermal process that transforms hazardous organic materials into gaseous components and a solid residue (coke) containing fixed carbon and ash. Upon cooling, the gaseous components condense, leaving an oil/tar residue. Pyrolysis typically occurs at operating temperatures above 800F. Pyrolysis is applicable to a wide range of organic wastes and is generally not used in treating wastes consisting primarily of inorganics and metals. Pyrolysis of scrapped tires will be an important process. Pyrolysis systems may be applicable to a number of organic materials that "crack" or undergo a chemical decomposition in the presence of heat. Pyrolysis has shown promise in treating organic contaminants in soils and oily sludges. Chemical contaminants for which treatment data exist include polychlorinated biphenyls (PCBs), dioxins, polycyclic aromatic hydrocarbons, and many other organics." (Noyes, p. 467)

There are a number of practical limitations that are associated with the process of pyrolysis. As it works best for a few limited types of waste. It is not a practical technology for the majority of wastes.

Refuse Derived Fuel (RDF) –Fired Combustion (Noyes, p. 469-471)

"Municipal waste that has been pre-processed, regardless of the degree, is termed refuse derived fuel or RDF. The degree of pre-processing can vary from bulky-item removal and shredding to removal of materials, glass and other inorganic materials. Additionally, the combustible fraction may be powdered or compressed into pellets or briquettes. finally, the processed waste may be burned alone or in combination with coal.

The waste is injected into the furnace through an air-driven distributor. Partial burning takes place while the waste is in suspension, with larger material falling onto the grate and burning out on the fuel bed. Both underfire and overfire air are provided typically at lower excess rates than for mass burn systems because of better waste uniformity. Heat release rates are comparable to mass burn combustors, but temperatures are often high because of smaller furnace volume and other factors."

"The basic guidelines for minimizing emissions of trace organics that apply to mass burn systems also apply to RDF systems. These guidelines require that:

1. Stable stoichiometries be maintained through proper distribution of fuel and combustion air;
2. Good mixing be achieved at a sufficiently high temperature to adequately destroy trace organic species;
3. The design and operational performance of the system be verified through monitoring or performance tests." (Noyes, p. 469)

"Good combustion guidelines for minimizing trace organic emissions from RDF-fired MWC's are as follows:

Design:

1. Temperature at fully mixed height
2. Underfire air control
3. Overfire air capacity
4. Overfire air injector design
5. Furnace exit gas temperature

Operation/Control:

1. Excess air
2. Turndown restrictions
3. Start-up procedures
4. Use of auxiliary fuel

Verification:

1. Oxygen in flue gas
2. CO in flue gas
3. Furnace temperature at fully mixed height
4. Temperature at APCD inlet
5. Adequate air distribution" (Noyes p.470)

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Noyes, Robert, ed. Unit Operations in Environmental Engineering. Park Ridge: Noyes Publications, 1994.

APPENDIX B

SUMMARY OF RELEVANT INFORMATION COLLECTED FROM DOE DOCUMENT

INTEGRATED WASTE MANAGEMENT

PUTTING THE PIECES TOGETHER

DRAFT FINAL

National Renewable Energy Laboratory

U.S. Department of Energy

February 1992

DEVELOPING COST ESTIMATES FOR INTEGRATED MSW MANAGEMENT

This chapter presents a methodology that local governments can use to estimate the cost of an efficient integrated waste management system. A range of cost estimates is presented for each component of an integrated MSW management system, and the assumptions relating to each estimate are explained and presented in a manner that allows local officials to estimate the specific costs applicable to their communities. The chapter is organized according to the following sections:

[Insert cost piece of puzzle.]

(1) General approach
(2) Mixed waste collection
(3) Transfer and transport
(4) Curbside collection of recyclables
(5) Materials recovery facilities (MRFs)
(6) Compost facilities
(7) Waste-to-energy (WTE) facilities
(8) Landfill disposal
(9) Combining cost components for integrated management
(10) Conclusions

GENERAL APPROACH

This section explains the analytical assumptions and general methodology that were used to derive the integrated MSW management cost estimates presented in this chapter. These cost estimates are based on a broad search of available literature (through 1991) on the capital and operating costs of MSW management. While the actual "costs per ton" reported by specific communities generally fall within the range of cost estimates presented in this chapter, local costs can vary over a much wider range. In the analysis presented below, the cost per ton for each method of MSW management is derived from specific cost components (e.g., the cost of a collection truck) in order to help local governments better understand the critical cost factors that explain the wide variations in reported average costs.

Modern Facilities

All of the costs described in this chapter reflect the cost of modern waste management facilities, including the expense of satisfying stringent environmental regulations. The cost of landfill disposal, for example, is stated in 1990 dollars and is based on the cost of new landfills satisfying the latest federal environmental standards. Existing landfill costs or tipping fees are often significantly lower than the costs of a new landfill. The remaining operating life of these low-cost landfills, however, is often less than five years, and the lead-time for new landfills and WTE facilities can be close to five years. To plan, local governments should therefore compare new landfill costs, rather than current costs or tipping fees, to the costs of other MSW management options.

Economically-Sized Facilities

The cost estimates for each component of MSW management reflect the cost of economically-sized facilities. Collection and transport vehicles, transfer stations, and MRFs can be economic on a relatively small scale, allowing many communities to manage these activities efficiently while maintaining local control. WTE facilities, modern landfills, and some composting facilities are most efficient when operated on a much larger scale. Therefore, the cost estimates presented here for these management options will generally apply only to regional facilities receiving waste from several communities.

Steady-State Costs

The cost estimates in this chapter represent steady-state or long-term costs. Thus, they do not include program development costs (e.g., community outreach programs to promote recycling). Furthermore, they do not include any higher costs that may arise when new waste management practices are first introduced, due to underutilization of invested capital. For example, WTE cost estimates assume that the facility operates at 85 percent of its design capacity. If a facility is substantially underutilized during its first year of operation, the costs per ton will be higher during that year. Likewise, the cost of curbside collection of recyclables is based on a steady-state scenario in which local governments operate an economically efficient ratio of mixed waste collection vehicles and recycling trucks.

Total Versus Avoided Cost

The cost estimation methodology does not deduct the landfill disposal costs avoided by diverting waste to other management options. Deducting "avoided costs" can be misleading because these "savings" may be misinterpreted as indicating that certain waste management options will be profitable, when this is not true. To avoid the problem, this chapter presents total costs for each facet MSW management method. Section 9 presents a cost comparison framework which can be used to determine avoided costs.

Inflation and Discounted Current Costs

The cost calculations do not incorporate any explicit assumptions with respect to inflation. Instead, a range of nominal interest rates are used to determine the capital and interest costs per ton for each management option. Prevailing interest rates reflect *implicit* assumptions about inflation because investors demand higher interest rates when they anticipate higher inflation. A further discussion of inflation is provided in Section 9 of this chapter.

All of the cost estimates in this chapter are stated in 1990 dollars. Standard financial formulas are used to discount future costs (i.e., landfill closure and post-closure) to current cost equivalents and amortize (i.e., allocate) capital and interest costs over the useful life of an investment. Accounting costs recorded by local governments may differ due to variations in amortization schedules.

Costs Versus Prices

This analysis describes the cost components inherent to each of MSW management method in order to illustrate the economic factors that must be considered in MSW management planning. These generic cost estimates may differ from the prices paid by communities that contract with waste management vendors, due to vendor profit and tax considerations excluded from this analysis.

Local governments that contract with commercial vendors can use this cost analysis to plan for the proper mix of services that must be purchased from vendors. Understanding generic cost components may also be useful in working with vendors to control costs. For example, vendor pricing for collection and MRF processing of recyclables may vary significantly depending on whether the vendor or the community bears the risk of fluctuations in the value of recycled materials. An understanding of the determinants of market values and recycling costs is needed to compare and evaluate the prices and contract terms offered by different vendors.

Taxes

This cost analysis does not incorporate any tax considerations, either for vendor income taxes or for waste-end taxes. Waste-end taxes may be a significant factor in the tipping fees paid by local communities for waste management at landfills and WTE facilities.

COST COMPONENTS

The general costing methodology used throughout this chapter consist of 5 steps:

(1) Define capital investment in terms of capital per ton per year (tpy);
(2) Convert capital per tpy to capital and interest (C&I) costs per ton;
(3) Estimate operation and maintenance (O&M) costs per ton;
(4) Estimate residue/ash disposal costs per ton collected; and
(5) Estimate facility revenues per ton collected.

This methodology is used to derive a range of cost estimates for each component of integrated MSW management. Section 9 presents a framework for combining the cost components that are applicable to different MSW management alternatives.

Capital per Ton per Year (tpy)

Capital requirements for MSW management include any investments in facilities or equipment that must be financed and amortized over the operating life of the investment. Most capital costs in this analysis are stated in terms of capital per ton per year (capital/tpy). For example, a compactor truck that costs $99,000 and collects 2600 tpy of residential waste entails a capital requirement of $38 per tpy ($99,000 divided by 2600 equals $38).

Defining capital requirements in terms of capital/tpy substantially reduces the large number of investment scenarios that a costing analysis may otherwise consider. In the case of collection vehicles, for example, different communities report substantial variations in the payload and purchase price of compactor trucks, the number of payloads collected per day per truck, the number of collection days per year, and the number of back-up trucks required per operating truck. Each community, however, can calculate its own capital/tpy requirements for collection vehicles, as follows:

- Estimate annual tonnage collected by a collection fleet;
- Determine the capital cost of that fleet; and
- Divide the capital investment by the annual tonnage.

Individual communities can use this method to calculate their own capital/tpy estimates for different components of MSW management, under different purchasing option and operating scenarios (e.g., large versus small payload vehicles, and one, two, or three person collection crews). Each community can then estimate its capital and interest (C&I) costs per ton for each scenario, as described below.

One capital investment that is not presented in terms of capital/tpy is the investment in collection vehicles for curbside recycling. To understand the critical cost factors in curbside recycling, it is more useful to begin with capital per cubic yard per year (capital/cypy), because capital/tpy will vary over an extremely wide range depending on the mix of materials collected. For example, it would take 10 collection trucks full of aluminum cans to equal the tonnage of one collection truck full of glass bottles. Therefore, capital and operating costs for curbside recycling are initially discussed in terms of costs per cubic yard and later converted into costs per ton for different types of recycled material.

Capital and Interest (C&I)

A range of capital/tpy estimates is presented for each component of MSW management. These estimates are converted to capital and interest (C&I) costs per ton, under finance rate (i.e., interest rate) assumptions of 6, 8 and 10 percent. This format allows local governments to interpolate their own C&I costs per ton, based on available finance rates and the capital/tpy requirements of their particular investments.

Operation and Maintenance (O&M)

Operation and maintenance (O&M) costs are the on-going annual costs of MSW management, excluding debt service for capital and interest costs. Local governments can calculate O&M costs per ton by estimating annual O&M costs and dividing by associated annual tonnage. This analysis presents a likely range of O&M costs per ton for each component of MSW management.

Ash/Residue Disposal

The O&M costs per ton presented for WTE and MRFs exclude the cost of combustion ash and MRF residue disposal. These costs are listed separately and stated in terms of costs per ton collected, to be comparable to other cost per ton estimates. For example, if MRF residue disposal costs are $50 per ton, and the residue rate is 10 percent, then disposal costs are $5 per ton of collected recyclables.

Facility Revenues per Ton Collected

Revenues generated by MSW management options (i.e., WTE facilities and MRFs) are stated in terms of facility revenues per ton collected. MRF revenues are calculated by deducting delivery costs from the price per ton paid by end-users. For example, if an end-user pays $15 per delivered ton, but a MRF pays $10 per ton for delivery, then facility revenues are only $5 per delivered ton. For illustrative purposes only, the discussion of MRF revenues in this chapter assumes delivery costs of $10 per ton for all recycled materials. Actual delivery costs, and end-user prices, will vary by material and by location. Communities must research their local markets for recycled materials to estimate facility revenue per delivered ton by material type.

MIXED WASTE COLLECTION

Mixed waste collection cost estimates are based on garbage collection using two person crews and standard hydraulic compactor trucks. The cost estimates and assumptions cited below reflect equipment vendor prices for new vehicles, specified crew compensation assumptions, and available data on other collection costs (e.g., fuel, vehicle maintenance, insurance, and management overhead). Mixed waste collection costs are part of the total MSW management costs incurred by landfills and WTE facilities, and may approximate the collection costs associated with composting facilities. Curbside collection costs for recyclables processed at MRFs are discussed in a separate section.

Capital Cost Estimates

Exhibit 1 presents the capital costs of collecting mixed waste, which vary from $4.18 to $7.51 per ton. These cost per ton estimates depend on the capital/tpy estimates and alternative finance rates. The capital/tpy estimate of $38 per tpy was derived using the following assumptions:

- $90,000 purchase price for a compactor truck;
- 1 back-up truck per 10 operating trucks;
- 5 ton payload;
- 2 payloads per day per operating truck; and
- 260 days of operation per year (5 days per week, 52 weeks per year).

Exhibit 1
Mixed Waste Collection Capital Cost Estimates

Capital/TPY	Finance Rate	C&I/Ton
$31	6%	$4.18
38	6	5.23
46	6	6.27
31	8	4.59
38	8	5.73
46	8	6.88
31	10	5.01
38	10	6.26
46	10	7.51

The capital/tpy per "operating" truck in this example is $99,000 (including one-tenth of a back-up truck) and each operating truck collects 2600 tons per year (i.e., 5 tons per payload, 2 payloads per day, 260 days per year). Therefore, the capital cost per tpy is $38 ($99,000/2600). Capital per tpy would be $31 if the capital per operating truck (including one-tenth of a back-up truck) were $80,000 ($80,000/2600 = $31), and $46 if the capital per operating truck were $120,000. These three scenarios are reflected in Exhibit 1.

Interpolating Local Costs

The following example illustrates how local officials can use Exhibit 1 to interpolate capital costs per ton for mixed waste collection for their communities:

Assumptions:

Capital per operating truck = $110,000
Payload = 5 ton
Payloads collected per day = 2
Days of operation per year = 260
Finance rate = 9%
Truck operating life = 10 years

Step 1: Calculate capital/TPY:

$$\text{Capital/TPY} = \frac{110{,}000}{5 \times 2 \times 260} = \$42$$

Step 2: Interpolate costs/ton from Exhibit 1

$42 is half-way between $38 and $46. Therefore, capital cost per ton will be half-way between $5.73 and $6.88 at an 8% finance rate (Exhibit 1).

Capital costs/ton = $6.31 at 8%.

At a 10% finance rate, capital cost per ton will be half-way between $6.26 and $7.51.

Capital costs/ton = $6.89 at 10%.

At a finance rate of 9%, the capital cost/ton will be half-way between $6.31 and $6.89.

Thus, capital cost/ton = $6.60 at 9%.

