CAT Comparison
Economics of CAT 3516A+ versus CAT 3520 Engines

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Introduction

Cornerstone Environmental Group, LLC (Cornerstone) has compared the economic feasibility of using landfill gas (LFG) to produce electricity with CAT 3516 A+ and CAT 3520 engines. The evaluation is based on specific LFG generation rates and considers the cost of design, equipment procurement, equipment installation, electricity sales, and operations and maintenance (O&M). The paper presents the results of Cornerstone's analysis of project expenses, project revenues, and final net cash flows for a 15 year project life.

Initially, Cornerstone evaluated the LFG generation and recovery potential, and composition. These issues are important in determining if a landfill gas to energy (LFGTE) project is feasible. The Landfill was assumed to have a total of 2,000 standard cubic feet per minute (scfm) at the peak flow rate of the site. The Landfill was assumed to have enough LFG generated to support a LFGTE energy plant that is ultimately composed of either seven (7) CAT 3516A+ engines or four (4) CAT 3520 engines.

This paper includes estimating the project expenses and revenues. Project expenses include one time capital costs and annual operation and maintenance costs. Capital costs are composed of equipment costs, engineering costs, construction costs, and other one time costs. Operation and maintenance expenses include maintenance costs, spare parts, administrative expenses, and overhaul costs. These assumptions did not include royalties to the owner. Assumptions that Cornerstone used in the evaluation are explained in detail in this paper.

From the project expenses and revenue analysis, Cornerstone developed a financial proforma and a sensitivity analysis for the two LFGTE projects (CAT 3516A+ and CAT 3520). The financial proforma is a direct comparison between the project expenses and revenues over the 15 year project life. Cornerstone ran six scenario varying forecast assumptions for grid electric purchase price, operation and maintenance costs, and maintenance timing. The results are summarized in the sensitivity analysis. The sensitivity analysis indicates that the final net cash flow of the six scenarios is most sensitive to energy prices and O&M costs.

In addition to the total net cash flow, the sensitivity analysis indicates whether or not the LFGTE project will provide an income or loss to the developer. As shown in the sensitivity analysis, both the 3516A+ and the 3520 CAT engine scenarios provide a profit. A portion of this profit can then be shared with the Landfill owner in order to entice them to sign a 15-year gas sale contract.

Economic Feasibility Background

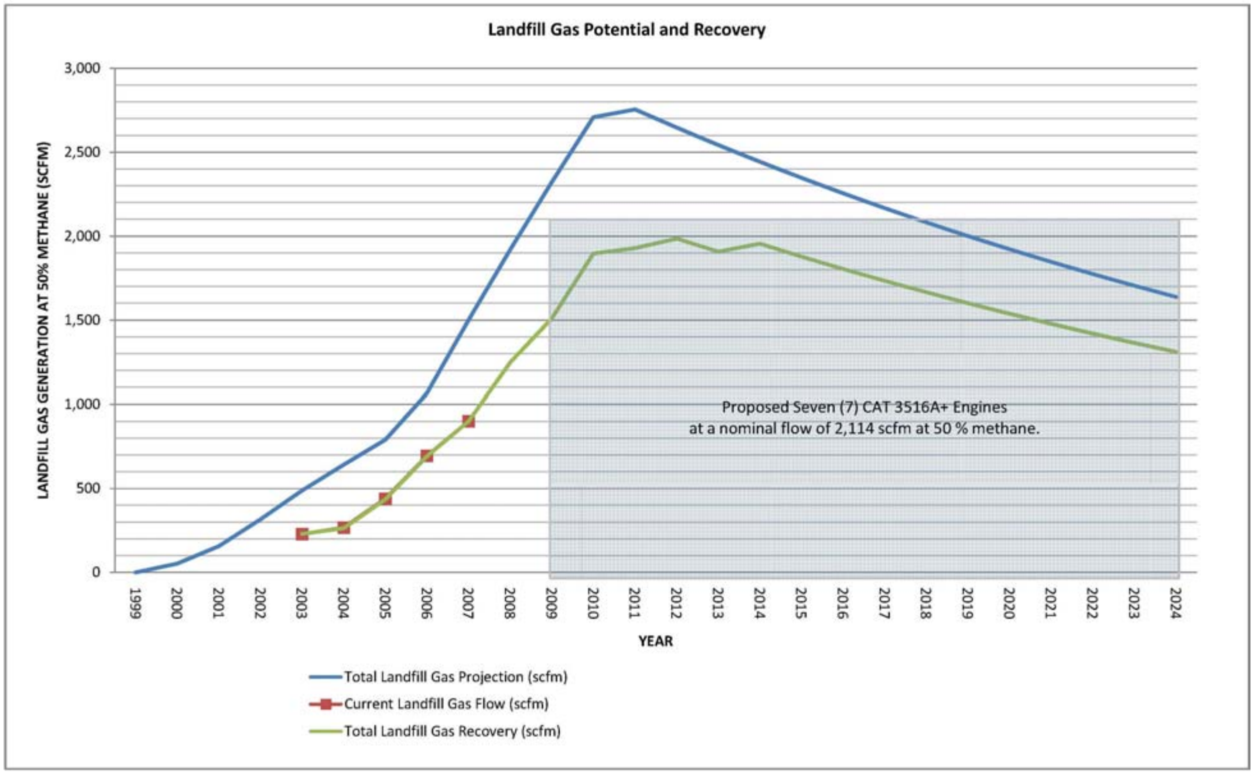
Prior to conducting an economic evaluation of a LFGTE facility, it is important to determine if a generation plant can feasibly be installed and if additional landfill gas treatment is required. In order to accomplish this, information regarding LFG quality, composition, and quantity are reviewed by Cornerstone, and the results are described in the following sections.

