IS LANDFILL GAS GREEN ENERGY?

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EXECUTIVE SUMMARY

Municipal solid waste landfills, long reviled by the environmental community as sources of air and water pollution, have in recent years benefited from numerous subsidies associated with alternative fuels and renewable power. Federal and state tax credits and payments are now offered to landfill facilities that collect and utilize landfill gas for heat or electricity generation. Three related concerns have been raised with regard to these incentives. First, some have raised concerns about the health impacts of the exhaust from burning landfill gas. Second, some have pointed to the substantial environmental and public health damage caused by landfills and called into question the sustainability of landfills themselves and thus landfill gas. Finally, some have suggested that these subsidies are just another stone on the scale promoting landfilling over recycling.

The United States generated 231.9 million tons of municipal solid waste (MSW) in 2000, 55 percent of which ended up in the country's 2000 landfills (see **Figure ES - 1**). Landfill gas (LFG) is naturally produced by the decomposition of organic materials (also known as biomass) in landfills, and approximately 60 percent of the non-recovered MSW is organic. Landfill gas contains mostly methane and carbon dioxide, both of which are greenhouse gases that contribute to global warming. Methane, which comprises about 55 percent of LFG,[1] has 23 times the global warming potential of carbon dioxide,[2] and although its worldwide emissions are much smaller than those of carbon dioxide, methane's potency as a greenhouse gas has marked it as the second most important anthropogenic (originating from human activity) greenhouse gas. In addition, LFG may contain small but significant amounts of ozone-forming volatile organic compounds (VOCs) and toxic or carcinogenic hazardous air pollutants (HAPs).

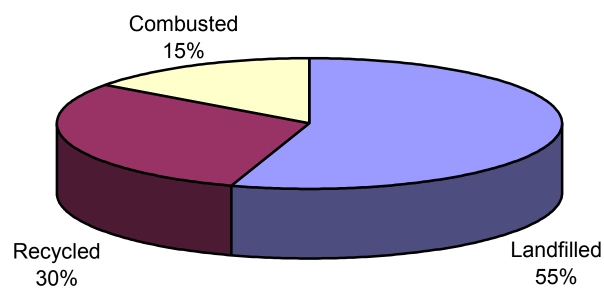

Figure ES - 1. **Municipal Solid Waste End Use in 2000. Source: EPA 2000.**

Landfill gas is a threat to human health and global warming, and flaring or utilizing it for energy greatly reduces its climate change impact. Burning LFG also serves to mitigate its public health impact by destroying the majority of hazardous air pollutants in landfill gas through the combustion process. Furthermore, using LFG to produce electricity avoids the need to generate electricity at traditional power plants and thus reduces air pollution from these plants. However, LFG combustion produces minute quantities of dioxins, an extremely toxic group of chemicals that are harmful even in very small amounts. In our analysis of the environmental impacts associated with LFG, first we look at the toxicity of LFG and exhaust from the combustion of LFG, then we add in the emissions from displaced electric generation, and finally we look at source reduction and recycling as alternative waste-management options.

Since the cost-effectiveness of recycling programs is directly linked to the cost of alternative waste-management options, landfill-gas energy (LFGE) subsidies could possibly reduce the competitiveness of recycling programs by enabling landfill operators to charge lower tipping fees. Each LFGE project is uniquely affected by LFGE incentives. Some projects may depend on subsidies to break even, while others may be cost-effective even without subsidization. We start our analysis with an overview of existing subsidies, evaluation of the economics of LFGE subsidies, and an attempt to quantify the short-term effect of LFGE subsidies on landfill tipping fees. Finally, we recognize that these subsidies are additive and must be looked at in the context of a whole range of incentives for landfilling over recycling. Thus, as with the environmental impacts, we need to look at LFGE subsidies in broader contexts and over longer periods of time.

This paper examines these concerns as quantitatively as possible. Many of the claims of both LFGE proponents and critics are highly dependent on how broad a view one takes both in terms of how much of the existing infrastructure one examines and how far into the future one is willing to look. In drawing our conclusions on these matters and laying out the policy guidance that follows from these conclusions, we have tried to balance idealism and reality. As Allen Hershkowitz wrote in his wonderful book, *Bronx Ecology*: "To truly deliver tangible ecological benefits to the world, environmentalists must emphasize a practical side to idealism." [3]

AIR POLLUTION IMPACTS

Key Findings:

- **Combustion of raw LFG in a flare, an engine, or a turbine dramatically reduces the overall toxicity.** Raw LFG contains many hazardous air pollutants, many of which are carcinogenic. The destruction of the vast majority of these more than makes up for the formation of minute amounts of dioxins. Our analysis of the inhalation cancer-risk factor suggests that the overall toxicity of LFG combustion is 23 times less than that of raw LFG.
- **Collection and combustion dramatically reduces global warming impacts and toxicity.** As mentioned above, LFG contains a lot of methane and methane is a very powerful heat-trapping gas. The combustion of LFG converts the methane to carbon dioxide, which while still a heat-trapping gas, is dramatically less powerful.
- **Using LFG to generate electricity further reduces the greenhouse gas impacts and also reduces emissions of nitrogen oxides, sulfur dioxide and mercury.** By displacing demand for electricity from traditional power plants, LFGE projects further reduce these important pollutants. However, when LFG is already being flared, the emission reductions are substantially less. Furthermore much depends on exactly what type of power plant is being displaced. If new natural-gas power plants or renewables are being displaced, then LFG may be better off simply flared.
- **Burying garbage in landfills results in the release of more heat-trapping gases than any other waste-management option.** The best way to combat LFG is to avoid landfilling biomass. This is true regardless of how much LFG is collected and used for energy. The best strategies are resource reduction and recycling.
- **Because LFG is a by-product of landfills, and landfills are such a poor way to manage our waste, LFG can not be considered renewable.** In addition to the global

The best way to combat LFG is to avoid landfilling biomass. This is true regardless of how much LFG is collected and used for energy. The best strategies are resource reduction and recycling.

warming impacts of landfills, they are also a source of groundwater pollution. At best, the Environmental Protection Agency's (EPA) current landfill regulations merely postpone the inevitable damage landfills will cause. Landfills are simply unsustainable, and therefore so is LFG.

Based on these findings, we can establish the following hierarchy of priorities:

1. **Avoid LFG by avoiding landfills.** The first priority must be increased resource reduction and recycling. Biomass—especially paper—is easily recycled or composted. If there is no biomass in landfills, then there will be no LFG.
2. **Burn all LFG that is produced.** Even if we could close all landfills today, they would continue to produce LFG for years to come. Combusting LFG in an engine, a turbine, or simply in a flare has tremendous benefits in terms of reduced toxicity and reduced greenhouse gases. Sixty one percent of LFG is generated at landfills with no collection system and at least 25 percent of LFG at landfills with collection systems simply escapes. Collecting all of this gas and burning it—preferably for energy, but at least in a flare—should be a priority nearly equal to avoiding landfills.
3. **Use LFG for energy production.** While there are instances where the use of LFG for energy can increase the amount of certain pollutants, the balance of benefits is in favor of using LFG for energy. Generally turbines are cleaner than engines, though less efficient. However the benefits of LFGE are greatest if we also increase air pollution regulations and energy efficiency so that we displace coal plants instead of gas plants.

SUBSIDIES FOR LANDFILL-GAS ENERGY PROJECTS

There are two major federal subsidies for LFGE projects. The Renewable Energy Production Incentive (REPI) is only available to publicly owned projects and the Section 29 tax credit is only for landfills that installed collection systems before July 1998. Extensions and expansions were considered by Congress last year as part of the comprehensive energy bill that, in the end, did not pass. Various state and local governments also offer incentives. Two of the most intriguing policies that have been implemented at the state and local level are green pricing programs and renewable portfolio standards. Congress also considered a renewable portfolio standard that would have included LFGE.

The cost of electricity generation from LFG is dependent on a number of factors, including the presence or absence of a gas-recovery system, the size of the landfill, and type of conversion technology employed. On top of equipment cost, project cost components typically include grid interconnection costs and a number of soft costs. On a per-kilowatt-hour (kWh) basis, the cost of electricity generation can range from as low as 3.4 cents per kWh to as high as 10 cents per kWh.[4] It is usually much more economical to produce energy where there is already a collection system in place. **Figure ES - 2** shows the cost of LFGE production for projects relative to different electricity prices for projects of different sizes. Note that the current wholesale prices are generally not high enough by themselves to cover the cost of LFGE.