Although the payload and purchase price for various compactor trucks may vary significantly, the ratio of price to payload may not vary substantially because trucks that cost more will also tend to have larger payloads. The more significant variable is the number of payloads collected per day. Factors affecting the number of payloads per day include the distance between stops on the collection route, the distance from the collection zone to a transfer station or final management facility, and the size of the collection crew. In sparsely populated areas, a one-person crew might collect only one payload per day, doubling the capital costs in Exhibit 1. In a densely populated area, the use of three-person crews and transfer stations could result in four payloads per day, halving the costs in Exhibit 1.

Low, medium, and high capital costs per tpy in Exhibit 1 ($31, $38, and $46, respectively) are converted to C&I (capital and interest) costs per ton of mixed waste collected under interest rate assumptions of 6, 8, and 10 percent, assuming that each truck has an operating life of 10 years. This format allows local government officials to interpolate their own vehicle capital costs per ton of mixed waste collected based on prevailing interest rates and the purchase price of these compactor trucks.

Total Cost Estimates

Exhibit 2 shows low, medium, and high cost scenarios for total mixed waste collection. The costs are based on weekly collection service. Increasing collection frequency from once to twice a week increases total collection costs by roughly 26 percent. Costs do not double when service frequency doubles, because households will put out half as much garbage per collection day, which means that collection vehicles can serve more households per day.

Exhibit 2
Mixed Waste Collection
Total Cost Estimates
($/Ton)

	Low	Medium	High
C&I	$4.18	$5.73	$7.51
O&M	30.00	35.00	40.00
Total	34.18	40.73	47.51

C&I costs in Exhibit 2 are taken from Exhibit 1.

The medium O&M cost of $35 per ton assumes:

- Salary and fringe benefits of $60,000 per year per operating truck for a two-person crew ($30,000 apiece);
- Management overhead of $8000 per year per truck; and
- Annual vehicle expenses of $22,000, for fuel maintenance and repair, insurance, licenses, and taxes.

Thus, a truck collecting 2600 tons of mixed waste per year incurs O&M costs of $90,000 or $35 per ton. Assuming low operating costs of $30 per ton and high costs of $40 per ton, the total cost estimate for mixed waste collection can range from $34.18 to $47.51 per ton, with a medium cost of $40.73 per ton.

TRANSFER AND TRANSPORT

As new landfills and WTE and composting facilities are cited further away from population centers, local governments will need to consider transfer and transport costs. MRFs, however, may not incur transfer costs; their small economic size may allow their siting at locations as convenient to collection zones as transfer stations.

TRANSFER STATION

The cost estimates and assumptions cited below reflect available data on transfer station capital and operating costs. Capital cost can be substantially higher, however, in urban areas with very high land values.

Capital Cost Estimates

Exhibit 3 shows that transfer station capital costs can range from $0.96 to $1.53 per ton. The medium capital per tpy of $12 reflects the following assumptions:

- ◆ $624,000 capital cost of a transfer facility;
- ◆ 200 tons of waste received per day; and
- ◆ 260 days of operation per year.

Capital cost per tpy would be $11 for a facility costing $572,000 ($572,000/52,000), and $13 for a facility costing $676,000.

Exhibit 3
Transfer Station
Capital Cost Estimates

Capital/ TPY	Finance Rate	C&I/Ton
$11	6%	$0.96
12	6	1.05
13	6	1.13
11	8	1.12
12	8	1.22
13	8	1.32
11	10	1.29
12	10	1.41
13	10	1.53

These low, medium, and high capital costs per tpy are converted to C&I costs per ton of material received, under interest rate assumptions of 6, 8, and 10 percent, assuming that each facility has an operating life of 20 years. Exhibit 3 can be used to interpolate C&I costs per ton for different sets of assumptions concerning cost of facility, daily tonnage, operating days per year, and interest rates.

Total Cost Estimates

Exhibit 4 shows C&I, O&M, and total cost per ton for a 200 ton per day transfer station operating 260 days per year. Medium operating costs reflect salary and benefits of $60,000 (two people) plus $31,000 per year for compactor maintenance, power, utilities, insurance, and other overhead ($91,000 divided by 52,000 tons per year equals $1.75 per ton). The total costs for transfer range from $2.46 to $3.53 per ton, assuming an operating cost range of $1.50 to $2.00 per ton.

Exhibit 4
Transfer Station
Total Cost Estimates
($/Ton)

	Low	Medium	High
C&I	$0.96	$1.22	$1.53
O&M	1.50	1.75	2.00
Total	2.46	2.97	3.53

TRANSPORT

The cost estimates and assumptions cited below reflect available data on transport capital and operating costs. Cost estimates are presented for vehicles making one to four trips per day from transfer stations to waste management facilities (e.g., landfills). The number of trips per day reflects variations in the distance from transfer stations to management facilities, assuming that trucks are fully utilized under each scenario. Therefore, the costs per ton for different scenarios reflect variations in annual tonnage transported, rather than to variations in annual costs per vehicle.

Capital Cost Estimates

Exhibit 5 shows C&I costs for MSW transport ranging from $0.68 to $3.25 per ton. These costs depend on interest rates and the number of round trips that trucks make daily from a transfer station to a landfill, compost, or WTE facility. The capital per tpy for one round trip per day reflects the following assumptions:

- ♦ $104,000 per operating transport vehicle (tractor and trailer plus allocated share of back-up vehicle);
- ♦ 20 ton payload capacity; and
- ♦ 260 days per year of operation.

Exhibit 5
Transport
Capital Cost Estimates

Trips/ Day	Capital/ TPY	Finance Rate	C&I/Ton
4	$5.00	6%	$0.68
3	6.67	6	0.91
2	10.00	6	1.36
1	20.00	6	2.72
4	5.00	8	0.75
3	6.67	8	0.99
2	10.00	8	1.49
1	20.00	8	2.98
4	5.00	10	0.81
3	6.67	10	1.08
2	10.00	10	1.63
1	20.00	10	3.25

($104,000 divided by 5200 tons per year = $20 per tpy for one trip per day.)

Capital cost per ton has been calculated for one to four trips per day, under interest rate assumptions of 6, 8, and 10 percent, assuming that transport trucks have an operating life of 10 years. Exhibit 5 can be used to interpolate C&I costs per ton for a different set of assumptions concerning the cost of transport vehicles, payload capacity, operating days per year, and interest rates.

Total Cost Estimates

The distance from transfer station to management facility determines the transport operating costs. Exhibit 6 shows operating costs for four round trips per day of $2.50 per ton, assuming:

- ♦ 20,800 tons per year (20 ton payload, 4 trips/day, 260 days per year); and
- ♦ Operating expense of $52,000 per year ($30,000 salary and fringe benefits for driver, and $22,000 for fuel, maintenance, insurance, etc.).

Exhibit 6
Transport
Total Cost Estimates
($/Ton)

Trips/Day	4	3	2	1
C&I	$0.68	$0.99	$1.49	$3.25
O&M	2.50	3.33	5.00	10.00
Total	3.18	4.32	6.49	13.25

O&M costs double to $5 per ton when there are only 2 round trips per day, and double again to $10 per ton when there is only one round trip per day per vehicle. The total transport costs range from $3.18 per ton to $13.25 per ton.

CURBSIDE COLLECTION OF RECYCLABLES

Cost estimates for curbside collection of recyclables are based on weekly collection of newspaper and aluminum, steel, glass, and plastic containers. An aggressive recycling program, collecting a variety of recyclables, and supported by high recycling participation rates, could significantly reduce the amount of mixed waste collected. In the short run, aggressive recycling programs may increase the cost per ton for weekly mixed waste collection, because an existing fleet of mixed waste collection vehicles may become underutilized when recycling trucks gather a larger share of the waste stream. In the long run, however, recycling should not affect the steady-state cost per ton for weekly mixed waste collection, because the size of the mixed waste collection fleet can be reduced over time to restore efficient utilization. Furthermore, in areas where mixed waste is presently collected twice a week, an aggressive recycling program could facilitate a transition to weekly mixed waste collection, because weekly collection of recyclables would limit the amount of mixed waste accumulated by residents each week. In this case, the cost per ton for recyclables collection would be partially offset by a reduction in the long-run cost per ton for mixed waste collection.

Collection costs per ton for recyclables are extremely sensitive to the mix of materials collected, because there is substantial variation in the material density (i.e., tons per cubic yard) of different recyclables. For very dense materials like newspaper and glass, collection costs per ton are close to the cost of mixed waste collection. For aluminum, however, collection costs are several hundred dollars per ton. The material density of plastic containers is so low that economical recycling will generally require on-board plastic compaction equipment.

To accommodate these variations by material type, collection costs per cubic yard are presented for curbside collection of newspaper and aluminum, steel, and glass containers. Special adjustments are used to calculate the cost per cubic yard for plastic recycling. Costs per cubic yard for each material are then converted to costs per ton based on the material density of each recyclable on the collection truck.

The cost estimates and assumptions cited below reflect vendor prices for compartment trucks and household recycling containers, specified crew compensation assumptions, and available research on other collection vehicle costs. Material density factors, used to convert costs per cubic yard to costs per ton, reflect the results of a survey of several research reports on this issue. Cost adjustments for plastic container recycling capital costs are based on product specifications for on-board densifiers. Adjustments for plastic container recycling operating costs reflect available research on the incremental loading time associated with curbside compaction of plastics.

Capital Cost Estimates

Exhibit 7 presents estimates of the capital costs per cubic yard for curbside collection of newspaper and aluminum, steel, and glass containers.

Exhibit 7
Curbside Recyclable Collection Capital Cost Estimates

Vehicle Capital/ CYPY	Container Capital/ CYPY	Finance Rate	Vehicle C&I/CY	Container C&I/CY	Total C&I/CY
$4	$2	6%	$0.54	$0.27	$0.81
5	2	6	0.68	0.27	0.95
6	2	6	0.82	0.27	1.09
4	2	8	0.60	0.30	0.90
5	2	8	0.75	0.30	1.05
6	2	8	0.89	0.30	1.19
4	2	10	0.65	0.33	0.98
5	2	10	0.81	0.33	1.14
6	2	10	0.98	0.33	1.31

The average vehicle capital cost estimate of $5 per cubic yard per year (cypy) reflects the following assumptions:

- $71,000 compartment truck;
- One back-up truck for every 10 operating trucks;
- 30 cubic yard payload capacity;
- 2 payloads per day; and
- 260 days per year of operation.

($78,100 divided by 15,600 cubic yards per operating truck equals $5 per cypy).

In addition to vehicle capital costs, curbside collection programs must also consider the capital cost of household containers for recyclables. Many communities have found that containers are a worthwhile investment in aggressive weekly collection programs because the distribution of containers raises participation rates. The estimate for container capital per cypy in Exhibit 7 assumes that each collection truck serves 5000 households, and the cost of containers per household is $6.20. This container cost would cover one large container per household. In this analysis, the operating life of containers is assumed to be the same as that of collection trucks (i.e., ten years).

Total Cost Estimates

Exhibit 8 indicates total collection cost estimates of $5.82 to $7.30 per cubic yard for recycling newspapers and glass, aluminum, and steel containers based on a range of $5 to $6 per cubic yard for operating costs. The medium O&M cost estimate of $5.50 per cubic yard is based on the following annual operating costs per truck:

- $60,000 for a two-person crew ($30,000 apiece);
- Management overhead of $8000 per year; and
- Annual vehicle expenses of $18,000.

Exhibit 8
Curbside Recyclable Collection Total Cost Estimates
($/Cubic Yard)

	Low	Medium	High
C&I	$0.81	$1.05	$1.31
O&M	5.00	5.50	6.00
Total	**5.81**	**6.55**	**7.31**

($86,000 per year divided by 15,600 cubic yards per year per truck equals $5.50 per cubic yard). These O&M costs do not include the costs of advertising and other community outreach programs to encourage recycling.

Exhibit 9
Plastic Container Collection Total Cost Estimates
($/Cubic Yard)

	Low	Medium	High
C&I	$1.46	$1.89	$2.36
O&M	6.00	6.60	7.20
Total	**7.46**	**8.49**	**9.56**

Exhibit 9 presents capital and operating cost estimates per cubic yard for collection of plastic containers, based on the following adjustments to the collection cost estimates for other recyclables:

- C&I costs per cubic yard are 80 percent higher due to the capital cost of on-board plastic compaction equipment; and
- O&M costs per cubic yard are 20 percent higher due to power and maintenance costs for the compactor and additional labor costs for curbside loading and compaction of plastics.

Converting Costs per Cubic Yard to Costs per Ton

Exhibit 10
Material Density Factors
(Tons Per Cubic Yard)

Material	Tons/CY
Newspaper	0.180
Aluminum	0.020
Steel	0.060
Glass	0.208
Plastic	0.052

The material density factors in Exhibit 10 are used to convert cost per cubic yard into cost per ton. These are "on-board" material density factors, reflecting the assumption that the space allocated to each material is only 80 percent full at the completion of an average collection route. The wide variation in material density factors for different recyclables may account for much of the wide variation in collection costs per ton reported by different communities with cubside recycling programs. Even if collection costs per cubic yard were very similar, variations in the mix of materials recovered could result in wide variations in collection costs per ton.

Exhibit 11
Curbside Recyclable Collection Material Cost Estimates
($/Ton)

Material	Low	Medium	High
Newspaper	$32	$36	$41
Aluminum	291	327	365
Steel	97	109	122
Glass	28	31	35
Plastic	144	163	183

Recyclable collection costs per ton in Exhibit 11 reflect total collection costs per cubic yard divided by the density factor for each material (e.g., $6.55 per cubic yard divided by 0.02 tons of aluminum per cubic yard yields an aluminum collection cost estimate of $327 per ton). These cost estimates reflect the assumption that recycling trucks complete two routes per day (i.e., fill 80 percent of their cubic yard capacity, twice per day). If collection vehicles complete only one route per day (e.g., if low recycling rates double the length of collection routes needed to fill 80 percent of truck capacity), then costs per ton will be twice as high as those shown in Exhibit 11. In other words, the cost per truck would be the same, but each truck would collect half as much material.

Exhibit 12
Example: Average Collection Costs
($/Ton)

Material	% by Weight	Material Cost/Ton	Average Cost/Ton
Newspaper	65%	$36	$23.40
Aluminum	4	327	13.08
Steel	7	109	7.63
Glass	21	31	6.51
Plastic	3	163	4.89
All	100	–	55.51

Average collection costs for curbside recycling will depend on the mix of materials collected, as well as the cost assumptions applicable to a particular community. Exhibit 12 shows how local governments can calculate average costs for a particular mix of materials collected, based on the collection cost estimates presented in Exhibit 11. In this example, newspaper accounts for 65 percent of all recyclables by weight. Therefore, the average ton of recyclables includes 0.65 tons of newspaper, accounting for $23.40 in collection costs (0.65 times $36). Collection costs attributable to other materials are calculated in the same way. The weighted average collection cost of $55.51 per ton is the sum of the costs per mixed ton attributable to each material. The significance of material density in forecasting average costs per ton is illustrated by the fact that aluminum, in this example, accounts for only 4 percent of collected tons and more than 23 percent of collection costs.