LFG Recovery Potential

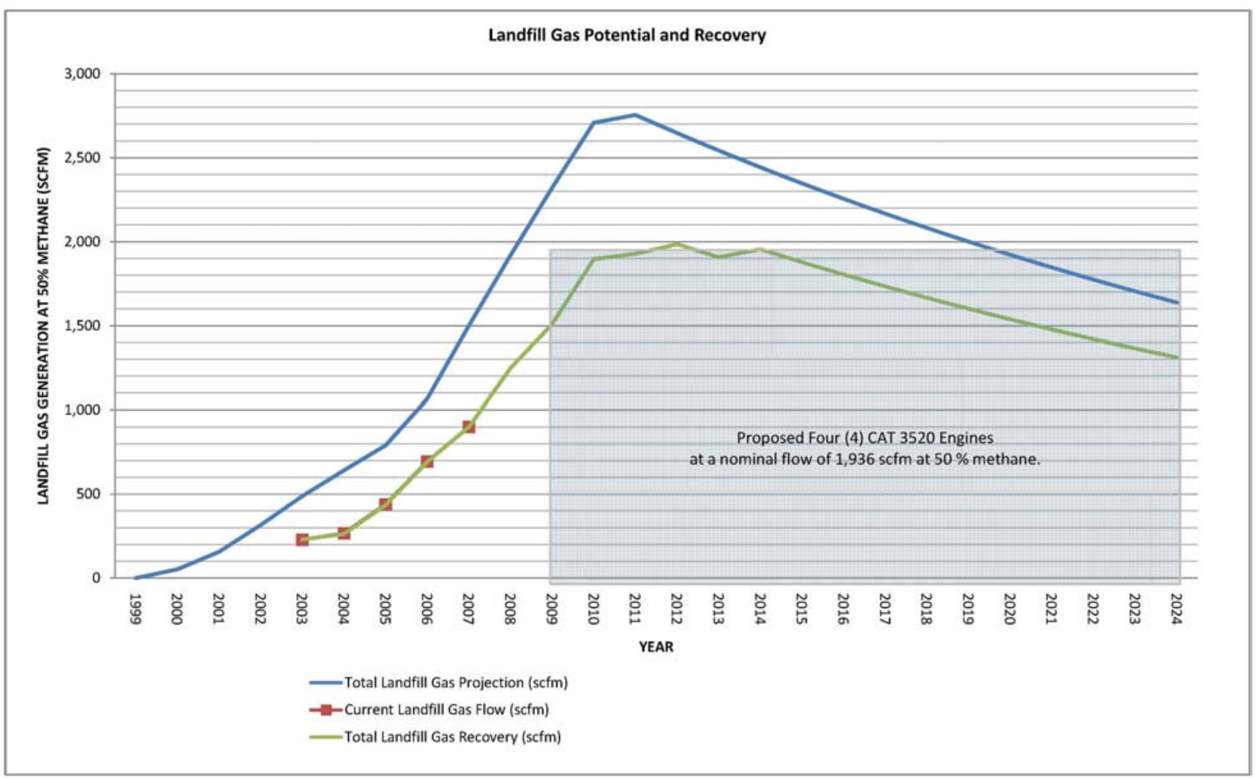
The economics of a LFGTE project depends on the LFG quantity and equipment choice. The industry typically employs a LFG generation model (LFG model) to estimate the quantity of LFG that will be generated and recovered at the Landfill. Next, the model results are compared to the manufacturer's requirements for the proposed engines to determine how many engines are appropriate.