In an attempt to bound the potential impacts of the REPI and section 29 tax credit, we analyzed five of the six largest LFGE projects receiving REPI payments and 117 landfills

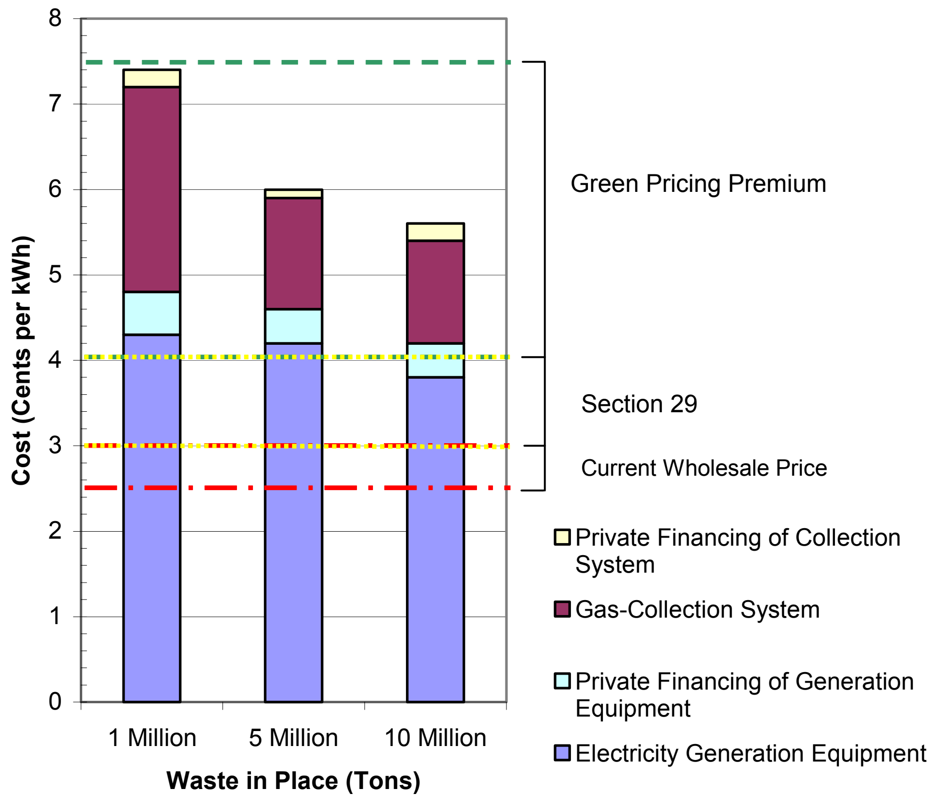

Figure ES - 2. **Landfill-Gas Energy Production Costs vs. Electricity Sales Revenue.**

on which the EPA has extensive operations data. By looking at how much these landfills have received or would receive assuming they were eligible and dividing that by the amount of waste they receive, we calculated the maximum value per ton received that the subsidies could be worth. For the REPI landfills, the value ranged from 13 to 78 cents per ton. For the Section 29 tax credit, the average value is 79 cents.

While it is tempting to directly compare these payments per ton of disposed waste to landfill tipping fees, the actual effect of the subsidies is almost impossible to quantify. Although there is some correlation between the amount of waste that an LFGE site accepts each year and the amount of electricity it produces, electricity generation (and hence the amount of REPI funding) is ultimately dependent on the amount of methane generated by the landfill. A landfill's methane generation rate depends on a number of factors, including size and depth of the landfill, the amount of waste in place, the age of the landfill, and regional climatic factors.

We also calculate the present value of the potential excess profit that projects could generate. Depending on the level of these excess profits and the discount rate used, a ton of waste can be worth between 3 cents and $2.06. That is of course assuming there are excess profits. As **Figure ES - 2** shows, even moderately sized projects that do not have to pay for private financing and receive the Section 29 credit will not necessarily be profitable.

Based on all of these calculations, it is tempting to conclude that while there is potential for incentives for LFGE projects to have an impact on tipping fees, the real work effects are likely to be small. However, these subsidies must be judged in a broader context. Incentives for LFGE projects are additional to all the subsidies that exist for landfilling in general. There are a host of incentives and policies that currently clearly tip the scales toward landfilling despite the clear benefits of recycling and resource reduction. For instance, in 1998 the Internal Revenue Service decided to end a tax exemption for recycling facilities still enjoyed by waste-management facilities.[5] Over time, policies such as this slow the development of recycling, keeping the cost high and artificially depressing the cost of burying garbage. Thus while it appears unlikely that REPI subsidies, Section 29 tax credits, or existing green pricing programs by themselves are causing a near-term shift away from recycling towards landfilling, they must be looked at in the context of a plethora of subsidies that clearly are causing such a shift.[6]

RECOMMENDATIONS

Based on these findings, we make the following recommendations for LFG-related public policy:

- **The EPA should expand the New Source Performance Standards (NSPS) rules to require collection systems at all landfills that accept biomass.**
- **The EPA should require LFGE projects at most landfills.**

Unfortunately, requiring collection or energy systems would require acknowledging the threat of global warming, a step that seems unlikely under the current administration. In the meantime, we can not afford to abandon incentives. However, we should make sure that we target them carefully. To this end, incentives should:

- **Favor non-NSPS landfills,**
- **Favor real renewables over LFGE projects,**
- **Favor closed landfills,**
- **Favor new LFGE projects over existing ones,**
- **Favor strict emissions requirements at NSPS landfills,**
- **Favor incentives that allocate subsidies competitively, and**
- **Limit the timeframe for all incentives and update economic analyses.**

Green pricing and renewable portfolio standard, both force technologies to compete for market share. This means that any incremental payment over the market price for electricity will be minimized, and thus the risk that incentives will be too large and will impact tipping fees is also minimized. However, this same feature means that if LFGE is successfully competing in green pricing programs and renewable portfolio standard, then potentially other cleaner and more sustainable sources of electricity are being driven out of the market.

There are three reasons that LFGE projects should be included in these types of policies. First and foremost, the reality is that landfills and LFG will be with us for years to come, and it is too toxic and too potent a greenhouse gas to not address. Here is where we must practice the "practical side of idealism." The second reason is that these mechanisms force LFGE projects to compete against other sources and to vie for public acceptance. Especially as more real renewables become available, any subsidy that LFGE projects can draw in the market place should go down or disappear. The third reason is subtler. Because LFGE is generally available in most states and often available at prices only slightly higher than traditional electricity, it can act as a pump-primer to get these types of policies in place. Therefore we make these three final recommendations specifically for green pricing and renewable portfolio standard:

- These policies should rely on LFGE from non-NSPS or closed landfills.
- To the extent that NSPS landfills are allowed to participate, only new conversions from flaring to energy should be allowed and only when strict emissions standards are met.
- Once a robust market for real renewables develops, only new LFGE projects at landfills that previously had no collection system should be included.

CHAPTER 1

AN OVERVIEW OF LANDFILLS AND LANDFILL-GAS

Landfills, long reviled by the environmental community as sources of air and water pollution, have in recent years benefited from numerous subsidies associated with alternative fuels and renewable power. Federal and state tax credits and payments are now offered to landfill facilities that collect and utilize landfill gas for heat or electricity generation. Three related concerns have been raised with regards to these incentives. First, some have raised concerns about the health impacts of the exhaust from burning landfill gas. Second, some have pointed to the substantial environmental and public health damage caused by landfills and called into question the sustainability of landfills themselves and thus landfill gas. Finally, some have suggested that these subsidies are just another stone on the scale promoting landfilling over recycling.

The United States generated 231.9 million tons of municipal solid waste (MSW) in 2000, 55 percent of which ended up in the country's 2000 landfills (see **Figure 1**). Landfill gas (LFG) is naturally produced by the decomposition of organic materials (also known as biomass) in landfills, and approximately 60 percent of the non-recovered MSW is organic. Landfill gas contains mostly methane and carbon dioxide, both of which are greenhouse gases that contribute to global warming. Methane, which comprises about 55 percent of LFG,[7] has 23 times the global warming potential of carbon dioxide,[8] and although its worldwide emissions are much smaller than those of carbon dioxide, methane's potency as a greenhouse gas has marked it as the second most important anthropogenic (originating from human activity) greenhouse gas.

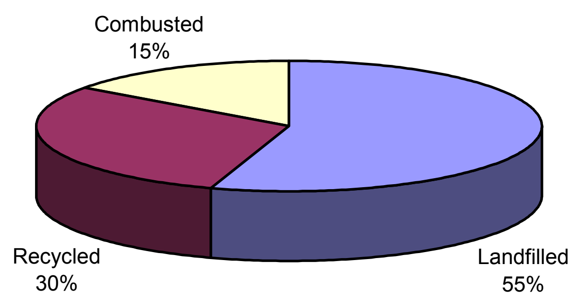

Figure 1. **Municipal Solid Waste End Use in 2000. Source: EPA 2000.**

Landfills represent the single largest human-made source of methane in the U.S. and are responsible for almost one-third of anthropogenic methane emissions.[9] In addition, LFG may contain small but significant amounts of ozone-forming volatile organic compounds (VOCs) and toxic or carcinogenic hazardous air pollutants (HAPs). Some trace compounds in LFG also contribute to unpleasant odors, which can be a nuisance for those who live near a landfill.