Factors Affecting Material Mix

The mix of recyclables collected at curbside can significantly impact MRF revenues (discussed in the next section) as well as average collection costs per ton of recyclables. Thus, material mix is an important determinant of the net cost of recycling. The mix of materials collected at curbside will depend on four factors:

- Share of residential recyclable generation by material type;
- Participation rate variations by material type;

- Recycling alternatives; and
- Material types collected at curbside.

The percentage share of residential recyclables attributable to each material type can be derived from local waste stream characterization studies. Nationwide, annual residential generation of newspaper is approximately equal to the combined residential generation of aluminum, steel, glass, and plastic (HDPE and PET) containers. Therefore, newspapers will usually account for at least 50% and often substantially more of recyclable tonnage collected at curbside.

Newspapers may account for a disproportionately large percentage of curbside recycling tonnage because recycling participation rates are higher for newspapers than for other materials. This may be especially true of curbside programs that collect recyclables only once every two weeks, because newspapers can be stored in a relatively small area (due to their material density), without concern about sanitary containment. Weekly curbside collection of recyclables may increase the percentage of steel and glass food containers recycled, because some consumers may be unwilling to store old food containers for longer periods.

In some states, bottle bills that create convenient recycling alternatives may limit the amount of containers collected at curbside. Container refund programs, in particular, may reduce curbside container tonnage by providing a financial incentive for consumers to divert containers from curbside recycling.

Another factor that affects the mix of recyclables collected at curbside is the variety of materials that local government decide to recycle. The net cost of recycling any particular material is an important factor in this decision. Net cost will depend on MRF processing costs and revenues by material type (discussed in the next section) and collection costs by material type. When comparing the collection costs in Exhibit 11 to MRF costs and revenues by material type, fixed and variable costs should be distinguished.

Fixed Versus Variable Recyclable Collection Costs

In general, the incremental (i.e., variable) cost of adding any particular material to a curbside recycling program will be less than the allocated cost per ton shown in Exhibit 11, because the allocated cost per ton for each material includes a portion of fixed costs. In addition to management overhead, more than half of all other collection costs might be defined as fixed costs because the time spent loading recyclables accounts for only about 50 percent of total collection time. Therefore, the incremental cost of collecting additional material types may be only half the allocated costs shown in Exhibit 11 because the fixed cost of travelling between collection stops will not increase when additional materials are recovered. Conversely, limiting the variety of recyclables collected will reduce the amount of materials loaded at each stop and increase the number of stops needed to fill the collection vehicle. For this reason, recycling programs that collect only one or two recyclables may incur collection costs per ton that are significantly higher than the collection cost per ton shown for these recyclables in Exhibit 11.

MATERIALS RECOVERY FACILITIES (MRFs)

The cost estimates and assumptions for materials recovery facilities (MRFs) reflect recent surveys of MRF capital and operating costs. The high-end of the capital/tpy range for MRFs reflects the capital investment for several highly automated MRFs that are presently under construction. The low end of the range shown for operating costs per ton ($25/ton) only partially reflects the operating cost reductions that many new MRFs expect to realize from automation. Many new automated MRFs anticipate O&M costs of $20 per ton or less. If these cost reductions are realized in full, then the total cost per ton for new automated MRFs may be below the low-end of the total cost range derived by this analysis.

Capital Cost Estimates

Exhibit 13 presents MRF C&I cost per ton estimates, which vary from $10.30 to $18.41 per ton of recyclables processed, depending on the capital costs per ton per year (tpy) and the prevailing interest rates. The average capital cost estimate of $120 per tpy reflects the following assumptions:

- ◆ Capital per ton of daily capacity is $31,200; and
- ◆ The facility operates 260 days per year.

Exhibit 13
MRF Capital Cost Estimates

Capital/ TPY	Finance Rate	C&I/Ton
100	6%	$10.30
120	6	12.36
140	6	14.41
100	8	11.68
120	8	14.02
140	8	16.36
100	10	13.15
120	10	15.78
140	10	18.41

Capital cost per tpy estimates are converted to C&I costs per ton of material received under interest rate assumptions of 6, 8, and 10 percent, assuming that each facility has a life of 15 years. Exhibit 13 can be used to interpolate C&I cost per ton for a different set of assumptions than given above.

The above costs apply to MRFs that process different mixes of recyclables. Although certain types of MRF equipment relate to specific recyclable materials (e.g., magnetic separation for steel cans), much of a MRF investment applies to all types of recyclables (e.g., land requirements, tipping and storage areas, and conveyor systems). The estimates based on a capital cost estimate of $140 per tpy may be appropriate for smaller MRFs, because larger MRFs (i.e., receiving more than 100 tons per day) realize some economies of scale.

Total Cost Estimates

Exhibit 14 presents cost per ton estimates for MRF processing of recyclables. Estimates of total costs range from $39.30 to $69.41 per ton, based on the following assumptions:

- Capital and interest expenses as estimated in Exhibit 13;
- O&M cost estimates from $25 to $45 per ton; and
- Disposal cost estimates for 10 percent residue at $40 to $60 per ton of residue (i.e., $4 to $6 per ton of waste received).

Exhibit 14
MRF Total Cost Estimates
($/Ton)

	Low	Medium	High
C&I	$10.30	$14.02	$18.41
O&M	25.00	35.00	45.00
Residue Disposal	4.00	5.00	6.00
Total	39.30	54.02	69.41

Revenue Estimates

The market values of recycled materials vary significantly throughout the country and fluctuate over time. The economics of curbside recycling in any particular community will be especially sensitive to local market values for recycled newspaper and aluminum, glass, steel, and plastic containers. MRFs will also receive and process office papers and corrugated cardboard. Revenues from these materials, however, may be credited, by negotiation, to the businesses that generate these wastes and incur the expense of separating and transporting recyclables to MRFs. Although the cost estimates and revenues presented here relate to residential recyclables, curbside recycling may complement commercial recycling by expanding the local infrastructure of MRFs.

To estimate the net cost of MRF recycling, revenues per ton of recycled material delivered to end-users must be adjusted to reflect the cost of delivery and the amount of residue loss at MRFs. The adjustment for MRF residue loss is made in order to calculate revenues per ton of collected recyclables, comparable to MRF and collection costs per ton of collected recyclables. Local governments can use this method to estimate MRF revenue per collected ton for different material types, based on local market values and delivery costs for each material, by making the following calculations:

- Net revenue per delivered ton = [revenue per delivered ton] minus [transport cost per delivered ton]; and
- MRF revenue per collected ton = [net revenue per delivered ton] multiplied by [the fraction of collected material recovered by MRFs (e.g., 90 percent)].

Exhibit 15 illustrates these adjustments, based on the following assumptions:

- 10 percent of all collected recyclables are lost to MRF residue that must be landfilled;
- Delivery costs for all recyclables are $10 per delivered ton; and
- 20 percent of collected glass is used for glassphalt, generating no revenue or transport costs. (This 20 percent is included in the residue loss column of Exhibit 15.)

If revenue received from an end-user of paper is $20 per ton and the cost of delivery to that end-user market is $10 per ton, then net revenue per ton of delivered paper is $10 per ton. If only 90 percent of collected paper is recovered by MRFs and delivered to end-users (i.e., 10 percent is residue loss), then MRF revenue is $9 per collected ton (90 percent of revenue per ton delivered).

Exhibit 15
MRF Revenue Estimates at $10/Ton Delivery Cost

	$/Ton Delivered			Residue	$/Ton Collected		
Materials	**Low**	**Med**	**High**	**Loss**	**Low**	**Med**	**High**
Newspaper	$ 0	$ 10	$ 20	10%	$ (9)	$ 0	$ 9
Aluminum	700	900	1,100	10	621	801	981
Steel	30	50	70	10	18	36	54
Glass	40	50	60	30	21	28	35
Plastic	100	130	160	10	81	108	135

Many MRFs experience residue rates close to 10 percent for materials other than glass. The residue rate for glass may be as high as 30 percent, due to breakage, but some local governments have found a market for this residue in the use of 5 percent mixed color cullet in asphalt mixes. Exhibit 15 reflects the assumption that 20 percent of collected glass is used in such "glassphalt" applications, in addition to the 10 percent of collected glass that is landfilled. The glassphalt market can reduce landfill costs for glass residue, but might not generate any significant revenue for glass recycling. Therefore, the revenue per collected ton of glass is estimated to be only 70 percent of the net revenue per delivered ton of color-separated glass.

The delivery cost assumption in Exhibit 15 is intended only to illustrate that delivery costs reduce MRF revenues. Actual delivery costs, like revenues, will vary by material type, because different recycled materials are delivered to different end-users at different locations.

Average MRF revenues per ton, like collection costs for recyclables, will depend on the mix of materials collected. Exhibit 16 illustrates how weighted average MRF revenues can be estimated in the same manner as described earlier for weighted average collection costs. This example assumes that MRF revenues per collected ton are the medium revenues shown for each material type in Exhibit 15. The mix of materials shown in this example is the same as shown earlier in the Exhibit 12 example of weighted average collection costs.

Exhibit 16
Example: Average MRF Revenues
($/Ton)

Material	% per MRF Ton	Revenue/ Material Ton	Average Revenue per Ton
Newspaper	65%	$ 0	$0.00
Aluminum	4	801	32.04
Steel	7	36	2.52
Glass	21	28	5.88
Plastic	3	108	3.24
All	100	–	43.68

COMPOSTING FACILITIES

This section estimates the costs of two composting technologies:

- **Leaf composting**, which entails relatively low capital and operating costs. Leaf composting complements WTE facilities by removing a component of the waste stream with a relatively high moisture content and substantially reducing the seasonal fluctuations in MSW received by WTE facilities.

- **Sludge/Grass/Food composting**, which entails much higher capital and operating costs. Facilities that compost the full spectrum of mixed wastes (and thereby compete with WTE facilities and landfills) may incur costs significantly higher than the estimated costs of composting sewage sludge, grass clippings, and food processing wastes, due to the additional expense of separating out contaminants in mixed waste.

LEAF COMPOSTING

The cost estimates and assumptions for leaf composting reflect available data on "low-technology" composting operations (i.e., open-air windrows, as opposed to in-vessel systems with odor control). These cost estimates do not reflect any incremental costs associated with separate curbside collections for leaves. For the purpose of cost comparisons (presented in the penultimate section of this chapter), this analysis uses mixed waste collection costs to approximate separate collection costs for leaves. Reported collection cost for leaves, however, span a much wider range than reported mixed waste collection costs. Therefore, separate collection of leaves (and grass clippings) may entail collection costs above the high end of the estimated range for mixed waste collection.

Capital Cost Estimates

The estimated C&I costs for a leaf composting facility range from $6.79 to $11.39 per ton of leaves received, depending on capital costs per tpy and the prevailing interest rates. The estimated average capital cost of $60 per tpy is based on the following assumptions:

- $300,000 facility capital cost;

- Finance rates from 6 to 10 percent; and

- Facility receiving 5,000 tons of leaves per year.

Exhibit 17
Leaf Composting
Capital Cost Estimates

Capital/ TPY	Finance Rate	C&I/Ton
50	6%	$ 6.79
60	6	8.15
70	6	9.51
50	8	7.45
60	8	8.94
70	8	10.43
50	10	8.14
60	10	9.76
70	10	11.39

The low and high capital cost estimates are assumed to be $50 and $70 per tpy. The actual capital costs per tpy for a community will depend largely on:

- Land values;
- The type of equipment used (e.g., front-end loader or windrow); and
- Whether shredding and screening equipment is purchased to make compost more marketable.

Low, medium, and high capital cost estimates per tpy are converted to C&I costs per ton of leaves received, under interest rate assumptions of 6, 8, and 10 percent, assuming that the equipment has a 10 year operating life. Exhibit 17 can be used to interpolate C&I costs per ton for different sets of assumptions than given above.

Total Costs

The estimated operating costs of leaf composting facilities range from $6 to $18 per ton of leaves. Thus, estimated total costs vary from $12.79 to $29.39 per ton of leaves received, as shown in Exhibit 18.

Exhibit 18
Leaf Composting
Total Cost Estimates
($/Ton)

	Low	Medium	High
C&I	$6.79	$8.94	$11.39
O&M	6.00	12.00	18.00
Total	12.79	20.94	29.39

These cost estimates assume that a community receives no revenue from the sale of leaf compost. While some communities credit leaf compost with $5 to $10 per ton for the avoided cost of daily landfill cover, this application may not absorb large quantities of compost. Other communities report revenue of up to $20 per ton of compost, but these communities also report costs per ton well above the "high" estimate in Exhibit 18, suggesting that their higher revenues may simply pay for shredding, screening, and bagging equipment and delivery costs needed to find markets for compost. In most communities, compost revenues per ton of leaves collected are likely to be negligible for the following reasons:

- Composting reduces the weight of leaves by 20 to 60 percent;
- The market value of unscreened compost is generally less than $5 per delivered ton (i.e., $2 to $4 per ton of collected leaves); and
- Delivery costs may completely offset compost revenue.

SLUDGE/GRASS/FOOD COMPOSTING

The cost estimates and assumptions cited below reflect available research on "high-technology" composting facilities (i.e, in-vessel systems) receiving a mixture of sludge and yard waste and/or food processing wastes. Facilities that receive the full spectrum of mixed waste generally incur capital costs similar to those described here, but operating costs may be significantly higher due to the additional expense of separating out contaminants in mixed waste.

Capital Cost Estimates

Estimates of C&I costs for facilities composting sewage sludge, grass clippings, and food processing wastes vary from $13.08 to $23.49 per ton. These estimates assume:

- Capital costs of $150 to $200 per tpy of capacity;
- 20 year facility life; and
- Financing rates of 6 to 10 percent.

Exhibit 19
Sludge/Grass/Food Composting
Capital Cost Estimates

Capital/ TPY	Finance Rate	C&I/Ton
$150	6%	$13.08
175	6	15.26
200	6	17.44
150	8	15.28
175	8	17.82
200	8	20.37
150	10	17.62
175	10	20.56
200	10	23.49

Total Cost Estimates

Estimated operating costs for sewage sludge, grass clippings, and food wastes composting range from $15 to $25 per ton of waste received. Total cost estimates, therefore, should vary from $28.08 to $48.49 per ton of waste received. As in the case of leaf compost, revenues are unlikely to significantly affect the total costs because delivery costs are likely to offset or exceed any revenues.