The model output indicates that the maximum generation of LFG, which is expected to be delivered to the LFGTE plant by the LFG collection and control system, is approximately 2,755 scfm in 2011. The estimated maximum recovery of LFG is 1,985 scfm in 2012, assuming 70% recovery efficiency. The figures below show the LFG model results, the current LFG recovery results, and the generator capacity for both the Caterpillar G3516A+ and the G3520.

CAT 3516A+ Engines in Comparison to Project LFG flow



CAT 3520 Engines in Comparison to Project LFG flow



Production Summary

Cornerstone used the LFG model output to determine the number of engines that could be installed at the Landfill. Cornerstone determined that the maximum number of engines that can be deployed to process the LFG at peak LFG flow is: seven (7) CAT 3516A+ engines (6.4 MW gross capacity) or the four (4) CAT 3520 engines (6.4 MW gross capacity). Graphic display of the LFG flow needed to operate the engines at capacity and the estimate of the recovered LFG flow is also shown on the previous figures.

The CAT 3516A+ engine, which is manufactured by Caterpillar, Inc. provides low nitrogen oxide (NOx) emissions and operates at a good efficiency. Each CAT 3516A+ engine is rated to output 925 kilowatts (kW) of electricity and requires a nominal flow of 310 standard cubic feet per minute (scfm) of a low heating value (LHV) 500 btu/cf of landfill gas.

The CAT 3520 engine, which is manufactured by Caterpillar, Inc. provides low nitrogen oxide (NOx) emissions and also operates at a good efficiency. The CAT 3520 engine is rated to output 1,600 kW of electricity and requires a nominal flow of 484 scfm of a LHV 500 btu/cf of landfill gas.

The previous figures also estimate of how long the engine systems can operate at a 100 percent capacity after which time the engines will need to be turned down due to reduced LFG recovery. For instance, the Landfill will produce enough LFG to operate three (3) CAT 3520 engines in 2009, and upgrade to four (4) 3520 engines in 2010 through 2024 where the estimated recovered LFG reduces to approximately 1,310 scfm the engines will have to be turned down to operate at a lower capacity. This decline in LFG recovery conservatively assumes the site will not get a landfill expansion after their currently permitted landfill capacity is consumed.

Landfill Gas Composition

Another important piece of background information for determining the feasibility of a LFGTE facility is landfill gas composition. Several components in landfill gas such as siloxane, hydrogen sulfide, and chlorine can cause problems in the engines, if they are found at high enough concentrations. When high concentrations of these components exist, pretreatment of the LFG may be necessary. Typically, samples of LFG are obtained from the Landfill and tested for siloxane, hydrogen sulfide, and chlorine.

For this paper we have assumed the analytical results shown in the following table. As shown in the table, pretreatment is required since test results indicate the siloxane concentration in the LFG is above the maximum concentration allowed by Caterpillar. Treatment for siloxane has been added to the capital and O&M costs. Hydrogen sulfide levels, while below the concentration required by Caterpillar limit, will need to be reduced as part of the gas conditioning system in order for the siloxane removal system to work effectively.