LANDFILL-GAS CONTROL

Due to the significant environmental and public health impacts of unmitigated LFG releases to the atmosphere, the U.S. Environmental Protection Agency (EPA) began regulating municipal solid waste landfills and LFG in 1991 under the Resource Conservation and Recovery Act Subtitle D. This act, in part, requires landfill owners and operators to prevent the migration of LFG from the landfill site. In 1996, with the release of the EPA's Clean Air Act New Source Performance Standards (NSPS) and the associated emissions guidelines, newer landfill facilities with large design capacities are required to install a gas collection and control system that destroys at least 98 percent of toxic and smog-forming non-methane organic compounds.[10] Once the gas is collected, the two options for control systems are to either flare the gas or install a landfill-gas energy system.

Landfill-gas energy (LFGE) projects generate electricity, heat, or steam (or some combination thereof) from gas that would otherwise be flared or released to the atmosphere. **Table 1** provides a breakdown of the 350 operations LFGE project tracked by the EPA's Landfill Methane Outreach Program.

LANDFILL-GAS ENERGY USE	NUMBER OF PROJECTS
Electric	
Reciprocating Engines	187
Gas Turbines	31
Other	25
All Electric	243
Direct	
Boilers	29
Direct Thermal & Leachate Evaporation	47
Other	31
All Direct	107
Total	350
All Landfills	2239

Table 1. **Breakdown of the Different Types of Landfill-Gas Energy Projects. Source: EPA 2002.**

At NSPS landfills, where gas collection systems already have to be installed, an LFGE electricity project involves only the installation of energy conversion equipment. At non-NSPS landfills, an LFGE project requires the additional installation of a gas-recovery system, thus leading to higher costs. Unfortunately, current NSPS rules cover only about one-third of the LFG produced from landfills and 5 percent of landfills.[11]

The rate at which landfill gas is produced depends in part on the size, temperature, moisture, and organic content of the waste at a landfill. Since landfills continuously produce LFG, landfill-gas energy projects can utilize gas at economically feasible volumes for between 10 to 20 years.[12] Even landfills that have recently closed and are no longer accepting additional waste can develop cost-effective LFGE projects.

Collecting and combusting the gas from a typical 5 megawatt (MW) LFG project (the average capacity of operational projects is 4.1 MW)[13] at a non-NSPS landfill can provide the same greenhouse-gas reduction benefits of planting 80,000 acres of forest per year or removing the annual emissions from over 60,000 cars.[14] Producing electricity or heat from LFG provides the added environmental benefit of offsetting non-renewable fossil fuels that would otherwise be used to generate the same amount of energy. This avoids CO_2 emissions and can also lead to significant reductions in regulated air pollutants such as nitrogen oxides (a major contributor to urban ozone), sulfur dioxide (a major contributor to acid rain) and particulate matter (a contributor to respiratory health problems and often carcinogenic).

The EPA launched the Landfill Methane Outreach Program in 1994 as part of the U.S. commitment to reduce greenhouse gas emissions under the United Nations Framework Convention on Climate Change. The program is a voluntary program providing education, consulting, and support for the development of LFGE projects. To date, it has assisted in the development of more than 200 LFGE projects.

Of the estimated 2,000 municipal solid waste (MSW) landfills currently operating in the United States, 340 have operational LFG utilization projects, approximately two-thirds of which are electricity generation projects. **Figure 2** shows the growth of LFGE project development over the past twenty years (the number of projects in the chart is higher than 340 because some of the earlier projects are no longer operational). An additional 100 projects are under construction, and the EPA estimates that more than 600 other landfill sites with a potential capacity of 1550 MW present viable opportunities for such projects.[15]

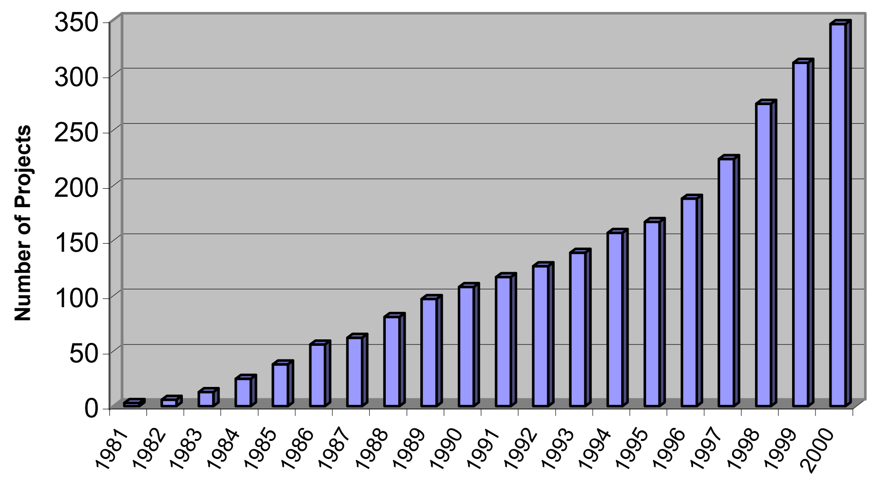

Figure 2. **Growth in LFGE Project Development. Source: EPA 2002c.**

The EPA estimates that in 2000, approximately one-third of the methane generated from landfills was recovered; of this portion, 45 percent was used for energy and 55 percent was flared.[16] However, this estimate is based on an assumption that gas-collection systems capture 75 percent of LFG, an assumption that appears unsubstantiated by any field testing.[17] Thus it appears likely that substantially less methane was actually recovered. In total, about 1500 MW of LFGE generation capacity has been built or is in the planning stages,[18] representing less than 0.2 percent of U.S. generating capacity.[19] Still, the number of LFGE projects has increased steadily in the past decade, more than tripling since 1990, and the potential capacity of LFGE is estimated to be 3000 to 6000 MW (between 0.4 percent and 0.8 percent of total capacity).[20] In the context of renewable energy, LFGE becomes more significant, representing approximately 13 percent of electricity generation from non-hydro, grid-connected renewables.[21]

SUBSIDIES AND AIR POLLUTION IMPACTS

The intent of LFGE subsidies should be to create opportunities for LFG recovery and/or use for energy where it is not required by law and it would be financially impracticable otherwise.

In recent years, LFGE projects have become eligible for a number of financial incentives associated with renewable energy generation and alternative fuel use. On the federal level, these include federal tax credits and production incentives. Landfill-gas energy also qualifies for several state-based subsidies. In California, almost $30 million have been either been spent on or set aside for new LFGE projects.[22] Where electricity markets have been deregulated, LFG is often included in green-power pricing programs, which allow consumers to purchase electricity generated from renewable and other relatively clean resources. This electricity is sold to the consumer for a premium, thus indirectly subsidizing LFGE projects. In combination, these incentives can significantly improve LFGE project economics.

The intent of LFGE subsidies should be to create opportunities for LFG recovery and/or use for energy where it is not required by law and it would be financially impracticable otherwise. But some have questioned the health impacts of using LFG for electricity generation, noting that LFG combustion produces minute quantities of dioxins and furans, chemicals that are extremely toxic even in limited amounts. Similar concerns over dioxin emissions from municipal solid waste combustion have caused it to be excluded from some renewable energy incentives.

Other critics contend that landfills as a whole are such a poor way to manage waste that when one looks at the lifecycle environmental and health impacts associated with landfill gas, LFGE does not deserve to be counted as green or renewable and thus should not be eligible for any incentives.

Still others argue that such incentives indirectly subsidize landfills at the expense of recycling and reuse programs. Part of this argument centers on the effect of LFGE subsidies on tipping fees, which are the disposal rates (usually per ton) charged by landfills. If LFGE subsidies exceed the cost of energy production and allow landfill owners to charge lower tipping fees, then it could become more difficult for recycling and composting to remain (or eventually become) cost competitive with landfilling as a waste management method. Opponents of LFGE subsidies also claim that even if these impacts are small, they are additive and so must be considered in the larger context of a host of policies that encourage landfilling over recycling.

This paper examines these concerns as quantitatively as possible. Many of the claims of both LFGE proponents and critics are highly dependent on how broad a view one takes both in terms how much of the existing infrastructure one examines and how far into the future one is willing to look. In drawing our conclusions on these matters and laying out the policy guidance that follows from these conclusions, we have tried to balance idealism and reality. As Allen Hershkowitz wrote in his wonderful book, *Bronx Ecology*: "To truly deliver tangible ecological benefits to the world, environmentalists must emphasize a practical side to idealism." [23]

CHAPTER 2

AIR POLLUTION

Landfill gas is a threat to human health and global warming, and flaring or utilizing it for energy greatly reduces its climate-change impact. Burning LFG also serves to mitigate its public health impact by destroying the majority of hazardous air pollutants in LFG through the combustion process. However, LFG combustion produces minute quantities of dioxins, an extremely toxic group of chemicals that are harmful even in very small amounts. In order to assess the health impacts of LFGE, it is essential to determine the seriousness of the health threat posed by LFGE dioxin emissions and to weigh it against the benefits of reducing the amounts of other hazardous air pollutants.

Landfill gas is an inevitable byproduct of landfilling organic materials, and as mentioned earlier, is produced in substantial quantities for at least 10 to 20 years.