Exhibit 20
Sludge/Grass/Food Composting
Total Cost Estimates
($/Ton)

	Low	Medium	High
C&I	$13.08	$17.82	$23.49
O&M	15.00	20.00	25.00
Total	**28.08**	**37.82**	**48.49**

WASTE-TO-ENERGY FACILITIES

The economics of WTE depend on the facility type (e.g., mass-burn, modular, or refuse-derived fuel) and the primary energy form produced (e.g., steam, electricity, or steam and electricity). The following analysis reflects the costs and characteristics of a mass-burn facility generating electricity, based on detailed data on operational and "advance-planned" facilities (i.e., facilities that will begin operations before 1996). Mass-burn facilities generating electricity account for a substantial majority of all WTE facilities presently under construction or in an advanced planning stage. The economics of smaller "modular" WTE facilities that sell steam (or cogenerate steam and electricity) are highly dependent on local market industrial demand for steam.

Capital Cost Estimates

The capital cost of WTE facilities is often stated in terms of capital per design ton per day (dtpd). Exhibit 21 presents estimates of capital cost per dtpd ranging from $80,000 to $160,000. Older mass-burn facilities have been built for less than $80,000 per dtpd, but the average cost of advance-planned facilities with extensive pollution control equipment is approximately $120,000 per dtpd. Larger facilities (receiving more than 1000 tons per day) often realize economies of scale that reduce capital costs per dtpd. Thus, smaller facilities are more likely to incur higher capital costs per dptd.

Exhibit 21
WTE Capital Cost Estimates

Capital/ DTPD	Finance Rate	C&I/Ton
$ 80,000	6%	$23.85
120,000	6	35.78
160,000	6	47.70
80,000	8	28.13
120,000	8	42.19
160,000	8	56.26
80,000	10	33.07
120,000	10	49.61
160,000	10	66.15

Low, medium, and high capital estimates per dtpd have been converted to C&I costs per ton of waste received, under interest rate assumptions of 6, 8, and 10 percent, assuming a 20 year operating life and 85 percent capacity utilization. Exhibit 21 can be used to interpolate C&I cost per ton for different sets of assumptions concerning capital per dtpd and interest rates.

With the set of assumptions detailed above, C&I costs per ton are estimated to range from $23.85 to $66.15.

Exhibit 22
Ash Disposal Cost Estimates

Ash/Waste Ton Received	Disposal Cost/Ash Ton	Disposal Cost/ Waste Ton
22%	$40	$8.80
22	50	11.00
22	60	13.20
24	40	9.60
24	50	12.00
24	60	14.40
26	40	10.40
26	50	13.00
26	60	15.60

Ash Disposal Cost Estimates

Ash disposal is another important cost for WTE facilities. Exhibit 22 shows cost estimates for ash disposal that range from $8.80 to $15.60 per ton of MSW received, assuming that:

- Ash produced by a mass-burn facility is 22 to 26 percent of the MSW received; and
- Ash disposal costs are $40 to $60 per ton (i.e., for transport and landfill disposal).

Total Cost Estimates

Exhibit 23 shows estimates of total WTE costs under low, medium, and high cost scenarios. Total cost estimates range from $47.65 to $116.75 per ton of MSW received. These estimates assume that O&M costs (excluding ash disposal) range from $15 to $35 per ton of MSW received. Average O&M costs for mass-burn facilities are approximately $25 per ton. In general, larger facilities report lower O&M costs per ton than smaller facilities.

Exhibit 23
WTE Total Cost Estimates
($/Ton)

	Low	Medium	High
C&I	$23.85	$42.19	$66.15
O&M	15.00	25.00	35.00
Ash Disposal	8.80	12.00	15.60
Total	**47.65**	**79.19**	**116.75**

Revenue Estimates

Revenue for a WTE facility depends on the revenue per kilowatt-hour (KWH) generated and the KWH generated per ton of MSW. Most mass-burn facilities generate 500 to 600 KWH per ton of MSW received, as assumed in Exhibit 24. Revenue per KWH can range from 2 cents to 11 cents, but most WTE facilities earn between 3 and 8 cents per KWH. For facilities earning 3 to 8 cents per KWH, Exhibit 24 shows that WTE revenue will range from $15 to $48 per ton.

Exhibit 24
WTE Revenue Estimates
($/Ton)

Revenue/ KWH	KWH/Ton Waste Received	Revenue/ Waste Ton
$0.030	500	$15.00
0.055	500	27.50
0.080	500	40.00
0.030	550	16.00
0.055	550	30.25
0.080	550	44.00
0.030	600	18.00
0.055	600	33.00
0.080	600	48.00

Integrated Management WTE Cost Reduction Estimates

The range of WTE cost and revenue estimates presented in Exhibits 23 and 24 are representative of WTE facilities designed to receive the full spectrum of the municipal solid waste stream, including non-combustibles and compostables with a high moisture content. Exhibit 25 presents estimates of the potential additional revenues and cost-savings that might be realized by new WTE facilities designed to complement other integrated MSW management options. These estimates reflect the following assumptions:

Exhibit 25
Cost Reduction Estimates for New WTE Facilities Designed for Integrated MSW Management
($/Ton)

	Low	Medium	High
C&I	1.41	2.48	3.85
Ash Disposal	4.40	6.00	7.80
KWH Revenue	1.50	3.03	4.80
Total Savings	**7.31**	**11.51**	**16.45**

- WTE facilities operate at 90 instead of 85 percent of design capacity because seasonal fluctuations in waste flow are reduced by diverting yard wastes to compost facilities.

- Removing a substantial portion of the metals and glass received by a WTE facility can reduce disposal ash by 50 percent.
- KWH revenue per ton increases by 10 percent per ton received because noncombustibles and compostables with a high moisture content (i.e., yard waste) are removed from the waste stream.

Exhibit 25 indicates that new WTE facilities, complemented by aggressive recycling of non-combustibles and yard waste composting, may incur net costs that are $7 to $16 per ton less than the net cost of WTE facilities receiving the full spectrum of MSW. In general, these savings may be achieved only by new WTE facilities designed to complement an integrated waste management strategy. Existing WTE facilities, however, may also reduce net costs slightly by recycling non-combustibles and thereby reducing WTE disposal ash.

LANDFILL DISPOSAL

The cost estimates and assumptions for landfills reflect engineering studies detailing costs for a modern landfill satisfying stringent environmental standards and designed to receive 1,000 tons per day or 260,000 tons per year over twenty years. Landfill costs can vary substantially due to variations in excavation costs, land values, liner requirements, the frequency of required ground water sampling, and other environmental monitoring requirements.

Capital Cost Estimates

Four types of capital costs affect the cost of landfill disposal:

- Pre-development costs;
- Construction costs;
- Closure costs; and
- The costs of post-closure care.

All of the cost estimates presented in this chapter exclude program development costs, such as community outreach and public relations efforts associated with siting new waste management facilities. In the case of landfills, however, site selection entails significant additional expenditures for hydrogeologic investigation (i.e., soil borings, ground water well installation, and soil and ground water analyses). Thus, a substantial capital expenditure may be made at several failed sites for every site approved for landfill construction.

Closure and post-closure costs, like pre-development and construction costs, are not reflected in the annual O&M costs of landfills, but must be financed and amortized over the operating life of the landfill. Although closure and post-closure costs are incurred 20 to 50 years after landfill construction, these future costs can be converted into current capital costs (comparable to construction capital cost) by using standard financial formulas to calculate the present value of future cash flows. The "capital cost" of closure and post-closure is thus stated in terms of the amount that must be invested at the time of site construction, in order for the principal and interest earned to be sufficient to pay for closure and post-closure costs as they fall due.

Pre-Development Cost Estimates. As shown in Exhibit 26, landfill pre-development C&I cost estimates vary from $13.10 to $61.26 per ton under the following assumptions:

Exhibit 26
Landfill Pre-Development Capital Cost Estimates

Cost/TPY per Site	Sites/ Landfill	Finance Rate	Capital Cost/Ton
$ 6	2	6%	$13.10
9	3	6	30.37
12	4	6	55.65
6	2	8	13.48
9	3	8	31.56
12	4	8	58.40
6	2	10	13.86
9	3	10	32.77
12	4	10	61.26

- Finance rates of 6 to 10 percent;
- Pre-development capital costs of $6 to $12 per tpy per site evaluated;
- Pre-development costs are incurred at 2 to 4 sites before a site is approved for landfill construction; and
- C&I cost per ton estimates depend on the length of the siting process and the number of sites rejected as follows:
  - A single site evaluation takes approximately one year;
  - The last site evaluation (for the approved site) occurs in the year prior to construction and therefore one year of interest expense is incurred;
  - The second to last site evaluation (the last failed site) takes place two years prior to construction; and
  - Each additional failed site evaluation takes place three or more years prior to construction.

Construction Cost Estimates. Estimated construction capital costs range from $20.8 million to $31.2 million for a facility receiving 1,000 tons per day (260 days per year). Therefore, capital cost estimates per tpy for construction range from $80 to $120, as shown in Exhibit 29.

Closure Cost Estimates. Exhibit 27 presents closure cost estimates in discounted current dollars. These estimates assume that:

- The facility will close after operating 20 years;
- The estimated cost of closure in current dollars is between $8 and $12 per tpy (i.e., approximately $2 to $3 million for a landfill receiving 260,000 tons per year); and

- Funds to cover closure costs would earn a real interest rate (i.e., the nominal interest rate minus the rate of inflation) of 1 percent. This rate of return reflects a risk-free investment in U.S. Treasury Bills.

With these assumptions, current capital costs are estimated to vary from $9.74 to $6.49 per tpy. In other words, to pay for future closure costs, $9.74 to $6.49 must be invested (at the time of site construction) per ton of waste to be landfilled per year.

Exhibit 27
Landfill Closure Capital Cost Estimates

Closure Cost/TPY	Real Interest Rate	Capital Cost/TPY
$8	1%	$6.49
10	1	8.11
12	1	9.74

Post-Closure Cost Estimates. Exhibit 28 presents post-closure cost estimates in discounted current dollars, which vary from $14.24 to $18.30 per tpy. These costs assume:

- A 30 year post-closure period;
- Post-closure costs for a 1,000 tpd landfill of $175,000 to $225,000 per year (in current dollars); and
- Funds to cover post-closure costs would earn a real interest rate of 1 percent.

Exhibit 28
Landfill Post-Closure Capital Cost Estimates

Post-Closure Cost/TPY	Real Interest Rate	Capital Cost/TPY
$20	1%	$14.24
23	1	16.27
26	1	18.30

Total Capital Cost Estimates. Exhibit 29 combines pre-development, construction, closure, and post-closure capital cost estimates per tpy and presents a range of C&I costs per ton, depending on prevailing interest rates. It shows that total capital requirements range from $113.83 to $209.30 per tpy, and the capital cost per ton of MSW landfilled can range from $9.92 to $24.58. These estimates reflect the costs presented in previous exhibits and assume that construction capital costs are between $80 and $120 per tpy (that is $20.8 million to $31.2 million for a facility receiving 1000 tons per day).

Exhibit 29
Landfill Capital Cost Estimates

Predev. Capital/ TPY	Constr. Capital/ TPY	Closure Capital/ TPY	P-Clos. Capital/ TPY	Capital/ TPY	Finance Rate	Capital Cost/Ton
13.10	$ 80	$6.49	$14.24	$113.83	6%	$ 9.92
30.37	100	8.11	16.27	154.76	6	13.49
55.65	120	9.74	18.30	203.69	6	17.76
13.48	80	6.49	14.24	114.21	8	11.63
31.56	100	8.11	16.27	155.94	8	15.88
58.40	120	9.74	18.30	206.44	8	21.03
13.86	80	6.49	14.24	114.59	10	13.46
32.77	100	8.11	16.27	157.15	10	18.46
61.26	120	9.74	18.30	209.30	10	24.58

Total Cost Estimates

Exhibit 30 shows that estimates of total landfill costs per ton of MSW can range from $24.92 to $45.58, assuming that operating costs for a 1000 ton per day facility range from $15 to $21 per ton (that is from $3.9 million to $5.5 million per year).

Exhibit 30
Landfill Total Cost Estimates
($/Ton)

	Low	Medium	High
C&I	$ 9.92	$15.88	$24.58
O&M	15.00	18.00	21.00
Total	24.92	33.88	45.58

COMBINING COST COMPONENTS FOR INTEGRATED MANAGEMENT

Exhibit 31 presents a framework that local governments can use to compare and combine the cost components of an integrated MSW management system. The range of cost estimates shown for each management option (reflecting cost estimates derived in earlier sections) indicates that no single management alternative is consistently less expensive than others. Specific communities, however, may find that local conditions can produce significant differences in the costs of MSW management options. In particular, local market values for electricity and recycled materials can substantially alter the net cost of WTE facilities and MRFs. (The net cost estimate range for these two management options could be much wider than shown in Exhibit 31 due to local conditions that might combine high costs with low revenues or high revenues with low costs.)

In general, most communities will find that an integrated MSW management system, combining a complement of options, including MRFs, WTE and composting facilities, and landfills, is more efficient than reliance on any single

Exhibit 31
Comparing/Combining MSW Management Cost Estimates
($/Ton)

	Landfill	WTE	MRF	Leaf Compost	Sludge/Grass/ Food Compost
Collection	$34-$48	$34-$48	$50-$90	$34-$48	$34-$48
Transfer/Transport	6-17	6-17	0	6-17	6-17
Facility Costs	25-46	48-117	39-69	13-29	28-48
Total Cost	65-111	88-182	89-159	53-94	68-113
Facility Revenue	0	15-48	20-50	0	0
Net Cost	65-111	73-134	69-109	53-94	68-113

management method. An integrated approach allows for different wastes to be handled in the most cost effective manner. To determine the mix of management methods that is most economical for a particular community, local officials must estimate the costs associated with each management option, including the following cost components:

- Collection;
- Transfer and transport;
- Facility cost estimates (C&I, O&M, and residue/ash disposal); and
- Facility revenue estimates (per collected ton, adjusted for delivery).

Collection

While all management options incur collection costs, the costs per ton for recyclables collection can be significantly higher than for mixed waste collection. Mixed waste collection costs associated with landfills and WTE facilities can range from $34 to $48 per ton, for collection systems with the cost characteristics considered here. Although reported collections costs for many communities do fall within this range, some local governments report substantially higher mixed waste collection costs. Some of the factors that may result in higher reported costs include:

- Higher service levels (e.g., twice per week collection versus once per week);
- Higher labor costs (e.g., crew-size per truck, average compensation per crew member, or management overhead per truck);
- Fewer tons hauled per year per truck (e.g., only one payload per day per truck) resulting in higher O&M and C&I costs per ton; and
- Higher finance rates (i.e., vehicles may have been financed at rates above 10 percent).