Landfill Gas Pretreatment Determination Results

LFG Component	Analytical Results	Max concentration allowed by CAT prior to voiding warrantee
Siloxane	0.88 ug/btu	0.60 ug/btu
Hydrogen Sulfide	54.71 ug/btu	60.0 ug/btu
Chlorine	0.00 ug/btu	20.0 ug/btu

Economic Evaluation

The economic evaluation addresses two scenarios: seven (7) CAT 3516A+ engines or four (4) CAT 3520 engines. This includes analyzing project expenses and revenues, performing a financial proformas on each scenario and a sensitivity analysis.

Project Expenses and Revenues

Determining the project expenses and revenues for a LFGTE facility is the first step in an economic evaluation. To evaluate the economic feasibility of a LFGTE project, Cornerstone developed a conservative estimate of project expenses. The key project expenses are the amortization of up-front capital costs and the annual operation and maintenance (O&M) expenses. Revenues are determined from the price that the local power utility will pay for the electricity that is placed on their grid. The project expenses and project revenues are discussed in the following sections.

Capital Costs

Capital costs associated for each LFGTE project include costs of the major equipment (i.e. flare, engines, piping, electrical switchgear, etc) as well as the costs associated with construction, emission controls, interconnections, permitting, engineering, and other costs. The list below describes the assumptions that were used to develop the capital cost estimate for the Landfill, and the tables indicate Cornerstone's estimated capital costs for the Landfill.

Capital Cost Estimate CAT 3516A+

Line Item	Description	
	April 16, 2008 Quote from Caterpillar	
1	7 – 3516A+ Landfill Gas Generator Sets	
	7 – Jacket Water Hot Water Recovery CHP Systems	
	7 – Engine Battery Charging Systems	
	7 – Engine Make-Up Oil Lube Systems	
	7 – Engine Crankcase Ventilation Systems	
	1 – 2000A, 4160 V Paralleling Switchgear System	
	1 – Landfill Gas Commissioning Service	
	Electrical Power Generation Solution Total Net Sum	**$6,192,698**
	Gas cleanup based gas chemistry	
	1 - SulfrStrip Continuous Hydrogen Sulfide Removal System	
	1 – SAGPack Moisture Removal & Gas Compression System	
	1 – SWOP Regenerative Siloxane Removal System	
	1 – Gas conditioning System Commissioning Services	
	Landfill Gas Conditioning System Solution total Net Sum	**$3,890,527**
	Adder Equipment for Conditioning System Sum	**$261,714**
	Total Cost of Equipment	**$10,344,939**
2	Installation of above equipment	$500,000
3	Concrete block building with bathroom	$800,000
4	Site Grading	$130,000
5	Utility Interconnect charges	$100,000
	Consulting/ Oversight	
6	Revision of the Site Air Permit	$30,000
6A	Engine Stack Test and Test Plan Development	$15,000
6B	Startup/Shutdowm Plan and Malfunction Prevention and Abatement Plan	$5,000
7	Design of the Power Plant	$300,000
8	CQA of the Power Plant	$150,000
9	Permit from the Town	$12,000
10	Operation and Maintenance Manual Development	$5,000
	Subtotal	**$12,391,939**
	15% contingency	$1,859,791
	TOTAL	**$14,250,730**

Capital Cost Estimate CAT 3520

Line Item	Description	
	April 16, 2008 Quote from Caterpillar	
1	4 – 3520 Landfill Gas Generator Sets	
	4 – Jacket Water Hot Water Recovery CHP Systems	
	4 – Engine Battery Charging Systems	
	4 – Engine Make-Up Oil Lube Systems	
	4 – Engine Crankcase Ventilation Systems	
	1 – 2000A, 4160 V Paralleling Switchgear System	
	1 –Landfill Gas Commissioning Service	
	Electrical Power Generation Solution Total Net Sum	**$4,554,582**
	Gas cleanup based gas chemistry	
	1 - SulfrStrip Continuous Hydrogen Sulfide Removal System	
	1 – SAGPack Moisture Removal & Gas Compression System	
	1 – SWOP Regenerative Siloxane Removal System	
	1 – Gas conditioning System Commissioning Services	
	Landfill Gas Conditioning System Solution total Net Sum	**$3,890,527**
	Adder Equipment for Conditioning System Sum	**$261,714**
	Total Cost of Equipment	**$8,706,823**
2	Installation of above equipment	$500,000
3	Concrete block building with bathroom	$700,000
4	Site Grading	$130,000
5	Utility Interconnect charges	$100,000
	Consulting/ Oversight	
6	Revision of the Site Air Permit	$30,000
6A	Engine Stack Test and Test Plan Development	$15,000
6B	Startup/Shutdowm Plan and Malfunction Prevention and Abatement Plan	$5,000
7	Design of the Power Plant	$300,000
8	CQA of the Power Plant	$150,000
9	Permit from the Town	$12,000
10	Operation and Maintenance Manual Development	$5,000
	Subtotal	**$10,653,823**
	15% contingency	$1,598,073
	TOTAL	**$12,251,896**