To people living next to a landfill, the health impacts immediately associated with raw LFG or exhaust from LFG combustion are of primary concern. However there is a broader context. Looking upstream from the landfill, LFG would never be generated in the first place if organic waste was recycled or composted. Looking downstream from LFGE projects, the energy these projects generate displaces energy that otherwise would have had to be generated at a power plant. To understand the full range of impacts, one generally has to do a lifecycle impact assessment, but for LFG this question is particularly complicated. Landfill gas is an inevitable byproduct of landfilling organic materials, and as mentioned earlier, is produced in substantial quantities for at least 10 to 20 years. Indeed, landfills can continue to produce LFG for decades after they are closed. Thus while our waste-management decisions today will directly effect the quantity (and therefore impacts) of LFG, once LFG is being generated, the waste is already buried and there is little, practically speaking, that can be done about it. In other words, we need to think of LFG in two timeframes: looking forward, the lifecycle impacts of LFG are directly tied to those of landfills; today however, the lifecycle impacts of LFG depend on what we do with it right now. Wise policy needs to balance these two timeframes.

In this chapter, we start with the narrowest—and some might say most urgent—analysis and then move out from there. First we look at the toxicity of LFG and exhaust from the combustion of LFG, then we add in the emissions from displaced electric generation, and finally we look at source reduction and recycling as alternative waste-management options.

THE TOXICITY OF RAW LANDFILL-GAS COMPARED TO LANDFILL-GAS COMBUSTION EXHAUST

As mentioned above, the combustion of raw LFG destroys the vast majority of the toxic elements in the gas but also creates very small quantities of dioxins.

What Are Dioxins?

Dioxins refer to hundreds of chemical compounds that are members of three closely related families: the chlorinated dibenzo-*p*-dioxins (CDDs), chlorinated dibenzofurans (CDFs), and certain polychlorinated biphenyls (PCBs).[24] Dioxins are released into the air from a number of industrial processes, including combustion processes such as commercial or municipal waste incineration and secondary copper smelting. Even cigarette smoking produces dioxins, albeit in extremely small amounts.

Exposure to dioxins at high levels increases the risk of cancer and can cause severe skin disease, excessive body hair, and possibly mild liver damage. Based on data from animal studies, there is also concern that exposure to low levels of dioxins over long periods (or high level exposures at sensitive times) might result in reproductive or developmental effects.[25] Dioxins are particularly dangerous to human health because they can travel very long distances and break down very slowly.

SOURCE	EMISSIONS (G TEQ_{DF}) IN 1995[1]	PERCENT OF TOTAL 1995 EMISSIONS
Municipal Solid Waste Incineration	1250	38%
Backyard Refuse Barrel Burning	628	1.8%
Medical Waste Incineration	488	0.4%
Secondary Copper Smelting	271	0.2%
Cement Kilns (Hazardous Waste Burning)	156	0.02%

Table 2. **Significant Sources of Dioxin-like Compounds in the United States. Source: EPA 2001.**

The EPA has developed a national inventory of annual dioxin releases from a variety of sources. The five largest sources of dioxin emissions are shown in **Table 2**.

Dioxin emissions from landfill gas

The EPA draft inventory report includes a section on LFG combustion data collected between 1990 and 1996.[26] The only U.S. study included in the report was conducted in 1990 and yielded an emissions factor of 0.24 ng I-TEQ/m^3 of exhaust.[27] (Note, I-TEQ and TEQ are toxic equivalency units, which allow amounts of different pollutants to be added together based on their relative toxicity, producing a total toxicity of a mix of pollutants.) The EPA averaged that figure with a much lower emissions factor of 0.041 ng I-TEQ/m^3 from a different study to arrive at an average emissions factor of 0.141 ng I-TEQ/m^3. Using this average, the EPA estimated annual U.S. emissions from LFG combustion at 6.6 g I-TEQ,[28] but concluded that the limited amount of available data was inadequate for developing national emissions estimates that could be included in the national inventory.[29]

Other recent studies of dioxin-emissions factors also produce a wide variation in test results, although the numbers are generally much lower. Source tests conducted by the Los Angeles County Sanitation Districts (LACSD) on LFG boilers at three different landfills yielded results between 0.01 and 0.04 ng TEQ/m^3. Test data from European sources exhibited even more variability. The most recent study was performed at the Fresh Kills landfill in New York. The LFG flare at Fresh Kills produced an average dioxin emissions rate of 0.0051 ng TEQ/m^3.[30] Data from these tests and others are shown in **Table 3**.

	Concentraion (ng I-TEQ/dscm @ 11%O2)			
Combustion Equipment	**Low**	**High**	**Mean**	**Notes**
Flare (shrouded)	0.00022	0.156	0.0136	11 units, 35 tests, 0.033 standard deviation
Flare (shrouded)			0.0051	1 unit, Freshkills, 1999
Flare (candle)	0.00186	0.155		2 units, 2 tests
I.C. Engines	0.00004	0.318	0.0196	16 units, 36 tests, 0.0545 standard deviation
I.C. Engines			0.001	2 units, 6 tests, results include non-detections
Engine with afterburner	0.00028	0.00667	0.0031	3 units, 6 tests, 0.00244 standard deviation
Boiler			0.00004	1 unit, 1 test
Boiler	0.025	0.051		3 units, 8 tests, results include non-detections
Turbine	0.0084	1.83		2 units, 3 tests, low is average of 2 tests at 1 unit

Table 3. **Dioxin Emissions Summary for Combustion Equipment. Source: Caponi et. al 1998, Hill& Caponi 2000.**

One may wonder why the Fresh Kills test data are about 67 times lower than the data from the only U.S. test cited in the EPA inventory of dioxin sources (0.0051 ng TEQ vs. 0.24). The wide range of data is perhaps partly attributable to site-specific differences among landfills. The composition of LFG is dependent on the content of the waste that exists at a particular landfill, in addition to the landfill's atmospheric conditions and structural features, all of which influence dioxin formation. The EPA study was conducted several years earlier than the Fresh Kills study, and combustion and landfill gas treatment methods as well as regulations regarding the permissible content of MSW have likely since improved. Also, dioxin testing is still a rather inexact science. Even within each sampling of dioxin emissions at the same source there exists a significant range of data points.

Using the EPA's average emissions factor of 0.141 ng I-TEQ/m^3 from its dioxin inventory (which is higher than most of the values in Table 2) and assuming that 9.65 billion cubic meters of LFG combusted in 2000,[31] we arrive at a high-end estimate of annual dioxins emissions of 13.5 g I-TEQ. The figure should be viewed as an upper bound of possible emissions from landfill gas combustion, and the actual number is likely to be much lower if actual dioxins emissions rates are more similar to those in Table 2, but we can use the figure to make some qualitative comparisons of the dioxin risk from LFGE versus that of other sources. The estimate is about two orders of magnitude less than the annual emissions from municipal solid waste incineration, which is the largest dioxin source in the U.S. At this level, LFG combustion in 2000 would have represented about 0.4 percent of total dioxin emissions in 1995.[32] If we were to use a more conservative emissions factor of 0.1 ng TEQ/m^3 (which is still high compared to the data in Table 2), we would arrive at annual dioxin emissions of 0.965 g, which represents only 0.03 percent of 1995 total emissions. **Table 4** compares the high-end estimated dioxin emissions in 2000 to the emissions from other common sources in 1995.

SOURCE	EMISSIONS (G TEQ IN 1995)	PERCENT OF TOTAL 1995 EMISSIONS	RANK (AMONG 37 SOURCES)
MSW Incineration	1250	38%	1
Coal-Fired Utilities	60.1	1.8%	8
LFG Combustion	13.5[(1)]	0.4%	17
Unleaded Gasoline	5.6	0.2%	22
Cigarette Smoke	0.8	0.02%	30

[(1)]High-end estimate using data from 2000.

Table 4. **Dioxin Emissions from Common Sources. Source: EPA 2001.**

Given these numbers, along with the emissions data in Tables 2 and 3, one might conclude that nationally the human health impact of dioxin emissions from LFG combustion is small. Even so, LFG combustion is far from innocuous, and any amount of dioxin emissions is potentially harmful to human health. People living near landfills are right to demand the best control process for LFG.

Comparing the Overall Toxicity

In addition to methane and carbon dioxide, landfill gas contains a large number of VOCs, many of which are listed as hazardous air pollutants (HAP) that pose threats to human health. The EPA National Air Toxics Program has designated municipal landfills as one of the 29 most significant area sources of HAPs.[33] This is why, as mentioned earlier, the EPA has mandated the collection and mitigation of LFG. The NSPS regulations require that at least 98 percent of these compounds be destroyed by the mitigation process, and burning in one form or another is the process of choice at landfills. Unfortunately, in the heat of the combustion process, some of these HAPs reconstitute themselves as dioxins. Thus, looking solely at the quantity of dioxins emitted from LFGE projects paints a misleading picture of the air quality impacts of these systems. To understand the broader context, it is helpful to compare the overall toxicity of raw (unburned) LFG to that of LFG combustion exhaust. Are the HAPs in raw LFG more toxic than the HAPs left over after combustion plus the dioxins formed during combustion?