Collection costs for recyclables may be as low as $50 per ton if newspaper and glass account for a very large percentage of collected tons (e.g., more than 85 percent). Recyclable collection costs would approach $90 per ton for systems with the cost characteristics considered here, if aluminum steel and plastic containers accounted for a relatively large share of collected recyclables. Reported costs for many curbside collection programs fall within this range (i.e., $50 to $90 per ton), but some communities report substantially higher costs. Higher collection costs for recyclables may result from any of the same factors that increase mixed waste collection costs. Recycling collection costs, however, may be especially sensitive to variations in the tonnage hauled per truck per year resulting from variations in recycling participation rates.

Exhibit 31 reflects the assumption that collection costs for composting can be approximated by the cost of mixed waste collection, but costs will depend on which components of the waste stream are composted (e.g., sewage sludge, yard waste, and food processing waste). Some communities report yard waste collection costs that are substantially higher than mixed waste collection costs. By contrast, there may be no "collection" costs associated with composting sewage sludge or food processing wastes, because the cost estimates for transfer and transport may fully reflect the cost of loading and transporting compostables from sewage treatment plants or food processing facilities.

Transfer and Transport

As new landfills, WTE plants, and composting facilities are sited further from population centers, transfer and transport costs are likely to be incurred with each of these MSW management options. MRFs, however, may incur no transfer/transport costs. Because MRFs are similar to transfer stations in terms of land requirements and economic size (in tons per day), a recycling program that collects a substantial portion of the local waste stream should support the siting of MRFs at locations as convenient to collection zones as transfer stations.

The range of cost estimates in Exhibit 31 for transfer/transport includes transport cost estimates of $3 to $13 per ton (i.e., 50 to 76 percent of combined transfer/transport costs). Transport costs per ton are a function of the distance from transport stations to waste management facilities. To minimize land acquisition costs, new landfills are likely to be located relatively far from population centers. Thus, most communities will find that transfer/transport costs associated with landfills are near the high end of the range shown in Exhibit 31. At present, some communities are actually paying transport costs of $30 per ton or more, in order to reach distant landfills.

Facility Cost Estimates

The facility cost range shown for landfills and compost, WTE, and materials recovery facilities include the capital and interest (C&I), operations and maintenance (O&M), and residue/ash disposal costs for each of these management options. The capital-intensive nature of WTE facilities makes the facility cost of this MSW management option especially sensitive to interest rates. In general, financing a WTE facility at 6 percent versus 10 percent will reduce the cost per ton for this management option by $10 to $20.

Facility Revenue Estimates

Facility revenues per ton of MSW for WTE facilities reflect a range of 4.5 to 6.5 cents per kilowatt hour (KWH). Facility revenues for MRFs are revenues per collected ton of mixed newspaper and aluminum, steel, glass, and plastic containers, adjusted for delivery costs of $10 per ton and residue loss. Although some compost facilities earn revenues, Exhibit 31 reflects the assumption that delivery costs offset any revenue received.

As noted above, local market values for electricity and recycled materials can substantially alter the net cost of WTE facilities and MRFs. In the case of MRF recycling, local governments must consider local delivery costs and MRF residue rates, as well as market values, to estimate facility revenues.

IMPACT OF INFLATION

In addition to comparing current costs, local governments should consider the potential impact of inflation. The components of net cost that are sensitive to inflation include:

- Operation and maintenance costs for all MSW management options;
- Residue/ash disposal costs; and
- Revenues for WTE and MRF recycling.

In contrast, capital and interest (C&I) costs, if financed at a fixed rate, will not change over the life of the facility or equipment financed, regardless of changes in the rate of inflation. C&I costs account for less than one-third of collection, transfer, and transport costs. C&I also accounts for approximately two-thirds of composting facility costs and 50 percent of landfill costs. However, C&I costs may account for more than 100 percent of the net facility costs (i.e., facility costs minus revenues) for MRFs and WTE facilities because revenues may exceed the sum of O&M and ash/residue disposal costs. Thus, if inflation is expected to affect revenues to the same extent that it affects operating and disposal costs, the net facility cost per ton for MRFs and WTE facilities may decline over time, while 50 percent of the facility cost per ton for landfills and two-thirds of the facility cost for composting are subject to inflationary cost increases.

AVOIDED COSTS VERSUS INTEGRATED MANAGEMENT

Exhibit 31 can be used as a framework for comparing the net cost of any MSW management option with the avoided (i.e., total) cost of land disposal. Alternatively, Exhibit 13 can be used to combine complementary options, in order to estimate the integrated system costs of different MSW management strategies. Implementing the latter approach requires more regional cooperation, and closer working relationships with waste management vendors, but may reduce waste management costs for many communities.

CONCLUSION

The economics of building new waste management facilities favor an integrated approach. As shown by Exhibit 31, no single waste management method is consistently less expensive than other alternatives, although the costs for each community will vary according to recycling markets, population density, land values, electricity rates, and other factors. The cost estimates provided in this chapter, which include the cost of meeting new environmental standards, may represent dramatic increases in waste management expenditures for many communities.

Planning an integrated waste management system can minimize costs by taking advantages of the most economic management option for each portion of the waste stream. The life of many communities' most valuable MSW management resource -- the landfill -- can be extended by reducing the volume of refuse through combustion in a WTE plant. If yard wastes are composted, WTE facilities can be sized more efficiently, which saves capital expenditures for boilers. Recycling programs can recover non-combustible and non-degradable materials and other high-value items from the waste stream. Transfer stations can help communities take advantage of the economies of scale presented by regional facilities. The most economical mix of options will be driven by local conditions.

An integrated waste management system involves more than just facilities. To serve a community successfully, environmental controls and public participation must be thoroughly integrated throughout planning, implementation, and operation of the system. Incorporating these elements can help restore public confidence in our ability to manage waste safely by distinguishing today's practices from waste management in the past. By utilizing a combination of methods, integrated programs may also provide communities with the flexibility to manage the waste challenges of the future.

APPENDIX C

SUMMARY OF RELEVANT INFORMATION COLLECTED FROM FOSTER WHEELER POWER SYSTEMS, INC.

To document Foster Wheeler Power System's capabilities and experience in resource recovery, we are including data on our operating plants. The reference plants discussed in this section are the Charleston, Camden, Hudson Falls and Commerce resource recovery plants. Foster Wheeler's successful development, execution and operation of these facilities exhibit our commitment to the refuse incineration industry on a build, own and operate basis.

Foster Wheeler built the first water wall mass-burning refuse boilers in the U.S. almost 30 years ago, and it is the only U.S. company that has had a resource recovery plant successfully complete an entire life cycle.

The Charleston plant is a total Foster Wheeler responsibility from permitting through 20 year operation. Foster Wheeler has been successfully operating this plant at over a 90% capacity factor since it began commercial operation on November 1, 1989. This project was completed two months ahead of schedule despite the interruption of Hurricane Hugo.

Camden, also a full service operating plant, began commercial operations on July 1, 1991 within schedule and budget. This award-winning facility successfully met all full acceptance standards on its initial testing, and exemplifies our outstanding performance record in the resource recovery industry.

Our Camden Resource Recovery Facility received the 1995 Facility Recognition Award for Combustion Processes from the American Society of Mechanical Engineers (ASME), Solid Waste Processing Division, for an excellent performance record and several innovative achievements.

Hudson Falls is our most recent full service operating plant. The facility began commercial operation on February 14, 1992 after passing all required performance tests on its initial testing.

Commerce is included as it represents the first facility to go into operation in the U.S. with a dry scrubber/baghouse and Thermal DeNOx systems. The facility began commercial operation in December 1986 and has received several awards for its low emissions. Refer to the color diagram located on the following page for an illustrated tour of a typical Foster Wheeler resource recovery facility.

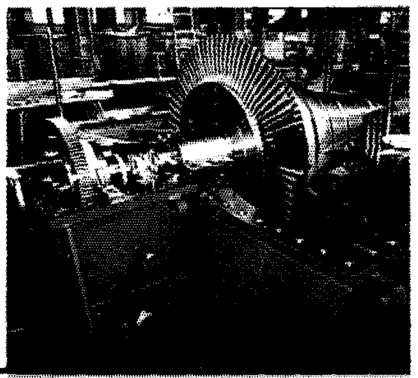
All of our operating plants reflects Foster Wheeler's commitment to minimize environmental impact through state-of-the-art technologies for emissions controls and combustion efficiency to insure reliability and profitability. Not only have each of our operating plants passed all performance tests on its initial testing, but all of our plants continue operating at above a 90% annual capacity factor while meeting permitted levels.

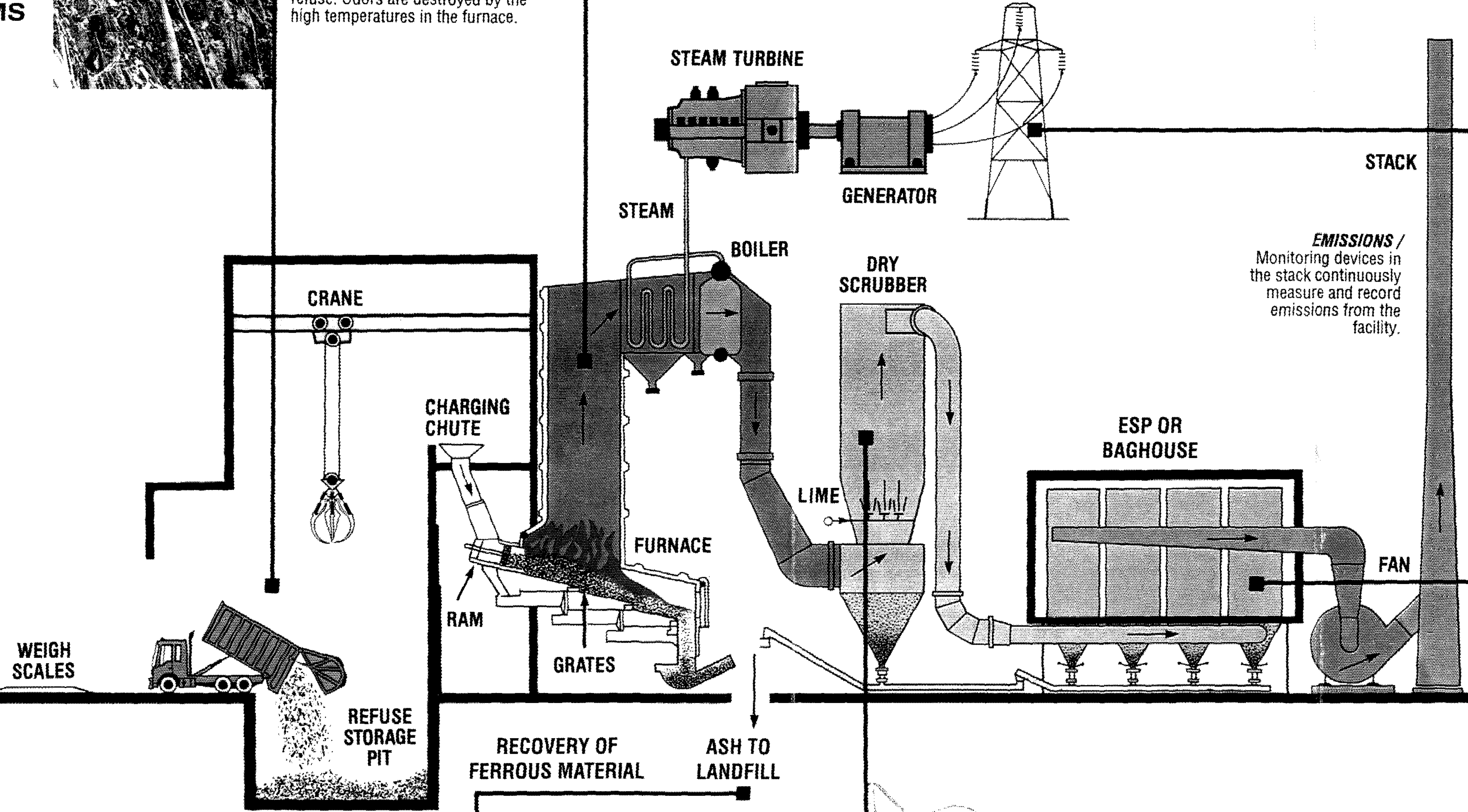

FOSTER WHEELER
CHARLESTON

**OSTER WHEELER
OWER SYSTEMS**

REFUSE STORAGE PIT / After weigh-in, the trucks discharge their loads into the refuse storage pit. The storage pit has capacity enough to run the facility for three to four days. The crane operator scoops up 10,000 lb. loads of refuse and delivers them to the furnace feed chutes. The entire storage pit area is enclosed and air is continually drawn into the refuse storage building to eliminate the escape of odors or dust. This air is then used for the burning of the refuse. Odors are destroyed by the high temperatures in the furnace.

FURNACE AND BOILER / After the refuse reaches the bottom of the feed chute, hydraulic rams push it into the burning area. The floor of the furnace contains moving grates which move the burning refuse through the furnace. Air drawn from the refuse pit passes upwards through the grates to insure complete combustion. The hot gases of combustion rise through the furnace as they travel to the boiler bank. The walls of the furnace contain steel tubes carrying water which begins to heat as the gases pass over the tubes. As the hot gases pass through the boiler, the hot water contained in the boiler tubing is converted to high pressure and temperature steam.

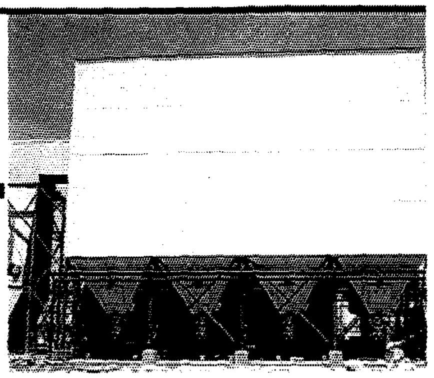




EMISSIONS / Monitoring devices in the stack continuously measure and record emissions from the facility.

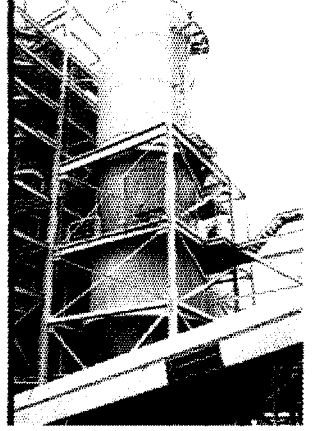
TURBINE-GENERATOR / The steam leavi
the boiler enters a steam turbine. The
high pressure steam causes the turbine
blades to turn at high speed. The turbine
is coupled to a generator which produce
electricity to be sold to the utility compa

VEIGH SCALES / Each truck must be weighed and a tipping fee levied based upon the weight of refuse delivered to the Facility.