A discussion of each item in the capital cost estimate is as follows:

- **Line Item 1 - Engines and other Equipment** The quotes included prices for additional equipment (i.e. cooling, exhaust, charging, oil lube, gas train, ventilation, switchgear, and gas conditioning systems). The supplier included a markup costs on products they do not sell. As a result, the total equipment cost is likely 10 percent high.

- **Line Item 2 - Installation of equipment** Installation of all equipment can be bid to a local general contractor.

- **Line Item 3 - Concrete block building with bathroom** Steel buildings can also be used at a lower cost. However, concrete buildings can assist in noise reduction but at a higher cost to the project. Since Cornerstone understands that concrete buildings are more expensive which adds another degree of conservativeness to the estimate, Cornerstone assumed that the project developer will install a concrete building at the Landfill.

- **Line Item 4 - Site Grading** Site grading includes costs for excavating the area for the foundation or footings and for drainage around the facility.

- **Line Item 5 - Utility interconnect charges** Negotiations with the local power utility are used to confirm this capital cost, Cornerstone assumed a conservative charge.

- **Line Item 6 - Revision of the Site Air Permit** Most likely the Landfill will need to revise the air permit to include emission requirements for the engines which is required by state and federal regulations. The price in the capital cost estimate includes permit preparation and the first year of semi annual reports.

- **Line Item 6A - Engine Stack Test** Regulations require that when a generation plant is installed that one of the generators be tested to determine if it meets emission requirements. Cornerstone included a price for this stack test that includes the preparation of the test plan and engineering time.

- **Line Item 6B - Startup/Shutdown/Malfunction and Malfunction Prevention and Abatement Plans** The Landfill will need to update their Startup/Shutdown/ Malfunction and Malfunction Prevention and Abatement Plans to include the engines. Cornerstone included a price for this task that includes preparation and engineering time.

- **Line Item 7 - Design of the Power Plant** This line item includes engineering costs to design and specify the power plant.

- **Line Item 8 - CQA of the Power Plant and Wellfield Modifications** Cornerstone recommends having someone observe the construction of the plant and wellfield modifications to make sure the contractors are following project specifications. As a result, Cornerstone included a cost for this task.

- **Line Item 9 - Permit from the Town** Cornerstone assumed that the project will need to obtain a conditional use permit from the local township to install and operate the LFGTE plant at the Landfill. The cost estimate includes time to prepare and implement the permit.

- **Line Item 10 - Operation and Maintenance Manual** For use when operating the plant.

O&M Costs

Operation and maintenance (O&M) costs may vary for each landfill due to the equipment. Typical O&M costs include fixed expenses which are labor, insurance, administrative expenses, spare parts, fees, annual reports, and emission offsets. These expenses are not dependent on the time that the engines operate or the amount of electricity produced. Other O&M costs are variable expenses that include periodic maintenance, major overhauls, water, and consumables (i.e. lubricating oil, spark plugs, filters, and hydraulic fluid). Variable expenses are the opposite of fix expenses since they are typically dependent on the amount of the time the LFGTE plant is operating.

For the Landfill O&M costs, Cornerstone developed an O&M cost estimate based upon historic costs from numerous similar plants and these are described in the table titled "O&M Cost Assumptions". Unlike the capital costs which are a onetime costs, O&M costs are annual costs. As a result, Cornerstone estimated a yearly O&M cost for the years 2009 through 2024 and these costs are shown in the financial proforma generated for the Landfill.