Using the EPA default concentrations and California Air Resource Board cancer risk factors, NRDC performed an analysis comparing the overall toxicity of raw LFG to that of LFG combustion exhaust. The detailed explanations and calculations can be found in Appendix A, but the unit of comparison bears some explanation. When LFG is burned, it is mixed with air. As a result, one cannot simply compare the amount of pollution in a cubic meter of LFG with that in a cubic meter of exhaust. Instead, we have chosen to ask how much LFG would be needed to generate a megawatt-hour (MWh) of electricity from an engine operating at 36 percent efficiency. As can be seen above in **Table 1**, reciprocating engines are the most common way to use LFG to produce energy. As it turns out, the answer is slightly less than 19,000 cubic feet. This allows us to compare the pounds of pollution in this amount of unburned LFG to the amount of pollution in the exhaust created from combusting this amount of LFG. For pollution in raw LFG or the exhaust from a flare, neither of which involve the production of electricity, we measure the pollution in lbs/MWh-equivalent. For pollution in the exhaust from the engine or a turbine, we measure the pollution in simple lbs/MWh. The advantage of this unit of measurement increases in the next section when we start taking into account the displaced emissions from electric power plants.

	Inhalation Cancer Potency Factor $(mg/kg\text{-}d)^{-1}$	Dioxin based TEQ	AP-42 Raw LFG Concentration (PPM)	Raw LFG		LFG Combustion Exhaust	
				lb/MWh-equiv[1]	lb TEQ/MWh-equiv[2]	lb/MWh-Equiv.[3]	lb TEQ/MWh-Equiv
1,1,2,2-Tetrachloroethane	2.00E-01	1.54E-06	1.11	9.84E-03	1.51E-08	1.97E-04	3.03E-10
1,1-Dichloroethane (ethylidene dichloride)	5.70E-03	4.38E-08	2.35	1.23E-02	5.39E-10	2.46E-04	1.08E-11
1,2-Dichloroethane (ethylene dichloride)	7.00E-02	5.38E-07	0.41	2.14E-03	1.15E-09	4.29E-05	2.31E-11
Carbon tetrachloride	1.50E-01	1.15E-06	0.004	3.25E-05	3.75E-11	6.50E-07	7.50E-13
Chloroform	1.90E-02	1.46E-07	0.03	1.89E-04	2.77E-11	3.79E-06	5.53E-13
Dichlorobenzene	4.00E-02	3.08E-07	0.21	1.63E-03	5.02E-10	3.26E-05	1.00E-11
Dichloromethane (methylene chloride)	3.50E-03	2.69E-08	14.3	6.42E-02	1.73E-09	1.28E-03	3.46E-11
Ethylene dibromide	2.50E-01	1.92E-06	0.001	9.93E-06	1.91E-11	1.99E-07	3.82E-13
Perchloroethylene (tetrachloroethylene)	2.10E-02	1.62E-07	3.73	3.27E-02	5.28E-09	6.54E-04	1.06E-10
Trichloroethylene (trichloroethene)	7.00E-03	5.38E-08	2.82	1.96E-02	1.05E-09	3.92E-04	2.11E-11
Vinyl chloride	2.70E-01	2.08E-06	7.34	2.42E-02	5.03E-08	4.85E-04	1.01E-09
Polychlorinated Dibenzo-P-Dioxins (2,3,7,8-TCDD)	1.30E+05	1.00E+00	0	0.00E+00	0.00E+00	1.65E-09	1.65E-09
Total					7.58E-08		3.17E-09

Table 5. **Hazardous Air Pollutants in Landfill Gas. Source: CARB 2002, EPA 2000e.**

The California Air Resource Board has inhalation-cancer-potency factors for 11 of the 44 HAPs found in LFG. Using these factors and the EPA's upper-bound average dioxin emissions factor of 0.198 ng TEQ/m^3 of exhaust, we calculated that the exhaust from LFG combustion has a total inhalation cancer potency of $3.17 * 10^{-9}$ lb TEQ/MWh-equiv. compared to $7.58 * 10^{-8}$ lb TEQ/MWh-equiv. for raw LFG. In other words, raw landfill gas is approximately 24 times more carcinogenic to human health than landfill gas combustion exhaust.[34] **Table 5** lists the HAPs, their cancer potency, and their dioxin-equivalent TEQ, simple concentrations in raw landfill gas, their lbs/MWh concentrations, and the lbs TEQ before and after combustion. These results show that burning raw LFG greatly reduces the cancer risk of LFG.

There are three sources of uncertainty that are worth noting in this calculation. First, the exact makeup of LFG is not known, neither in terms of which pollutants nor how much of those pollutants.[35] The Waste Industry Air Coalition (WAIC) is pressing the EPA to change all of the default concentrations listed in for LFG in AP-42. Most, but not all, of the WIAC proposed concentrations are substantially lower than those currently used by the EPA.[36] For the 11 pollutants with ARB inhalation cancer-risk factors, WIAC's proposed numbers would reduce the combined risk factor by nearly 80 percent. While the reduced toxicity of raw LFG makes the formation of dioxins proportionately more significant, combustion still reduces the cancer risk factor by more than eight times. The WIAC data is presented in more detail in Appendix A.

The simple fact is that not enough is known about LFG or LFGE exhaust to be sanguine about it. Nevertheless, all the existing data indicates that flaring or generating electricity from landfill gas greatly reduces its toxicity

Furthermore, as mentioned earlier, the makeup of LFG will vary depending on the landfill design, contents, and surrounding environmental conditions. Second, the cancer risk factors are hardly exact numbers.[37] And third, not all LFG combustion will destroy exactly 98 percent of toxics in LFG. Different temperatures and the thoroughness of combustion will result in different levels of destruction. The EPA's default assumptions for different flares, boilers, gas turbines, and internal combustion engines reflect a range of effectiveness from 86.1 percent to 99.7 percent depending on the technology and the type of pollutant.[38] Nevertheless, given the conservative assumption about the level of dioxin formation and the 23-fold reduction, it seems highly unlikely that these uncertainties will change the conclusion that LFGE projects reduce the cancer risk from LFG.

While most surveys of dioxin emissions from various landfills suggest that LFG combustion is a minor source of dioxins at the national level, the emissions are not zero. More data is needed to quantitatively assess the health hazards of LFGE exhaust. Cancer potency factors are available for only 11 of the 44 HAPs known to be in LFG, and there are many more gaseous species in LFG than are regularly analyzed.[39] There are literally tens of thousands of human-made chemicals in use today. The human and environmental impacts are known for only a small fraction of these and only a portion of these are tested for at landfills. In other words, even if WIAC is right, it would be foolhardy not to make every effort to reduce the release of raw LFG into our air.

The simple fact is that not enough is known about LFG or LFGE exhaust to be sanguine about it. Nevertheless, all the existing data indicates that flaring or generating electricity from landfill gas greatly reduces its toxicity, and, though LFG combustion exhaust is certainly not a harmless substance, combustion is a far better alternative to allowing LFG to escape uncontrolled to the atmosphere.

GREENHOUSE GASES AND OTHER AIR POLLUTANTS

But what of the broader picture? Landfill gas energy projects displace alternative sources of energy, and landfills displace alternative forms of waste management. Again the time frame for our analysis is crucial. In the short-term, LFGE projects producing electricity displace just the existing mix of power plants against which they compete. In the long-run, however, LFGE projects effect decisions about whether or not new power plants get built. Similarly, in the short-term, LFG is only produced from waste that has already been buried, but in the long-run even slight changes in the marginal cost of landfilling will also effect how much reuse and recycling take place. First let us turn to the interactions between LFGE and electric power plants.

If we limit our perspective to LFG that is already being produced, there are four basic scenarios that we must consider:

1. Raw LFG is released directly to the atmosphere, and we get our electricity from power plants;
2. LFG is flared and we get our electricity from power plants;
3. We use LFG in a reciprocating engine to generate electricity; or
4. We use LFG in a turbine to generate electricity.

Landfill gas can also be used in boilers, and the basic approach used below could be applied to such a situation, but to limit our analysis, we will focus here on electricity. Thus there are five distinct sources of pollution that we must analyze if we are to understand the cumulative pollution from each of these scenarios: raw LFG, flare exhaust, LFG engine exhaust, LFG turbine exhaust, and power plants. Because power plants and LFG engines and turbines all vary in size and efficiency, measuring pollution on either a concentration basis or a fuel input basis can lead to misleading conclusions. As mentioned earlier, a certain amount of pollution in a cubic foot of raw LFG is not comparable to the amount of pollution in a cubic foot of exhaust. Similarly, looking at the amount of pollution emitted per Btu of LFG burned in an engine gives us no insight into how much pollution could be avoided at a power plant. For these reasons among others, we will use the metric of pounds of pollution per megawatt-hour generated. As mentioned earlier, for raw LFG and for flares, which obviously do not generate any megawatt-hours, we look at the pounds of pollution in the amount of LFG that would be needed to generate a megawatt-hour from a lean burn reciprocating engine running at 36 percent efficiency.

