Case Study - Landfill Power Generation

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1. Introduction to Global Change

In the past decade, nations have begun to better understand the relationship between human activities and global climate change. One of the most important issues in this area is that the combustion of fossil fuels releases greenhouse gases into the atmosphere, which seems to be causing the global temperature to increase. This occurs because the additional carbon dioxide and other greenhouse gases that we emit into the atmosphere 'trap' the energy on the planet, causing it to get warmer. The warming effect has many side effects, such as the melting of polar ice caps, changes in weather patterns, and increases in sea levels. However, burning fossil fuels is not the only way in which greenhouse gases end up in the atmosphere.

The main greenhouse gases are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Each of these gases has a different impact in the atmosphere – i.e. each has a different 'global warming potential'. If we use carbon dioxide as a baseline unit, one ton of methane released into the atmosphere is counted as 21 tons of carbon dioxide– so methane has a potential to warm 21 times higher than carbon dioxide.

All of this is especially important due to recent international conferences trying to find ways to decrease the amount of greenhouse gases being emitted. For example, the Kyoto Protocol meetings in 1997 attempted to have countries agree to reduce their emissions of greenhouse gases. Specifically, the United States agreed to reduce emissions from 1990 levels by 7 percent during the period 2008 to 2012.

Since the Kyoto meetings, there have been attempts to implement the Protocol (even though some countries like the U.S. have not ratified it yet). The meeting in The Hague, Netherlands in late 2000 inevitably failed because nations could not agree on how to consider the effects of greenhouse gas ‘sinks’ like forests, which remove carbon dioxide from the atmosphere, and thus lead to an overall lower net amount of emissions for a country. This failure happened because the original intent of these meetings was to seek ways to reduce emissions rather than finding alternatives (or "loopholes" as some would say), which would increase the benefits of sinks.

2. Methane Emissions

As stated above, burning fossil fuels is not the only source of greenhouse gases. The estimated quantity of greenhouse gas releases in the United States in 1999 was about 1,800 million metric tons of carbon equivalents (found by weighting all gases by their warming potential). About 10% of this total is from methane releases. One of the major sources nationwide of methane releases is from landfills.

As often the case in the United States, municipal solid waste (garbage), demolition waste, and some industrial waste are collected by trucks and brought to nearby landfills. In addition, depending on the cost of landfill disposal (also known as the 'tipping fee,' which may vary between landfills), the waste may be transported to a landfill where the total cost of disposal (including trucking time) is lower. An important shift over the last two decades has been from generic 'dumping' of waste to well-engineered landfilling. The engineering of landfills enables more sophisticated processes like monitoring and pollution control.

A natural result of waste decaying in landfills is the production of byproduct gases. This occurs because of the anaerobic degradation of biodegradable organic wastes. One of the byproducts of this decay process is the production of methane (CH_4). While there are several phases with unique characteristics, the most important is the methane production phase, which is generally the steady state.

The methane production phase can be described by the following stabilization equation:

$$CHONS + H_2O \text{ ----> } H_2O + CO_2 + CH_4 + H_2 + NH_4 + HS$$

where the transition is driven by the presence of anaerobic bacteria. It may take 4-5 years after closure to reach the methane production phase. Landfill gas is generally composed of 65% methane and 35% carbon dioxide [Kiely 1997]. However, the actual composition of gases depends upon the amount of organic matter feedstock, rain infiltration, the anaerobic environment, and the age of the landfill.

With the large volume of degradable materials, the amount of methane produced can be significant. Overall, landfills are estimated to produce 37% of methane emissions, or about 4% of total greenhouse gas emissions in the U.S. [EPA 1999]. Methane released from landfills adds to the other unpleasant odors that come with them. To partially reduce this odor, methane has often been flared (i.e. burned off). Flaring methane results in 7.5 times less global warming potential than venting (releasing it in an uncontrolled manner).

Since methane is combustible (and is 95% of the composition of natural gas), recently people have become very serious about using the methane in a more valuable and environmentally efficient manner. The most popular solutions are to either collect and pipe the methane to a nearby utility, or to collect and convert the methane on-site into electricity. Fortunately, methane emissions from landfills are a relatively constant source of fuel - the landfill is constantly producing it. Either way, the methane is not released into the atmosphere and represents a cheap and abundant energy source as well as a way to reduce greenhouse gas emissions. Some of the additional benefits are that other more polluting energy sources (e.g. coal-fired power plants) might be phased out by electricity generation from methane. Also, a landfill can actually 'sell back' the electricity it generates to a local electric utility and earn revenue.