O&M Cost Assumptions

Assumption 1 – Full time onsite maintenance person.
Cornerstone assumed two full time mechanics to be stationed the plant. One mechanic may have to spend approximately 8 hours per week tuning the LFG wellfield.
Assumption 2 – One manager to manage the operations of the LFGTE plant at the Landfill
Cornerstone assumed one ¼ time person to manage the operations of the LFGTE plant. This one person would oversee the energy plant.
Assumption 3 – No salvage value for the engines included after 15 year project life
The engines require a major overhaul every five years. If the engines are shut down after fifteen years the cost for the third overhaul would not have to occur. In addition, to be conservative no salvage value for the engines was included at the end of the fifteen year term. If the engines are properly maintained and overhauled, they have a resale value of approximately 35 percent of the original purchase price after 15 years of operation. The costs for all major overhauls are spread-out in each year of project life instead of only including them in years 5 and 10.
Assumption 4 – Spare parts
An inventory of spare parts will be kept onsite for maintenance purposes.

For renewable energy projects the local power utility typically provides electric buyback rates that vary with off peak and on peak times of the day/year. Considering the peak/off-peak pricing, it is more advantageous to the operator to perform maintenance of the engines during off peak utility periods. Cornerstone calculated an average rate for two different maintenance scenarios: Scenario 1 – if maintenance is performed during peak electric buyback hours and Scenario 2 – if maintenance is performed 50 percent of the time during peak hours and the remaining 50 percent during off peak times.

Financial Proforma

A 15 year project life financial proforma was developed that compares the expenses and revenues, for each engine type. Financial proforma spreadsheets were utilized incorporating the assumptions previously discussed. In addition, the proforma includes the analysis of fuel needed; capital cost, O&M cost, and energy output. Cornerstone's evaluation of the number of generators concluded that seven (7) CAT 3516A+ engine is appropriate at the Landfill in the years 1 to 5. Also, four (4) CAT 3520 engines are appropriate at the Landfill in the years 1 to 8.

The following table summarizes the assumptions that Cornerstone used to calculate the financial proforma for electricity generation over the fifteen year project life at the Landfill including:

a. 85 or 95 percent on-line is assumed depending on which of the six scenarios Cornerstone analyzed. The 5 to 15 percent down-time accounts for scheduled and unscheduled maintenance.
b. Assume onsite parasitic load for motor/blower, lights, pumps, etc. for CAT 3516A+ engines are 7 percent of gross electrical production and is 4 percent for CAT 3520 engines.
c. A 15 percent contingency fee has been added to the total capital cost.
d. Finance period is 10 years.
e. The developer's cost of capital (ie: interest) is 5 percent.
f. The power purchase price includes one cent/kwh for environmental attributes, and is assumed to escalate at a rate of 2% per year.
g. Year 1 average O&M cost will be 2.0 cents per gross kWh for CAT 3516A+ and 2.5 cents per gross kWh for CAT 3520, which includes complete preventative and major service expenses for the engines.
h. The cost for all O&M expenses and administrative fees will increase at a rate of 1.2 percent per year.

Financial Proformas - Worst Case Scenario

Production Parameters	3516A+ engines	3520 engines
Gross Heat Rate, btu/kwh	10,054	9,084
Capacity of a Engine (kW)	925	1600
CAT Engine On-Line Factor (%)	85	85
Onsite Electrical Use, Parasitic (%)	7.0	4.0
Capital Costs	**3516A+ engines**	**3520 engines**
Engine (2008 $)	$14,253,730	$12,251,896
Contingency (%)	15	15
Finance Period (yrs)	10	10
Cost of Capital, Interest (%)	5	5
Average Wholesale Energy Price and the environmental attributes (Year 1 ¢/kWh)	6.76	6.76
Annual Revenue Escalation Rate (%)	2.0	2.0
Operations and Maintenance Costs	**3516A+ engines**	**3520 engines**
O&M for engine & compression (Year 1 $/gross kw)	0.020	0.025
Annual Inflation of O&M Cost (%)	1.2	1.2

Sensitivity Analysis

Cornerstone varied key input parameters used in the proforma. This included a sensitivity analysis of six different situations. These six situations are:

1. Worst Case,
2. Same As 1 But Higher On-Line Time,
3. Same As 1 But Lower O&M Price,
4. Same As 1 But Different Maintenance Timing,
5. Same As 1 But With Lower Capital, and
6. All Up Side Potentials Combined.