Beyond the HAPs discussed above, there are six major air pollutants for which adequate data exists to compare these four scenarios. These pollutants are nitrogen oxides (NO_x), sulfur dioxide (SO_2), volatile organic compounds (VOC), particulate mater (PM), mercury (HG), and carbon dioxide (CO_2). These pollutants contribute to local, regional, and global environmental and public health impacts including asthma, cancer, cardio pulmonary diseases, damage to the nervous system, acid rain, ground-level ozone, and global warming. While much more could be said about these impacts, we focus here on the reasons that the rate of pollution for each of these contaminants differs for each of the five sources in our scenarios.

- **Nitrogen Oxides:** The formation of NO_x is primarily driven by the heat of combustion. Because there is such an abundant amount of nitrogen and oxygen in ambient air, the amount of nitrogen in the fuel plays a relatively small role in the amount of NO_x in exhaust. Thus because flares involve relatively low temperature combustion, they result in the least amount of NO_x. It is also important to note that while NO_x emissions are regularly controlled at large power plants, because of the multitude of contaminants in LFG, engines and turbines running on LFG generally are not equipped with NO_x

emissions controls. In fact, the EPA recently promulgated so called Maximum Achievable Control Technology (MACT) standards, and the EPA explicitly did not set MACT standards for LFG engines because of the contamination problem.[40]

- **Sulfur Dioxide:** The formation of SO_2, on the other hand is almost entirely driven by the amount of sulfur in the fuel being burned. Raw LFG does have sulfur in it, though not in the form of SO_2. While this means that there will be SO_2 in the exhaust when LFG is burned, unfortunately, there is limited data on the emissions rates from flares, engines, and turbines. While SO_2 emissions can be controlled at large power plants, in LFG combustion, the preferred approach is cleaning the gas before combustion. In engines and turbines, this step is fairly common as the sulfur compounds can damage the equipment. In flares, however, clean up is not the norm. Unfortunately, the limited data available on LFG combustion does not specify if any clean up was done, so this expected variation between flares, engines, and turbines is not seen in our analysis.
- **Volatile Organic Compounds:** The level of VOCs in exhaust is a measure of how complete the combustion process is and the temperature. At high enough temperatures and in the presence of enough oxygen, VOCs will be destroyed. Recall that it is the destruction of VOCs, many of which are HAPs, that was the basis for the EPA's landfill New Source Performance Standard. That rule requires destruction of 98 percent of the HAPs in LFG. In engines and turbines there is an important interaction between NO_x and VOCs. To reduce the temperature of combustion and thus NO_x formation, engines and turbines are often run with less oxygen than fuel (known as "lean burn" configurations); unfortunately, this can result in incomplete combustion. At landfills this is often addresses with what are known as "afterburner" flares, which are essentially designed to finish the combustion job. As a result, the level of VOC emissions from LFG engines and turbines can be misleading.
- **Particulate Mater:** In clean gaseous fuels, PM is largely limited to the coalescing of contaminants into ultra-fine particles (less than 2.5 micron in diameter). Landfill gas is of course far from a clean gaseous fuel. The contaminants are more numerous and more toxic than what is found in natural gas, for instance. Unfortunately, the data is limited and does not specify the size or speciation of PM. As a result, while comparisons can be made between our five sources, no broad conclusions about the related health effects should be drawn.
- **Mercury:** This heavy metal is often looked at as a benchmark for a range of toxic pollutants that are likely to effect the environment and population near a source of pollution. While HG comes in many forms, it is not destroyed in the combustion process. Thus while there is no data on HG emissions from LFG combustion, we have assumed that any amount found in raw LFG will be in the combustion exhaust as well.
- **Carbon Dioxide:** Emissions of CO_2 are driven virtually entirely by the carbon content in the fuel. Of course, all of the carbon in LFG comes from biomass, which at some point earlier had to suck that carbon out of the CO_2 in the air. Thus, in terms of CO_2 emissions, LFG is normally considered carbon neutral. However, about 55 percent of LFG is methane (CH_4), which has 23 times the heat-trapping capabilities of CO_2. Thus raw LFG is decidedly not carbon neutral. When we look at the CO_2 content of raw LFG, we will add in 23 times the CH_4 content. In our analysis, we ignore the CO_2 in

raw LFG and consider flaring and combustion in an engine to have zero net CO_2 emissions. Turbines are less efficient, meaning that they can displace less traditional electricity, thus we count the difference in CO_2 emissions between turbines and engines against turbines. We will look at the broader context of LFG and greenhouse gas emissions later, but suffice it to say here that the fact that biomass is carbon neutral does not make landfilling a good waste management practice from a global warming perspective. If we listed recycling as an option here, it would have a large negative CO_2 emissions rate.

Table 6 presents a composite of the readily available data for all of these pollutants from all five of the sources involved in our scenarios. In many cases, these numbers are simple averages of the range of available data, in others there is only one source of data or we have discounted data due to improbable results. The ranges, where available, are presented below the composite and all the available data with source information is presented in Appendix A.

In **Table 6**, we also present emissions rates for average coal and new natural-gas power plants as well as all power plants. When a LFGE project produces electricity, that electricity does not have to be generated elsewhere, but what exact type of power plant is being displaced is far from clear and depends on the time of day, time of year, and geographic location. The easiest solution is to simply assume that an average mix of all power plants is being avoided. In the short-run, we can bound the probable answer by looking at the dirtiest type of power plants, namely coal, and the cleaner type of power plants, namely new gas. In the short-term, neither extreme is likely to be displaced, but over time, new generation such as LFGE either encourages more retirements of old plants such as coal plants, or discourages the construction of new plants, such as gas plants. Which occurs will depend on a range of policies. If we enact stricter air pollution regulations and encourage energy efficiency, then LFGE will primarily displace old plants. If we continue with the status quo, the competition will be primarily among which new plants get built. We'll come back to this issue of displacement later because there are situations where renewable sources of electricity might actually be displaced, and this dramatically changes the picture.

If we enact stricter air pollution regulations and encourage energy efficiency, then LFGE will primarily displace old plants. If we continue with the status quo, the competition will be primarily among which new plants get built.

Armed with these numbers, we can start to look at the cumulative emissions associated with each scenario identified above. Recall from our earlier discussion of the EPA NSPS, that the first scenario, where raw LFG is being released and electricity is generated at power plants, is likely to occur at a smaller landfill not subject to the NSPS rules. The second scenario, where LFG is flared and electricity is still generated at power plants, could occur at small or large landfills, but only where a gas collection system is in place. At larger landfills, the NSPS rules make this the baseline. The third and fourth scenarios, where LFG is used in an engine or a turbine to generate electricity displacing power plants, are the heart of our analysis. The question we're trying to answer at this point is: does the use of LFG in engines or turbines increase or decrease the amount of any of these key pollutants. **Table 7** shows the basis for our comparison.

EMISSIONS SOURCE	NO_x	SO_2	VOC	PM	HG	CO_2
	(ALL DATA IS IN LBS/MWH)					
All Electric Power Plants	2.96[a] (2.79-2.96)	6.28[a] (5.96-6.28)	0.025[b]	0.14[b]	2.66E-05[b]	1417[a] (1351-1417)
All Coal Power Plants	4.81[a] (4.56-4.81)	11.05[a] (10.77-11.05)	0.032[b]	0.24[b]	4.92E-05[b]	2210[a] (2182-2210)
New Gas Power Plants	0.07[b]	0.004[b]	0.015[b]	0.05[b]	1.80E-06[b]	861[b]
Raw LFG	0.002[b]	0[b]	0.60[b]	-na-	3.10E-06[b]	9796 (CH_4 in CO_2 equiv.)[b,d]
Flare	0.5[c] (0.4-0.8)	0.024[b]	0.40[c] (0.3-0.5)	0.2[b]		0[d]
LFG Recip. Engine	3.0[c] (1.9-2.6)		1.6[c] (0.78-1.9)	0.5[b]		
LFG Turbine	2.0[c] (1.2-4.0)	0.03[b]	0.12[c] (0.07-0.16)	0.3[c] (0.29-0.30)	4.13E-06[b]	938[a,d] (632-3752)

[a] Best data chosen.
[b] Only one source of data.
[c] Simple average of available data.
[d] These data assume that CO_2 emissions of 2814 lbs/MWh (the only data point available) from LFG are bio-based and thus carbon neutral.