ISPOSAL / The ash discharging from the grates at
bottom of the furnace is called bottom ash. This is
hed and then transported by conveyors to the ash
rage building for ultimate transport to the landfill.
ash carried through the furnace and boiler by the
ustion gases is called flyash. Along with lime and
oducts of the reactions in the dry scrubber, flyash
llected in the ESP or baghouse and combined for
sport to the landfill. The total ash (bottom ash and
sh) represents 25% of the weight of the incoming
fuse but only 10% by volume. In other words, the
refuse volume is reduced by 90%.

DRY SCRUBBER / After leaving the boiler, the hot combustion gases enter a sophisticated air pollution control system. The dry scrubber neutralizes acid gases such as sulphur dioxide and hydrochloric acid by reaction with a lime slurry which is sprayed into the gas stream. Heavy metals in the gas stream condense due to the reduction in temperature in the scrubber and become attached to the particles of flyash.



ELECTROSTATIC PRECIPITATOR / The ESP uses the principal of opposites attracting in order to collect particulate matter. As gases from the scrubber are drawn through the ESP the particulate matter is electrically charged. The charged particles are attracted to oppositely charged plates hung in rows along the gas passage. Particulate builds on the plates while clean gases exit to the stack thus eliminating any visible plume. Particles and flyash fall from the plates into bottom hoppers and are transported to the combined ash storage building

BAGHOUSE / The baghouse operates like a gigantic vacuu
cleaner. As the gases from the scrubber are drawn through t
baghouse, particulate matter and flyash are collected on t
outside of the bags and the cleaned gas passes through t
bags to the stack. The baghouse contains a number of modul
each incorporating many bags. Each module may be remov
from service during plant operation for cleaning of the bags by
reverse flow of air from the inside of the bags. Particles ar
flyash fall from the bags into hoppers at the bottom of t
baghouse and are transported to the combined ash stora
building. This process removes particulate matter dow
to the sub-microscopic levels, eliminating any visib
plume from the stac

A. CHARLESTON COUNTY RESOURCE RECOVERY FACILITY

Location: Charleston, South Carolina

Owner Contact:
AT&T Credit Corporation
44 Whippany Road
Morristown, NJ 07962
Attn: General Counsel

Plant Manager:
Roger Maxey
Foster Wheeler Charleston
P.O. Box 70459
Charleston, SC 29415-0459
(803) 566-9322

Client Reference Contact:
Richard Field
Operations Manager
Charleston County Recycling Center
13 Romney Street
Charleston, SC
(803) 720-7111

Foster Wheeler Responsibility: Foster Wheeler Power Systems (FWPS) was awarded the contract to build, own and operate the Charleston County Resource Recovery Facility in Charleston, South Carolina. Subsequent to successful completion and commercial operation of the plant, the equity ownership was sold to AT&T Credit Corporation as a financial investment. Foster Wheeler Charleston Resource Recovery, Inc. remains as the operator of the facility under terms of a 20 year operating lease.

Foster Wheeler was responsible for the design, engineering, procurement, construction and start-up of the Charleston Resource Recovery Facility, and remains responsible for long-term plant operations and maintenance.

Technology Used: FWPS utilized the Detroit Stoker grate technology, for which we have a formal agreement with Detroit Stoker for the supply and utilization of their equipment on all of our resource recovery projects.

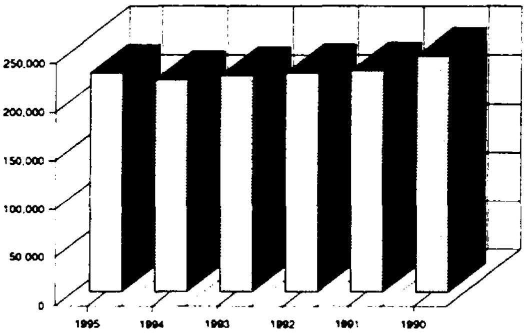
Plant Capacity: The plant capacity for 5,200 Btu/lb fuel is 600 tons per day(tpd) or 260,000,000 Btu/hr. Each of the two processing trains has a capacity of 300 tpd or 130,000,000 Btu/hr.

Commercial Operations Date: Initial refuse firing was August 8, 1989. The plant successfully passed all performance tests on its initial testing and entered commercial operation on November 1, 1989.

Annual Processed Tonnage: The facility is designed to process a minimum of 188,000 tons per year of 4844 Btu/lb processible waste.

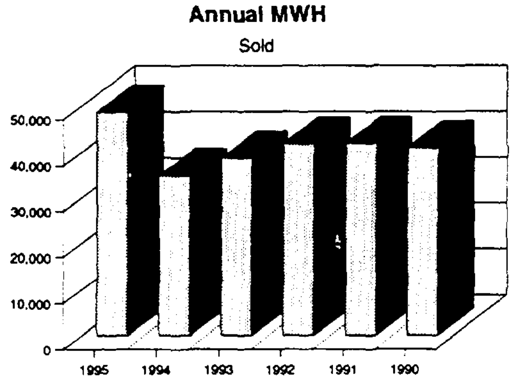
Annual Waste Delivery

(Tons)



Design Steam Conditions: The minimum amount of 750°F, 650 psig steam produced by the facility is guaranteed to be 6,400 pounds per ton of 4,844 Btu/lb fuel. During the Facility Acceptance Test, the steam produced was 6,847 pounds per ton of 4,844 Btu/lb fuel.

Annual Steam and Electrical Output: The plant is designed to export 10,000 kW of electricity while exporting 125,000 pounds per hour of 150 psig, 425°F steam.



Annual Tonnages of Residue and Bypass Waste: Please refer to the enclosed chart for bypass waste and residue quantities generated.

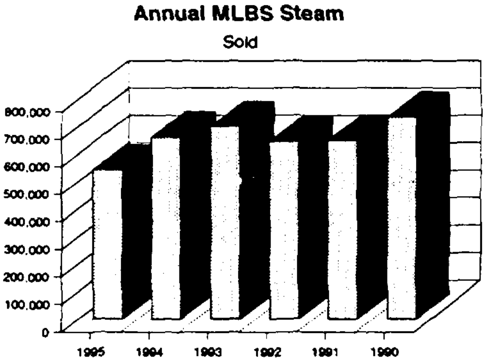
Method of Waste Handling and Storage Capacity: The facility has a two lane road, a scale house (located between the inbound and outbound scales) and an enclosed tipping floor to service the refuse trucks. The refuse trucks discharge the waste into the refuse storage pit, which has a storage capacity of 4 ½ days. Two overhead cranes (one of which is designed totally as a spare) move the MSW from the receiving pit to the charging hoppers of two identical mass burn steam generators.

From the charging hopper, the refuse is gravity fed from the feed chute to the hydraulic charging ram. The charging ram maintains a relatively thin and uniform fuel bed on the inclined Detroit Stoker Reciprograte.

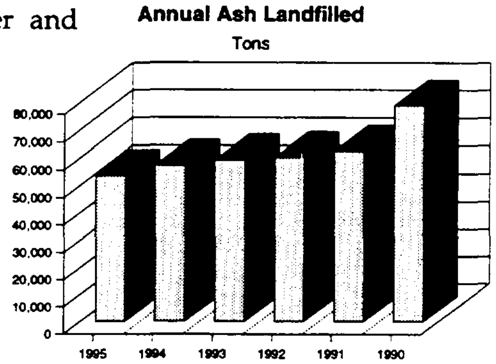
Tipping floor/pit size, capacities, special or unique features: The tipping floor is 165 feet long by 70 feet wide, providing 11,550 square feet area and nine tipping positions. The pit capacity is 6,000 cubic yards below the tipping floor elevation with an additional 5,760 cubic yards storage capacity available above the pit by utilizing the height of the back pit wall and end walls. This provides a storage capacity of approximately 4 ½ days.

Furnace/boiler system design, number of trains, capacities: The boiler system is Foster Wheeler's own waterwall boiler design consisting of two boiler trains, each with a design MCR capacity of 87,500 lb/hr of steam and a design loading each of 81,800 lb/hr of steam, both at 650 psig, 750°F when burning 4,844 Btu/lb MSW. The reciprocating grate system is an inclined, stepped system supplied by Detroit Stoker.

Boiler/water/steam system: The wastewater supply source is city water with an average daily usage of 410,000 gallons per day. The water treatment system consists of two 100% capacity parallel trains incorporating gravity filters and cation/anion demineralizers. Steam is produced at 650 psig, 750°F to drive the turbine generator, with extraction steam at 165 psig, 425°F for in-plant use and export. A water cooled condenser is provided to condense exhaust steam from the turbine and to maintain a low back pressure on the turbine. Cooling water is supplied by a circulating system including a mechanical-draft two cell cooling tower. The wastewater system consists of discharge to the municipal sewer.



Ash System - quench process, conveying systems, disposal points, volumes of ash, characteristics of ash: The residue remaining on the grates after burnout is quenched by water in an ash extractor before it is conveyed to the residue storage area. The ash is discharged onto a vibrating conveyor and transported to the residue storage area. Fly ash from the air pollution control devices, superheater and economizer is combined with bottom ash in the ash extractor, quenched and conveyed to the residue storage area for truck loading and hauling to the landfill.



Air Pollution Control System: The air pollution control system consists of two complete processing lines, one for each boiler. Each processing line includes a dry scrubber and an electrostatic precipitator.

Site Utilization - size, configuration, other facilities on site, special features: The site is located on approximately 17.8 acres with a rectangular configuration, and is located along a creek across from the Navy Base (steam purchaser).

Charleston Operating Summary

	1995	1994	1993	1992	1991	1990
Boiler Operation						
"A" Boiler						
% Availability	90.1	89.98	93.5	91.2	92.4	93.7
% Capacity	93.2	91.61	95.5	95.3	93.5	95.9
"B" Boiler						
% Availability	92.6	91.20	94.1	92.1	93.1	92.8
% Capacity	97.4	90.35	92.4	94.5	94.7	95.5
Total % Availability	91.4	90.59	93.8	91.6	92.7	93.2
Total % Capacity	95.3	90.98	93.9	95.0	94.1	95.7
MWH Sold	48,705	34,876	38,692	41,781	41,876	40,885
MLBS Steam	540,761	660,594	700,056	643,376	648,807	733,817
Refuse Received (tons)	225,660	218,863	223,309	225,827	228,206	243,144

Notes:
% Availability based upon boiler operating hours
% Capacity based upon design steam production


CAMDEN
RESOURCE RECOVERY FACILITY
FOSTER FW WHEELER

B. CAMDEN COUNTY RESOURCE RECOVERY FACILITY

Location: Camden, New Jersey

Owner Contact:
Foster Wheeler Camden County Resource Recovery Associates, Inc.
600 Morgan Boulevard
Camden, New Jersey 08104

Plant Manager:
Newt Wattis
Foster Wheeler Camden County
600 Morgan Boulevard
Camden, New Jersey 08104
(609) 966-7174

Client Reference Contact:
John W. Londres
Deputy Director Resource Recovery & Authority Operations
Pollution Control Financing Authority of Camden County
608 Morgan Boulevard
Camden, New Jersey 08104
(609) 541-1171

Foster Wheeler Responsibility: Foster Wheeler Power Systems was awarded the contract to build, own and operate the Camden County Resource Recovery Facility in Camden, New Jersey. *Foster Wheeler was responsible for the design, engineering, procurement, construction and start-up of the Camden County Resource Recovery Facility, and remains responsible for long-term plant operations and maintenance.*

Technology Used: FWPS utilized the Detroit Stoker Reciprograte grate technology, for which we have a formal agreement with Detroit Stoker for the supply and utilization of their equipment on all of our resource recovery projects.

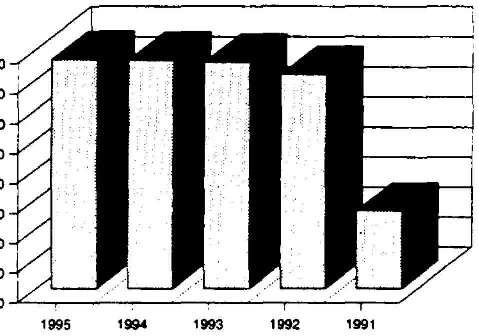
Plant Capacity: The plant capacity for 4,500 Btu/lb fuel is 1,050 tpd or 393,750,000 Btu/hr.

Each of the three processing trains has a capacity of 350 tpd or 131,250,000 Btu/hr.

Operations Date: Initial refuse firing was April 25, 1991. The plant successfully passed all performance tests on its initial testing and entered commercial operations on July 1, 1991.

Annual Processed Tonnage: The facility is designed to process a minimum of 306,600 tons per year of 4,500 Btu/lb processible waste. From July 1, 1991 to May 21, 1992, the facility had received and processed 245,761 tons of refuse with no bypass.

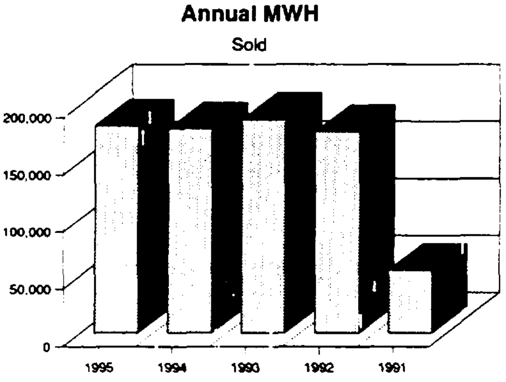
Annual Waste Delivery
(Tons)



Design Steam Conditions: The minimum amount of 750°F, 650 psig steam produced by the facility is guaranteed to be 5952 pounds per ton of 4949 Btu/lb fuel. During the Facility Acceptance Test the steam produced was 6,124 pounds per ton of 4,949 Btu/lb fuel.

Annual Steam and Electrical Output: At a higher heating value of 4,949 Btu/lb, the plant is designed and guaranteed to generate 525 kWh/ton. During Acceptance Testing, the plant actually generated 564 kWh/ton.

Annual Tonnages of Residue and Bypass Waste: There has been no bypass to date. The residue guarantee is 30% (dry) tons of residue per ton of refuse processed, no more than 5% (by weight) combustibles and 0.2% (by Weight) putrescibles. During Acceptance Testing, residue generation was 28% (dry) tons of residue per ton of refuse processed, combustible content was 1.35% (dry weight) and putrescible content was 0.00165% (by weight).



Method of Waste Handling and Storage Capacity: The facility has a two lane road, a scale house (located between the inbound and outbound scales) and an enclosed tipping floor to service the refuse trucks. The refuse trucks discharge the waste into the refuse storage pit, which has a storage capacity of 5 days. Two overhead cranes (one of which is designed totally as a spare) move the MSW from the receiving pit to the charging hoppers of two identical mass burn steam generators.