Cornerstone varied the forecast assumptions of on-line time, grid electric purchase price, O&M costs, and maintenance timing to determine which factors have the greatest impact on total net cash flow. The sensitivity analysis results indicate that the total net cash flow is most sensitive to energy prices and O&M costs, which are shown in the following tables.

CAT 3516A+ Financial Proforma and Sensitivity Analysis

Scenario	1	2	3	4	5	6
Sensitivity Analysis	**Worst Case**	**Same as #1 but Higher on-line time**	**Same as #1 but Lower O&M price**	**Same as #1 but different maintena nce timing**	**Same as #1 but with Lower Capital**	**All Upside Potentials Combine d**
Capital Cost ($ MILLIONS)	14.2	14.2	14.2	14.2	12.4	12.4
Year 1 grid electric purchase price (cents per kWh)	6.76	7.17	6.76	7.27	6.76	7.32
On-line time	85.0%	95.0%	85.0%	85.0%	85.0%	95.0%
Maintenance Timing	During Peak	During Peak	During Peak	1/2 during Peak	During Peak	1/2 during Peak
Year 1 O&M cost (cents per gross kWh)	2.0	2.0	1.8	2.0	2.0	2.0
RESULTS						
Operating Years to Pay off Capital	9	7	8	8	9	6
Profit after 15 operating years	$2.73 million	$9.04 million	$4.14 million	$5.97 million	$6.03 million	$13.41 million

Note: Profit is typically shared by energy developers with the landfill owner in exchange for the gas sales.

CAT 3520 Financial Proforma and Sensitivity Analysis

Scenario	1	2	3	4	5	6
Sensitivity Analysis	**Worst Case**	**Same as #1 but Higher on-line time**	**Same as #1 but Lower O&M price**	**Same as #1 but different maintena nce timing**	**Same as #1 but with Lower Capital**	**All Upside Potentials Combine d**
Year 1 Capital Cost ($ MILLIONS)	12.3	12.3	12.3	12.3	10.7	10.7
Year 1 grid electric purchase price (cents per kWh)	6.76	7.17	6.76	7.27	6.76	7.32
On-line time	85.0%	95.0%	85.0%	85.0%	85.0%	95.0%
Maintenance Timing	During Peak	During Peak	During Peak	1/2 during Peak	During Peak	1/2 during Peak
Year 1 O&M cost (cents per gross kWh)	2.5	2.5	2.3	2.5	2.5	2.5
RESULTS						
Operating Years to Pay off Capital	8	7	7	7	8	6
Profit after 15 operating years	$5.52 million	$11.99 million	$11.99 million	$9.03 million	$8.35 million	$15.98 million

Note: Profit is typically shared by energy developers with the landfill owner in exchange for the gas sales.

Conclusions

Fuel requirements, project expenses, and project revenues are the three most important components of an LFGTE economic feasibility study. The economics for this project are conservative because Cornerstone assumed that the Landfill will not get an expansion in the future and it is assumed that once there is not enough LFG to operate all engines at capacity, individual engines will be removed rather than running them at partial load.

Cornerstone's report presents six different scenarios. Utilizing the assumptions from the hypothetical Landfill, herein, the CAT 3520 engine presents the best option for a LFGTE plant with the highest financial gains for all six scenarios.

Cornerstone estimated that, at best, the CAT 3520 project will result in $15.98 million dollars of operating profit after operating for 15 years, plus the salvage value of the equipment at that time, plus tax credits, plus other environmental attributes, minus any royalty to the Landfill owner. Lastly, depending on the site specific LFG flow rates, gas chemistry, and electric buyback rates; the results of your site specific analysis may differ from those reported herein.