Table 6. **Summary of Major Pollutant Emissions Rates from Landfill-Gas Related Sources.**

	NO_x	SO_2	VOC	PM	HG	CO_2
(ALL DATA IN LBS/MWH)	GAS-ALL-COAL	G-A-C	G-A-C	G-A-C	G-A-C	G-A-C
Raw LFG + Power Plants	0.1 - 3.0 - 4.8	0.0 - 6.3 - 11.1	0.6 - 0.6 - 0.6	0.1 - 0.1 - 0.2	4.9E-06 - 3.0E-05 - 5.2E-05	10657 - 11213 - 12006
Flaring + Power Plants	0.6 - 3.5 - 5.3	0.0 - 6.3 - 11.1	0.4 - 0.4 - 0.4	0.3 - 0.3 - 0.4	4.9E-06 - 3.0E-05 - 5.2E-05	861 - 1417 - 2210
LFG Engine	3	0.024	1.6	0.5	3.10E-06	0
LFG Turbine	2	0.03	0.12	0.3	4.13E-06	938

Table 7. **Comparison of Emissions from Various Landfill-Gas Treatment Scenarios.**

From **Table 7**, we can draw the following conclusions when we assume that the first scenario (raw LFG and power plants) is our baseline:

- For the most part, the use of LFG in engines or turbines will reduce the amount of air pollution in comparison to releasing raw LFG and generating electricity at power plants.
- The largest exceptions to this is PM emissions, which would go up regardless of whether engines or turbines are used and of what type of power plants are displaced, and VOC emissions if engines are used. However, recall that we do not know the size

or speciation of the PM emissions and VOC emissions can be controlled with an afterburner flare.

- If only new gas plants are displaced by LFGE, then NO_x and SO_2 emissions would also go up.
- Carbon dioxide emissions are reduced dramatically, mostly through the destruction of methane. The methane in raw LFG is equivalent to nearly 10,000 lbs of CO_2.

If we use flaring plus power plant emissions as our baseline, the picture changes, but not dramatically. With this baseline, we can draw the following conclusions:

- Again for the most part, the use of LFG in engines or turbines will reduce the amount of air pollution in comparison to flaring LFG and generating electricity at power plants, but the improvements are not as large especially for NO_x and CO_2.
- Engines produce more NO_x, VOC, and PM pollution than turbines, and thus engines result in increases of these pollutants over the baseline except for NO_x when only coal plants are displaced.
- Because natural gas has so little sulfur in it, if only new gas plants are displaced, SO_2 emissions still go up for both engines and turbines burning LFG. However, as mentioned earlier, this may be an artifact of the limited data.
- Carbon dioxide emissions still generally go down, but the reduction is much smaller. In fact because turbines are less efficient than engines, they could actually produce a small increase in the CO_2 emissions if only new gas power plants are displaced.

One broad conclusion we can draw is that if LFGE projects start to compete with new gas-fired power plants, the benefits of these projects are very much in question. However, the strongest result that can be seen here is that combusting raw LFG in a flare, engine, or turbine, greatly reduces CO_2 emissions. While under various conditions, NO_x, SO_2, VOC, and PM can all go up when we start to combust LFG, the tremendous reduction in CO_2 and toxicity continue to argue strongly for ensuring that all LFG is combusted. Energy production will most often further increase the overall benefits, but this first step of simply burning LFG is the most important.

IS LANDFILL GAS RENEWABLE?

So far we have looked at the toxicity of LFG and exhaust from LFG combustion and at the pollution impacts when taking into account that electricity from LFGE projects would reduce emissions from power plants. But to determine whether or not LFG is renewable, we need to take a broader perspective. While the term renewable can mean a lot of things to different people, virtually all of them have at their heart a notion of sustainability—a practice that can be continued indefinitely. Landfill gas would not exist without landfills, therefore to determine whether or not LFG is sustainable, we must determine whether or not landfills are sustainable. This requires looking at landfills in the context of other waste-management practices.

The alternatives to landfilling are resource reduction (i.e. using less), recycling, composting (primarily for food and yard waste), and direct combustion. To compare these alternatives, we need to look at the lifecycle impacts of each one. These impacts start when virgin resources are extracted and harvested; they continue when the resources are processed into products, which in turn get used; and finally, the products either get recycled, composted, combusted, or landfilled. At each stage, there are potentially greenhouse gas emissions and greenhouse gas sinks.

Fortunately, the EPA has done a lifecycle impact analysis looking at the greenhouse gas emissions associated with all of these alternatives. **Table 8** is taken from the EPA's report *Solid Waste Management and Greenhouse Gases, A Life-Cycle Assessment of Emissions and Sinks*.[41] The table looks at the change in greenhouse gas emissions (measured in metric tons of CO_2 equivalency) associated with managing a ton of materials through resource reduction, recycling, composting, or combusting instead of landfilling. In developing this table, the EPA first calculated all the sources of greenhouse gas management involved in harvesting materials, making products, using them, and disposing of them through each of these waste management options. Then the EPA calculated all the ways in which greenhouse gases were removed from the atmosphere (known as sinks) over this lifecycle. Subtracting the sinks from the sources, the EPA calculated a net emissions rate for each management option. In **Table 8**, the EPA subtracts the net emissions from landfill from the net emissions associated with each other practice. The results tell us how many millions of metric tons of CO_2 equivalency would result from shifting a ton of each type of material away from landfilling toward one of the alternative practices.

Reducing the use of virgin resources leads to the greatest reduction in greenhouse gases, generally followed by resource reduction with the current mix of virgin and recycled materials and then by recycling.

The remarkable result to note is that for nearly every type of material, a shift away from landfilling leads to a reduction in greenhouse gas emissions. Reducing the use of virgin resources leads to the greatest reduction in greenhouse gases, generally followed by resource reduction with the current mix of virgin and recycled materials and then by recycling.

The results in **Table 8** take into account the current national average level of methane recovery and energy production, but the fundamental conclusion that resource reduction and recycling reduce greenhouse gas emissions in comparison to landfilling would not change with even the most extreme assumptions. The results assume that 51 percent of LFG is generated at landfills with no gas collection system of any kind, 26 percent is generated at landfills with a collection system and simple flares, and 24 percent is generated at landfills with collection systems and energy systems. However, LFG collection systems are far from 100 percent effective. The EPA assumes that the collection systems capture 75 percent of the gas reaching the surface of the landfill.[42] There is reason to believe that this number too high.[43] These assumptions raise a number of logical questions. For instance, would landfilling be superior to other options if all the LFG was collected and flared or used for energy? And what would be the significance if the collection efficiency is much lower? Using the EPA's model, even when we assume that all the LFG produced was being collected and flared or collected and used for energy, recycling and resource reduction still reduces greenhouse gases in comparison. And if the capture efficiency of existing LFG collection systems is on 50 percent, resource reduction and recycling only look that much better. **Table 9** explores these extreme scenarios for office paper and dimensional lumber, the forms of biomass that show the greatest and least greenhouse gas improvement under resource reduction in the EPA's base case.

Greenhouse Gas Emissions of Municipal Solid Waste Management Options Compared to Landfilling[1] ($MTCO_2E$/Ton)					
Material	**Source Reduction[2] Net Emissions Minus Landfilling Net Emissions (Current Mix)**	**Source Reduction Net Emissions Minus Landfilling Net Emissions(100% Virgin Inputs)**	**Recycling Net Emissions Minus Landfilling Net Emissions**	**Composting[3] Net Emissions Minus Landfilling Net Emissions**	**Combustion[4] Net Emissions Minus Landfilling Net Emissions**
Aluminum Cans	-9.18	-17.15	-15.11	NA	0.02
Steel Cans	-2.92	-3.72	-1.83	NA	-1.57
Glass	-0.54	-0.61	-0.32	NA	0.01
HDPE	-1.82	-1.99	-1.44	NA	0.81
LDPE	-2.29	-2.38	-1.75	NA	0.81
PET	-1.82	-2.18	-1.59	NA	1.00
Corrugated Cardboard	-2.17	-3.79	-2.88	NA	-0.96
Magazines/Third-class Mail	-3.36	-3.94	-2.26	NA	-0.05
Newspaper	-2.21	-4.07	-2.72	NA	-0.01
Office Paper	-5.23	-5.99	-4.77	NA	-2.94
Phonebooks	-3.94	-4.37	-2.57	NA	-0.01
Textbooks	-6.78	-7.13	-5.03	NA	-2.94
Dimensional Lumber	-1.63	NA	-2.07	NA	-0.43
Medium-density Fiberboard	-1.82	NA	-2.09	NA	-0.43
Food Discards	NA	NA	NA	-0.82	-0.81
Yard Trimmings	NA	NA	NA	0.15	0.11
Mixed Paper					
Broad Definition	NA	NA	-2.84	NA	-1.06
Residential Definition	NA	NA	-2.72	NA	-0.93
Office Paper Definition	NA	NA	-3.62	NA	-1.18
Mixed Plastics	NA	NA	-1.55	NA	0.90
Mixed Recyclables	NA	NA	-2.99	NA	-0.80
Mixed Organics	NA	NA	NA	-0.32	-0.33
Mixed MSW as Disposed	NA	NA	NA	NA	-0.38

Note that totals may not add due to rounding, and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[1] Values for landfilling reflect projected national average methane recovery in year 2000.

[2] Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[3] Calculation is based on assuming zero net emissions for composting.

[4] Values are for mass burn facilities with national average rate of ferrous recovery.