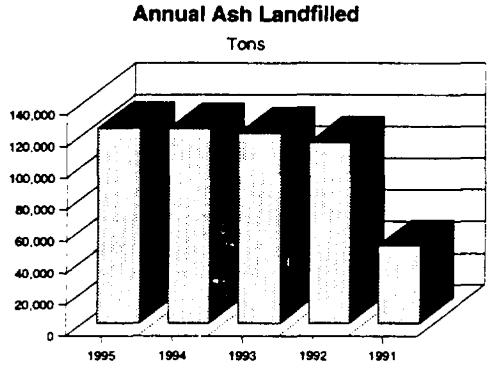
Tipping floor/pit size, capacities, special or unique features: The tipping floor is 290 feet long by 60 feet wide, providing 17,400 square feet area and twenty tipping positions. The pit capacity is 16,100 cubic yards below the tipping floor elevation with an additional 5,000 cubic yards storage capacity available above the pit by utilizing the height of the back pit wall and end walls. This provides a storage capacity of approximately 5 days.

Furnace/boiler system design, number of trains, capacities: The boiler system is Foster Wheeler's own waterwall boiler design consisting of three boiler trains each with a design MCR capacity of 104,000 lb/hr of steam and a design load each of 87,000 lb/hr of steam, both at 650 psig, 750°F when burning 4,500 Btu/lb MSW. The reciprocating grate system is an inclined, stepped system supplied by Detroit Stoker.

Boiler/water/steam system: The wastewater supply source is city water and well water with an average daily usage of 239,000 gallons and 200,000 gallons per day, respectively (under no steam export conditions). The water treatment system consists of two 100% capacity parallel trains incorporating gravity filters and cation/anion demineralizers. A water cooled condenser is provided to condense exhaust steam from the turbine and to maintain a low back pressure on the turbine. Cooling water is supplied by a circulating system including a mechanical-draft two cell cooling tower. The wastewater system consists of discharge to the municipal sewer.

Ash System - quench process, conveying systems, disposal points, volumes of ash, characteristics of ash: The residue remaining on the grates after burnout is quenched by water in an ash extractor before it is conveyed to the residue storage area. Fly ash from the air pollution control devices, superheater and economizer is combined with bottom ash in the ash extractor, quenched and conveyed to the residue storage area for truck loading and hauling to the landfill.

Air Pollution Control System: The air pollution control system consists of three complete processing lines, one for each boiler. Each processing line consists of a dry scrubber and an electrostatic precipitator.



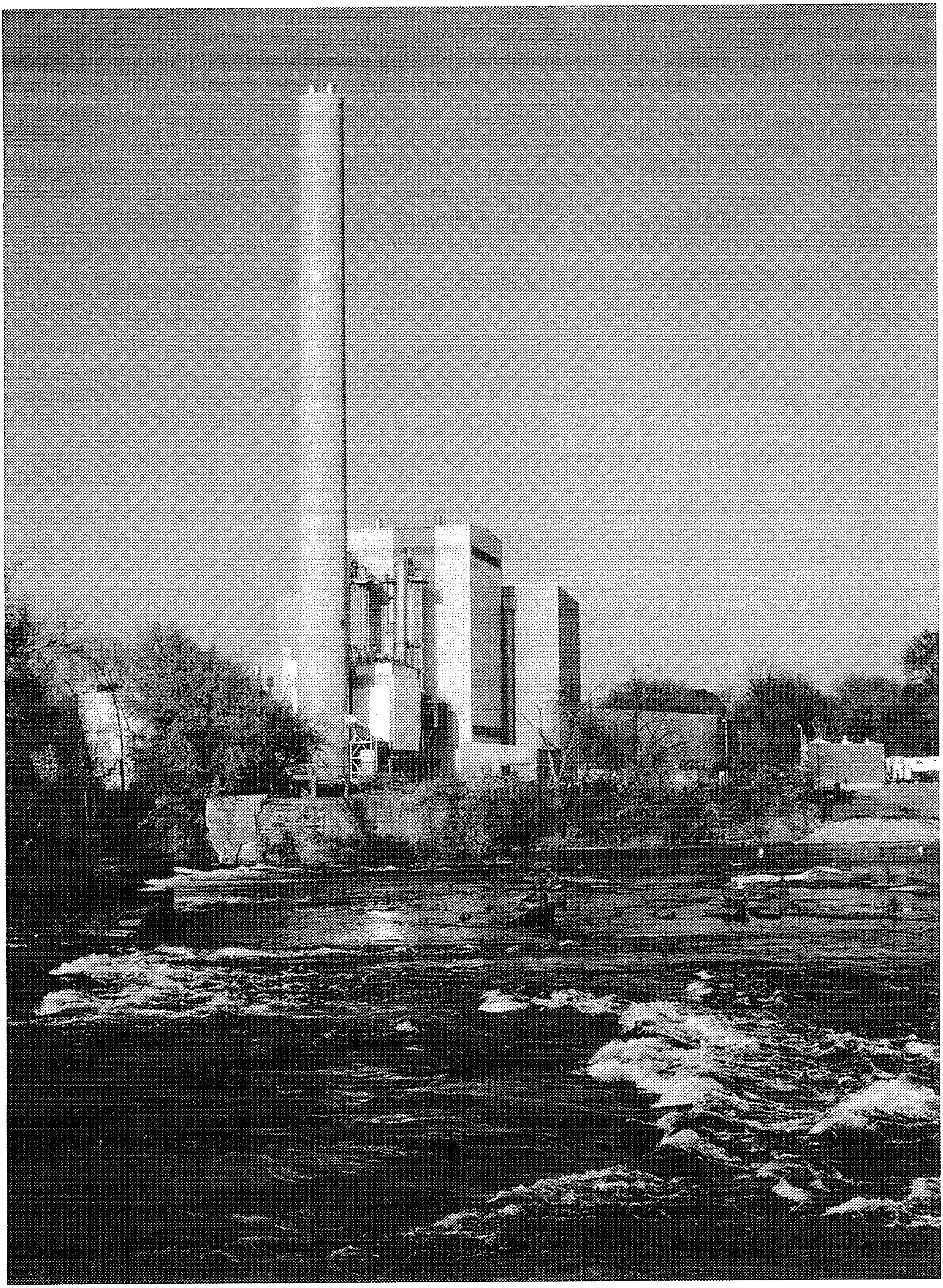
Site Utilization - size, configuration, other facilities on site, special features: The site is located on approximately 12 acres with a rectangular configuration, and is bounded by I-676 and Newton Creek.

Secondary material recovery operations at the Reference Plant. There is ferrous material recovery at this plant.

Camden Operating Summary

	1995	1994	1993	1992	1991
Boiler Operation					
"A" Boiler					
% Availability	92.7	90.88	92.2	89.3	79.7
% Capacity	93.6	91.57	95.5	95.8	75.8
"B" Boiler					
% Availability	92.7	92.60	93.6	90.2	77.5
% Capacity	94.3	93.61	96.6	95.8	72.4
"C" Boiler					
% Availability	93.8	94.09	92.9	86.5	64.0
% Capacity	95.4	96.42	97.2	93.9	60.4
Total % Availability	93.1	92.52	92.9	85.8	73.7
Total % Capacity	94.4	93.86	96.3	95.1	69.5
MWH Sold	180,768	178,300	186,386	176,073	54,655
Refuse Received (tons)	382,926	381,495	376,556	357,968	130,711

Notes:
% Availability based upon boiler operating hours
% Capacity based upon design steam production
Low availability/capacity for years 1991 and 1992 due to lack of waste.



C. HUDSON FALLS RESOURCE RECOVERY FACILITY

Location: Hudson Falls, New York

Plant Manager:
Dan Walsh
61 River Street
Hudson Falls, NY 12839-0191
(518) 747-2390

Client Reference Contact:
Stephen P. Blakeslee
Solid Waste Coordinator
c/o Industrial Development Agency
111 River Street
P.O. Box 706
Hudson Falls, New York 12839
(518) 747-3845

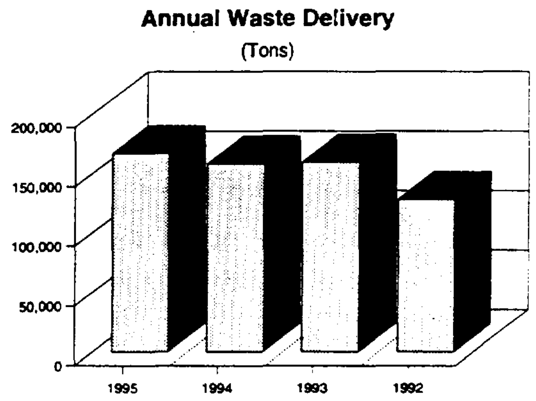
Foster Wheeler Responsibility: Foster Wheeler Power Systems was awarded the contract to build, own and operate the Hudson Falls Resource Recovery Facility (also referred to as the Adirondack Resource Recovery Facility) in Hudson Falls, New York. *Foster Wheeler was responsible for the design, engineering, procurement, construction and start-up of the Hudson Falls Resource Recovery Facility, followed by 20 years of commercial operation.*

Technology Used: FWPS utilized the Detroit Stoker grate technology, for which we have a formal agreement with Detroit Stoker for the supply and utilization of their equipment on all of our resource recovery projects.

Plant Capacity: The plant capacity for 6,200 Btu/lb fuel is 400 tpd with two processing trains, each with a capacity of 200 tpd.

Commercial Operations Date: The plant successfully passed all performance tests on its initial testing and entered commercial operation on February 14, 1992.

Annual Processed Tonnage: The facility is designed to process a minimum of 117,000 tons per year of processible waste.



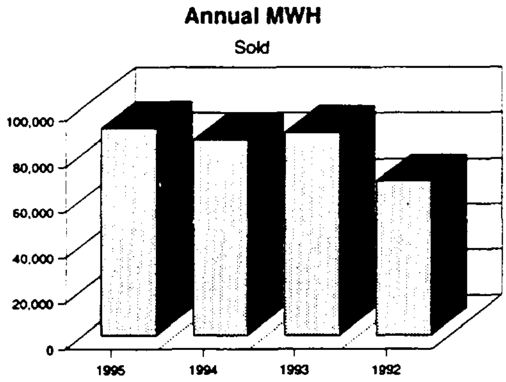
Design Steam Conditions: The amount of 750°F, 650 psig steam produced by the facility with 6,200 Btu/lb fuel is 143,000 lb/hr at MCR.

Annual Steam and Electrical Output: The plant is designed to produce 13.4 MW of electricity (gross) at MCR. The plant does not export steam to outside users.

Annual Tonnages of Residue and Bypass Waste: The plant processed more than 54,000 tons of waste in its first 5 months of operation.

Method of Waste Handling and Storage Capacity: The facility has a two lane road, a scale house (located between the inbound and outbound scales) and an enclosed tipping floor to service the refuse trucks. The refuse trucks discharge the waste into the refuse storage pit, which has a storage capacity of 3½ days. Two overhead cranes (one of which is designed totally as a spare) move the MSW from the receiving pit to the charging hoppers of two identical mass burn steam generators. From the charging hopper, the refuse is gravity fed from the feed chute to the hydraulic charging ram.

The charging ram maintains a relatively thin and uniform fuel bed on the inclined Detroit Stoker Reciprograte.



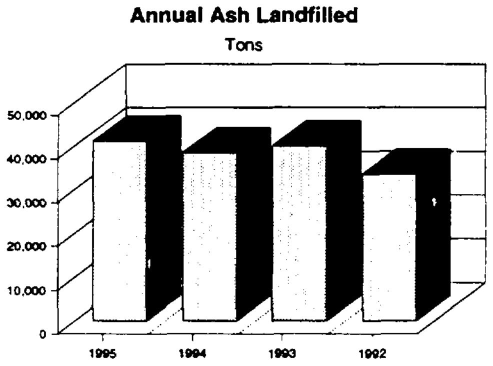
Tipping floor/pit size, capacities, special or unique features: The tipping floor is 165 feet long by 70 feet wide, providing 11,550 square feet area and nine tipping positions. The pit capacity is 6,000 cubic yards below the tipping floor elevation with an additional 5,760 cubic yards storage capacity available above the pit, by utilizing the height of the back pit wall and end walls. This provides a storage capacity of approximately 4½ days.

Furnace/boiler system design, number of trains, capacities: The boiler system is Foster Wheeler's own waterwall boiler design consisting of two boiler trains, each with a design MCR capacity of 71,570 lb/hr of steam at 650 psig, 750°F, when burning 6,200 Btu/lb MSW. The reciprocating grate system is an inclined, stepped system supplied by Detroit Stoker.

Boiler/water/steam system: The wastewater supply source is city water. The water treatment system consists of two 100% capacity parallel trains incorporating gravity filters and cation/anion demineralizers.

Ash System - quench process, conveying systems, disposal points, volumes of ash, characteristics of ash: The residue remaining on the grates after burnout is quenched by water in an ash extractor before it is conveyed to the residue storage area. The ash is discharged onto a vibrating conveyor and transported to the residue storage area. Fly ash from the air pollution control devices, superheater and economizer is combined with bottom ash in the ash extractor, quenched and conveyed to the residue storage area for truck loading and hauling to the landfill.

Air Pollution Control System: The air pollution control system consists of two complete processing lines, one for each boiler. Each processing line includes a dry scrubber and an electrostatic precipitator.



Secondary material recovery operations at the Reference Plant: There is ferrous material recovery at this plant.

Hudson Falls Operating Summary

	1995	1994	1993	1992
Boiler Operation				
"A" Boiler				
% Availability	95.7	95.39	95.6	92.2
% Capacity	97.2	92.32	94.7	86.1
"B" Boiler				
% Availability	95.6	95.92	96.0	94.8
% Capacity	94.6	91.60	93.2	88.0
Total % Availability	95.6	95.70	95.8	93.5
Total % Capacity	95.9	92.0	94.0	87.1
MWH Sold	90,816	85,824	88,990	67,815
Refuse Received (tons)	166,402	157,435	159,026	127,798

Notes:
% Availability based upon boiler operating hours
% Capacity based upon design steam production

In addition, Foster Wheeler Power Systems is currently implementing several resource recovery projects, one of which is currently under construction. These are described below.

Robbins WTE Facility

Foster Wheeler Power Systems was selected to design, build, and operate this country's first waste-to-energy facility to utilize circulating fluidized bed (CFB) technology for the combustion of municipal solid waste. This 1,600 tpd facility, which is currently under construction, will serve southern suburban municipalities in Cook County, Illinois. The plant, owned by the Village of Robbins, will be operated under a 32-year agreement by Foster Wheeler Illinois, who will have the responsibility for all technical, commercial and financial activities of the project.

The plant will process residential and commercial trash into refuse derived fuel (RDF) by removing about 25% of the incoming waste as recyclable materials, and shredding the remainder. The RDF produced will be burned in two 600 ton-per-day circulating fluidized bed (CFB) boilers designed and fabricated by Foster Wheeler Energy Corporation and to be erected by Foster Wheeler Constructors, Inc. The plant will generate in excess of 50 megawatts of electrical energy for sale to Commonwealth Edison, enough power to supply more than 50,000 homes.