However, generating electricity from landfill methane is not free (or even cheap). To start, a collection system must be built to guide the methane from underground (representing old layers of waste deposited in the landfill) to the internal combustion engines that will turn electric generators and create excess energy to sell back to the utility. This requires the construction of wells to go down into the landfill and a fairly extensive series of pipes to lead to the engines. Of course, the engine/generator units must be purchased as well, and they must be controlled and maintained.

3. A Specific Landfill's Parameters

Let's consider the Modern Landfill, located in York, PA and owned and operated by Republic Services, Inc. The size of this landfill is 120 acres. The natural process of decay at this landfill is able to produce about 2.7 million cubic feet (mmcf) of methane per day. Methane weighs about 0.00002 ton per cubic foot (or 50,000 cubic feet per ton).

Republic could buy an engine/generator unit from Caterpillar that consumes 920 cubic feet of landfill gas per minute. At 100% load, the generator produces 3,050 kW (3.05 MW) of electricity. Thus in one hour, it would produce 3,050 kilowatt-hours of electricity. As a comparison, an average Pennsylvania coal-fired power plant is on the order of 100 MW. The capital costs of the engine/generator unit are between $900-$1200 per kilowatt, and the operating and maintenance costs are between 1 and 2 cents per kilowatt-hour [DOE 1997]. Currently the average wholesale price (the revenue the firm could expect to receive by selling electricity back to a utility) of electricity is 5 cents per kilowatt-hour.

There is also a renewable energy production tax credit (that can only be used to offset profits, not losses) of 1.5 cents per kilowatt-hour of electricity produced from landfill gas.

However, there is a catch. While there are no environmental laws in Pennsylvania (or a the federal level) restricting the production of greenhouse gases, the combustion of the methane will produce conventional pollutants, namely nitrogen oxide, carbon monoxide, and non-methane organic compounds. Releases of these pollutants are regulated by the state, and permits are required if emissions levels go over certain amounts.

4. Case Study Questions

Consider the base case of a landfill with an installed gas collection system (e.g. a network of underground pipes and wells) that is only venting (releasing) the gas into the air. Assume a tax rate of 40% on income and a discount rate of 15%. Do not consider any of the existing equipment when analyzing alternatives.

1) Perform a cash-flow analysis of installing a single flare able to burn off 1 million cubic feet of methane per day. The capital cost of this flare is $60,000, and yearly operation and maintenance is $10,000, with a 10-year lifetime. Also discuss the overall cash-flow if the landfill wants to flare all methane produced.

2) Perform a cash-flow analysis of installing one engine/generator combination at the York, PA facility. Assume a lifetime of 10 years. How does your answer scale up to the maximum number of engine/generator units possible given the amount of landfill gas being produced at this

site? Does generating electricity look better or worse than flaring from a purely economic perspective?

3) Discuss the policy situation of landfills in terms of the tradeoff between methane (greenhouse gas) emissions and potential conventional pollutant emissions from using engines and generators. If a landfill is currently venting methane (releasing uncontrolled), and considers flaring or generating electricity, what are the relative implications of this decision?

4) Parts 1 and 2 show the raw cash-flow values for installing flaring or electricity generation equipment. Assume that you know that the engines for generating electricity produce 4 lbs/hr of nitrogen oxides (NOx), 20 lbs/hr of carbon monoxide (CO), and 0.6 lbs/hr of non-methane organize compounds (NMOC). Alternatively, consider that flaring only burns off methane (not CO2) and that the result of flaring the methane is 7.5 times less emissions in CO2 equivalents.

a) Given median per-ton social costs of $1,000, $1, and $1,500 for NOx, CO, and NMOC, compare the effects of reducing greenhouse gases when social costs of CO2 are $15 per ton. If you 'add in' these social costs into your cash flows, which option is better?

b) What does your answer in part (4a) suggest is the amount society would be willing to pay per kilowatt-hour of electricity produced?

5. References

DOE 1997 U.S. Department of Energy, Renewable Energy Annual 1996, Published April 1997, via http://www.eia.doe.gov/cneaf/solar.renewables/renewable.energy.annual/chap10.html, last accessed 11/28/00.

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