The attractiveness of the plant to local communities is that it offers "one-stop" trash pickup. For a competitive price, a community can rely on the Robbins facility to take care of its recycling needs and dispose of its remaining waste to create energy. The resulting ash to be landfilled is less that 5% of the volume of the incoming waste.

The front-end waste processing system recovers ferrous materials, aluminum beverage cans, mixed glass and an organic stream for use as a compost feed. The removal of a large portion of the non-burnable and low heating value components of the waste stream help to provide a uniform, high quality fuel for very efficient combustion in the CFB boilers. The inherent effectiveness of CFB combustion and the state-of-the-art air pollution control equipment will demonstrate the Robbins plant to be the cleanest waste-to-energy facility in the U.S.

Foster Wheeler Montreal, Inc.

Foster Wheeler Power Systems was awarded the contract to design, build and operate the 2,250 tpd integrated resource recovery facility for the Island of Montreal. This is the first fully integrated solid waste management project in North America to be awarded to one company, with FWPS responsible for all aspects of the project. The project is currently in the permitting phase. The facility consists of the following components:

1.) 1,500 tpd Waste-to-Energy Facility

2.) 500 tpd Recycling Facility

3.) 250 tpd Composting Facility (leaf and yard waste only)

The mass burn facility will employ two identical 750 tpd Detroit Stoker Reciprogrates and Foster Wheeler Limited boilers, each with its own dry scrubber and baghouse. Thermal DeNOx is also included for the reduction of NOx emissions. Steam generated by the combustion of refuse will be used to generate 40 MW of electricity, which will be sold to the local utility. Provisions will be made to allow for the addition of a third train should future waste flows increase significantly.

The recycling facility will accept commingled recyclables, and sell the processed product as feedstock on the secondary materials market. Revenues received from the sale of recyclables will help offset the cost of collection and processing. The capacity of the recycling facility can be increased by adding a second shift. The composting facility will receive leaf and yard waste only.

Lisbon WTE Project

Foster Wheeler Power Systems, Inc., in joint venture with Foster Wheeler Conception Etudes Entretien, was selected by VALORSUL (Valorizacao e Tratamento de Residuos Solidos da Area Metropolitana de Lisboa [Norte], S.A.) to design, build and supply the mass burn, municipal solid WTE plant to be located in Loures, Portugal. The plant will be capable of treating 2,000 tpd of refuse from the municipalities of Amadora, Lisbon, Loures and Vila Franca de Xira, and will generate the net equivalent of 41.5 MW of electric power which will be sold to Electricida de Portugal on a long-term basis. The project represents a major example of VALORSUL's commitment to globally manage the municipal waste stream generated in the North Metropolitan Area of Lisbon.

The plant will employ Foster Wheeler boilers and all of the auxiliary, support and control systems necessary to comply with strict environmental protection requirements imposed by VALORSUL in anticipation of revised emission limits that are expected to be enforced by the European Union in the near future.

This project will draw on Foster Wheeler Power System's extensive experience in the design, construction and operation of such plants as well as on Foster Wheeler Conception Etudes Entretien's expertise in engineering and construction work, particularly in Portugal.

APPENDIX D

DESCRIPTION OF FLUIDIZED BED COMBUSTION TECHNOLOGY

A. Fluidized Bed Combustion Technology

Beginning in the 1970s there was a growing interest in finding ways to a) combust a wider range of fossil fuels, b) improve the efficiency of the combustion process and, c) combust the fossil fuels in a "cleaner" manner, i.e., with lower emissions. One outcome of research and development work was fluidized bed combustion technology which met the above objectives.

B. General Description of Fluidized-bed Combustion

"Fluidization" refers to the condition in which solid materials are given free-flowing, fluid-like behavior. As a gas is passed upward through a layer, or bed, of solid particles, the flow of gas produces forces which tend to separate the particles from one another. At low gas flows, the particles remain in contact with other solids and tend to resist movement. This condition is referred to as a fixed bed. As the gas flow is increased, a point is reached at which the forces on the particles are just sufficient to cause separation. The bed then becomes fluidized. The gas cushion between the solids allows the particles to move freely, giving the bed a liquid-like characteristic.

The transition from fixed bed to fluid bed can be described by ploting gas pressure drop through the bed versus gas velocity. For a fixed bed, pressure drop is proportional to the square of velocity. As velocity is increased, the bed becomes fluidized; the velocity at which this transition occurs is called the minimum fluidization velocity, V_{mf}. V_{mf} depends on many factors including particle diameter, gas and particle density, particle shape, gas viscosity, and bed void fraction. At velocities above V_{mf}, the pressure drop through the bed remains nearly constant and is equal to the weight of solids per unit area, as the drag forces on the particles just overcome the gravitational forces. Further increases in velocity bring about changes in the state of fluidization, to be discussed later.

In fluidized-bed combustion, fuel is burned in a bed of hot incombustible particles suspended by an upward flow of fluidizing gas. Typically, the fuel is a solid such as coal or biomass, although liquid and gaseous fuels can be readily used. The fluidizing gas is generally the combustion air and the gaseous products of combustion. Where sulfur capture is not required, the fuel ash may be supplemented by inert materials such as sand to maintain the bed. In applications where sulfur capture is required, limestone is used as the sorbent and forms a portion of the bed. Bed temperature is usually maintained between 1550°F - 1700°F (800°C - 900°C) by the use of heat-absorbing surface within or enclosing the bed. This temperature is optimal for the chemical processes needed to capture sulfur and control NO_x emissions. It also avoids ash softening in nearly all fuels. At this temperature, efficient combustion can be achieved because of the relatively long residence time of fuel in the bed and the good gas/solids contact there.

The above characteristics lead to the following major advantages of FBC:

Fuel Flexibility

Because temperature levels are held below the ash-softening level, the FBC boiler is not sensitive to fuel ash characteristics. A wide range of fuels with varying ash contents and properties can be burned in a single boiler.

The high thermal inertia of the bed mass provides for stable ignition and combustion of very low grade fuels such as fuels high in ash and/or moisture. Fuels with up to 70-percent ash and 50-percent moisture have been successfully burned in a fluid bed. The high thermal inertia of the bed also provides for good performance when firing low-volatile fuels such as anthracite, anthracite waste and petroleum coke.

Low Emissions

SO_2 emissions are controlled within the combustor by addition of a sorbent material, typically limestone, so a stack-gas SO_2 scrubber is not required. The sulfur sorbent can also react with other fuel constituents such as vanadium, reducing down-stream corrosion potential.

NO_x emissions are considered to come from two sources: oxidation of nitrogen in the air (thermal NO_x) and oxidation of nitrogen and/or nitrogen components in the fuel (fuel NO_x). At the low temperatures in FBC, thermal NO_x production is essentially zero. Design features such as staged combustion can significantly reduce fuel NO_x, leading to low total NO_x emissions.

C. Types of FBC Systems

The state of fluidization in an FBC boiler depends mainly on the bed-particle diameter and fluidizing velocity. There are two basic fluid-bed combustion systems, each operating in a different state of fluidization. At relatively low velocities and with coarse bed-particle size, the fluid bed is dense, with a uniform solids concentration, and has a well-defined surface. This system is called a *bubbling fluid bed* ("BFB"), because the air in excess of that required to fluidize the bed passes through the bed in the form of bubbles. The BFB is further characterized by modest bed solids mixing rate, and relatively low solids entrainment in the flue gas.

At higher velocities and with finer bed-particle size, the fluid bed surface becomes diffuse as solids entrainment increases, such that there is no longer a defined bed surface; recycle of entrained material to the bed at high rates is required to maintain bed inventory. The bulk density of the bed decreases with increasing height in the furnace. A fluidized-bed with these characteristics is called a *circulating fluid bed* ("CFB") because of the high rate of material circulating from the furnace to the particle recycle system and back to the furnace. The CFB is further characterized by very high solids-mixing rates.

Corresponding values for stoker firing and pulverized-fuel firing are also shown. Stoker firing incorporates a fixed bed, having lower velocity and coarser particle size than the BFB. Pulverized firing incorporates an entrained bed having higher velocity and finer particle size then the CFB.

C.1 Chemical Processes in FBC

Within the fluidized bed, several interrelated chemical processes occur, including combustion, sulfur capture, and NO_x reduction.

C.2 Fuel Combustion

Even at the relatively low temperature associated with fluidized-bed combustion, the combustion of fuel in a fluid bed is a rapid process. The combustion rate is mainly a function of the reactivity of the fuel and the fuel surface area available. Solid fuel can be considered to consist of volatile matter and fixed carbon (char) which remains after the volatiles are driven off. Volatile combustible matter generally burns more rapidly than the residual char and volatile combustion can be viewed as a separate process in parallel with char combustion. The concentration of char within the fluidized bed at any given time in typically about one percent. The char concentration will increase with less reactive fuels to the point at which the surface area available compensates for the lower reactivity. Because sulfur dioxide is released during the combustion process, fuel-burning characteristics can significantly influence sulfur capture.

The combustible loss from an FBC boiler is predominantly a function of the amount of char that escapes the system without burning. Generally, the loss from unburned volatiles is insignificant. The char particles escape from the bed in the flue gas or are drained from the bed in the bottom ash. With proper design, unburned carbon can be limited to 1% or less of fuel heat input for nearly all fuels.

C.3 Sulfur Capture

The use of limestone as a sulfur-capture sorbent allows sulfur emissions to be controlled within the fluidized bed during the combustion process. Limestone consists of calcium carbonate ($CaCO_3$) and various impurities. Lime (CaO) is formed by calcining the limestone to drive off carbon dioxide (CO_2)

$$CaCO_3 \rightarrow CaO + CO_2 \qquad (1)$$

Sulfur in the fuel is converted to sulfur dioxide (SO_2) during the combustion process. Although nearly all of the sulfur is oxidized, some of the inorganically bound sulfur may be retained in the ash. The sulfur dioxide combines with the calcined lime in the reaction:

$$SO_2 + CaO + \frac{1}{2} O_2 \rightarrow CaSO_4 \qquad (2)$$

Equations 1 and 2 indicate that a mole of calcium is required to capture one mole of sulfur. Then, defining the Ca/S molar ratio as moles of calcium in the limestone feed to moles of sulfur in the fuel feed, the theoretical minimum Ca/S required for a given level of sulfur removal is 1/1, which assumes 100-percent utilization of the sorbent.

In practical systems, 100-percent utilization is impossible to attain. Because the sulfation process takes place on the surface of the lime particles in the bed, the lime contained in the particle core is generally not utilized. Also, some SO_2 will escape capture if the total sorbent surface area within the bed is insufficient. Consequently, Ca/S mole ratios greater than 1/1 are necessary.

The porosity of the particle surface formed during calcination is a strong factor in sulfur capture. Slow calcination results in a highly porous particle with an exposed surface larger in area than that of a smooth particle of similar diameter. As it forms, calcium sulfate tends to block these pores. Deep pores provide large surface area but may plug with sulfate before being filled. The optimum provides the maximum surface that can be fully sulfated. The presence of magnesium carbonate ($MgCO_3$) tends to enhance limestone utilization, even though it does not participate in the sulfur-capture process. This is because, in calcining to MgO, the $MgCO_3$ increases the porosity of the stone.

The calcination process begins at around 1300°F (700°C) and, as does the sulfation process, improves as temperature increases. However, the most favorable combination of calcination and sulfation occurs at about 1550°F (840°C). Above this temperature, less-than-optimum porosity forms, limiting the sulfation capacity of the lime particles. Fig. 3 indicates the dependence of sulfur capture on temperature.

C.4 NO_x Reduction

NO_x emissions from an FBC boiler are generally less than 0.3 lb/million BTU (440 Mg/Nm^3). Although at the low temperatures typical of FBC no atmospheric nitrogen is converted to NO_x, laboratory data have shown that nearly all of the fuel nitrogen is converted to NO_x during the burning process. For a typical coal containing 1 percent nitrogen, the potential NO_x release is roughly 3 lbs/million BTU (4400 Mg/Nm^3). Thus, secondary processes are responsible for the low NO_x emissions.

Carbon monoxide (CO) and char present in the bed are strong reducing agents and appear to be the principal factors in lowering NO_x. These agents strip oxygen from the NO_x in a reduction reaction that produces elemental nitrogen (N_2).

Additional NO_x reduction can be achieved by injection of ammonia (NH_3) into the gas stream leaving the furnace, per the following reactions:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$

NO_x emissions can then be lowered to 0.1 lb/million BTU (150 Mg/Nm^3) and lower.

D. Bubbling Fluidized-bed (BFB) Steam Generators

Fuel is fed mechanically to the lower portion of the furnace above the surface of the bed. Primary air is supplied to the bottom of the furnace through an air distributor, with secondary air fed through one or more elevations of air ports above the bed. Devolitilization, or gasification of the fuel, takes place in the bed. Combustion of the gases takes place above the bed. Flue gas leaves the furnace and passes over the various heat transfer surfaces such as superheater, generating bank, economizer and air heater.

Solids inventory in the furnace is controlled by draining hot solids through drains. Tramp material such as rocks can be removed from the bed by controlling the draining rate or frequency.

Early on, the BFB technology was used for firing 100% coal. Because the coal burns mainly within the bed, heat transfer surface, in the form of in-bed tubing cooled with water and/or steam, was needed to control bed temperature to the desired level. The experience with in-bed tubing has been mixed, with some units needing frequent maintenance. Today, BFB technology is mainly used for biomass and coal firing is limited to 30-40% heat input. Because biomass burns both within and above the bed, no in-bed tubing is needed

Process Design

Design combustor velocity above the bed is established at 10 - 15 ft/sec (3 - 4.5 m/s). This velocity level provides reasonable furnace heat-transfer surface for a given height, low erosion rates, and an acceptable turndown range with adequate bed stability. SO_2 emissions can be reduced by up to 50-percent at Ca/S molar ratio of 2-4 (depending on fuel sulfur levels, limestone reactivity, etc.).

Part-Load Operation

Turndown is accomplished by reducing both fuel and air to the unit. In the process, grid and furnace velocity are kept above a minimum level in order to produce adequate mixing and fluidization for reasonable fuel combustion and to avoid severe temperature maldistribution and backsifting of bed material into the air plenum.

Start-up

Start-up is accomplished by means of start-up burners located in the lower furnace walls and/or in the primary air duct. The start-up burners fire oil or gas. Minimum primary-air flow is established and the start-up burners are used to heat the bed material. When solid-fuel permissive temperature is reached (typically 1000°F to 1100°F (540°C to 600°C)), solid fuel is added. Temperature is further increased by adding solid fuel and backing out start-up fuel. At about 25 percent load, the boiler can run on solid fuel alone.