Table 8. **Greenhouse Gas Emissions of Municipal Solid Waste Management Options Compared to Landfilling. Source: EPA 2002e.**

Greenhouse Gas Emissions of Municipal Solid Waste Management Options Compared to Landfilling (MTCO2E/Ton)			
	Source Reduction Net Emissions Minus Landfilling Net Emissions (Current Mix)	Recycling Net Emissions Minus Landfilling Net Emissions	Combustion Net Emissions Minus Landfilling Net Emissions
	Base Case		
Office Paper	-5.23	-4.76	-2.93
Dimensional Lumber	-1.63	-2.07	-0.43
	100% collection and flaring		
Office Paper	-2.83	-2.36	-0.53
Dimensional Lumber	-1.29	-1.73	-0.09
	100% collection and energy production		
Office Paper	-2.05	-1.58	0.25
Dimensional Lumber	-1.18	-1.62	0.02
	50% Collection Efficiency		
Office Paper	-5.76	-5.29	-3.46
Dimensional Lumber	-1.70	-2.14	-0.50

Table 9. **Greenhouse Gas Emissions of Municipal Solid Waste Management Options under Extreme Scenarios.**

The simple fact that landfilling results in the most greenhouse gas production of any of the waste-management options is sufficient proof alone that landfilling is not a sustainable practice and thus that landfill gas is not renewable. Furthermore, one need look no further than the long-term threat of water pollution created by landfills for confirmation. In traditional landfills, the very moisture that enables biomass to decompose and produce LFG continues through the landfill, collecting contaminants along the way. When the water leaves the landfill, it is known as leachate, and it is often highly toxic—containing potentially thousands of human-made chemicals, many of which are carcinogenic.[44] Once groundwater is contaminated by leachate, it is essentially impossible to cleanup.

In the late 1980s, the threat of groundwater contamination by leachate led the EPA to establish regulations governing the lining of landfills and collection of leachate. Subtitle D or "dry-tomb" landfills are required to have at least composite clay covered by a thin sheet of plastic lining the bottom, a plastic cover over the top, leachate collection systems, and water pollution monitoring wells. Unfortunately, even the EPA acknowledges that the liners and collection systems will fail eventually.[45] The monitoring wells, which are required to be no more than 30 meters apart, may well not be working at this point either, but even if they are, they have little chance of detecting a lining failure. A lining failure is most likely to initially manifest as a crack and result in a finger of pollution.[46] The probability of this finger passing close enough to a well to contaminate samples taken there is small. As a result, at best, dry-tomb landfills are time bombs waiting to contaminate groundwater for future generations, though it seems quite likely that these Superfund-sites-in-waiting will evade the monitoring systems and poison drinking water today.

There are alternatives under consideration. So called bio-reactors intentionally circulate water through the landfill to speed up the leaching and decomposition process. Bio-reactors must achieve moisture saturation above 45 percent and can reach 65 percent in comparison with dry-tomb reactors which reach about 20 percent.[47] This creates risks of catastrophic failures of the landfill walls and dramatically uneven settling that can greatly reduce the efficacy of the gas-collection system. Even if bio-reactors could overcome their safety concerns and collect more methane, they cannot overcome the fact that landfills are still poor waste-management options from a global warming perspective.

The inevitable conclusion is that burying garbage in the ground is not a sustainable way to manage our waste. Therefore LFG can not be called a renewable despite the fact that biomass can be regrown. It's not the biomass that is unsustainable, it's the process that is converting that biomass into LFG.

ESTABLISHING A HIERARCHY OF PRIORITIES

We have gone from looking at LFG in the narrow context of its toxicity and that of LFG combustion, to the broadest possible context of the lifecycle of waste-management practices. This range has also spanned different timeframes. As long as LFG is being produced, toxicity will be an immediate concern. The overall air pollution impacts of LFG and LFGE projects depend on what type of power plants are displaced, something that will change over time. In the future, new plants or old plants may be pushed out by LFGE depending on a range of policies. Finally, while unfortunately landfills are not simply going to go away, it is clear that we need to move away from them as a waste-management practice and toward resource reduction and recycling. Across these different contexts and timeframes, LFG and LFGE are a decidedly mixed bag. Nevertheless, we can establish the following hierarchy of priorities:

1. **Avoid LFG by avoiding landfills.** The first priority must be increased resource reduction and recycling. Biomass—especially paper—is easily recycled or composted. If there is no biomass in landfills, then there will be no LFG.
2. **Burn all LFG that is produced.** Even if we could close all landfills today, they would continue to produce LFG for years to come. Combusting LFG in an engine, a turbine, or simply in a flare has tremendous benefits in terms of reduced toxicity and reduced greenhouse gases. Sixty-one percent of LFG is generated at landfills with no collection system and at least 25 percent of LFG at landfills with collection systems simply escapes. Collecting all of this gas and burning it—preferably for energy, but at least in a flare—should be a priority nearly equal to avoiding landfills.
3. **Use LFG for energy production.** While there are instances where the use of LFG for energy can increase the amount of certain pollutants, the balance of benefits is in favor of using LFG for energy. Generally turbines are cleaner than engines, though less efficient. However the benefits of LFGE are greatest if we also increase air pollution regulations and energy efficiency so that we displace coal plants instead of gas plants.

Ideally we would achieve all of these goals, and with them in mind, we can turn to the question of incentives and subsidies for LFGE and figure out how we can best achieve these priorities through public policy.

CHAPTER 3

SUBSIDIES AND LANDFILL-GAS ENERGY ECONOMICS

In recent years, LFGE projects have qualified for a number of federal and state subsidies associated with electricity generation from renewable and clean energy resources. Due to frequent changes in legislation and uncertainties related to electric industry deregulation, these subsidies are difficult to quantify. But some recycling advocates are concerned that LFGE subsidies amount to significant reductions in tipping fees, which are the disposal rates charged by landfill operators per ton of disposed waste.

In the long-run, however, all subsidies to landfills for energy projects are additive and must be looked at in the context of a whole range of incentives for landfilling over recycling.

Since the cost-effectiveness of recycling programs is directly linked to tipping fees, LFGE subsidies could possibly reduce the competitiveness of recycling programs by enabling landfill operators to charge lower tipping fees. As discussed earlier, diverting wastes through recycling and composting clearly represents the best alternative to landfill disposal from an environmental perspective, and it should be a top priority to ensure that LFGE subsidies do not compete with the viability of recycling. However, we also want to make sure that the LFG that is generated is collected and combusted, preferably to produce energy.

Each LFGE project is uniquely affected by LFGE incentives. Some projects may depend on subsidies to break even, while others may be cost-effective even without subsidization. To the extent possible, LFGE incentives ought to encourage LFG recovery and utilization without contributing to the coffers of landfills where projects are already profitable. A crucial question in this analysis is whether one considers the costs of a gas-collection system part of the cost of doing business or part of the cost of achieving a public good. If the costs are part of the baseline cost of business, then subsidies that cover these costs are subsidies for landfilling. If the costs are not part of the baseline, then subsidies can be seen as an investment towards the public good. We discuss this distinction further below in the **Breakeven Point** section. Unfortunately, this distinction is only one of many complex factors influencing LFGE project economics, and as a result, over-subsidization of some projects is a practical inevitability. In such instances, LFGE subsidies could potentially lead to reduced landfill tipping fees. We start our analysis with an overview of existing subsidies, then evaluate the economics of LFGE subsidies, and finally attempt to quantify the short-term effects of LFGE subsidies on landfill tipping fees.

In the long-run, however, all subsidies to landfills for energy projects are additive and must be looked at in the context of a whole range of incentives for landfilling over recycling. Thus, as with the environmental impacts, we need to look at LFGE subsidies in broader contexts and over longer periods of time.

OVERVIEW OF FEDERAL SUBSIDIES

Renewable Energy Production Incentive

The Renewable Energy Production Incentive (REPI) was authorized by the Energy Policy Act of 1992. The Renewable Energy Production Incentive provides an incentive payment of ¢1.5 per kWh (1993 dollars) to owners and operators of municipally owned facilities who generate electricity from a renewable source. The program has been in effect for a ten-year period and expires in September 2003. Under REPI, LFGE qualifies as a Tier 2 project. Tier 1 projects such as solar, wind, and closed-loop biomass have priority for annual funding. Since 1996, only Tier 1 projects have received 100 percent funding, while Tier 2 projects have received partial payments on a prorated basis. The Renewable Energy Production Incentive appropriations vary from year to year; recent annual appropriations have ranged from $1.5 to $4 million. In 2001, full funding of both Tier 1 and Tier 2 projects would have required an annual appropriation of over $28 million.[48]

The fluctuating amounts paid to LFGE projects in the past five years underscore the uncertain nature of REPI funding for LFGE. Landfill-gas energy projects have not received full funding since 1996, and without increased appropriations from Congress, can expect to receive less compensation per kilowatt-hour of electricity generated as production from Tier 1 sources and the number of claimants increase. **Table 10** shows how the funding and value to LFGE projects has fluctuated in recent years.

Payment Yr.	Production Yr.	$ to LGTE $000s	LFG as % of total funding	Payment ¢/kWh	% of full funding
1997	1996	1,879	75.4%	1.39	93%
1998	1997	1,213	90.8%	0.60	40%
1999	1998	1,715	75.4%	0.74	49%
2000	1999	382	42.5%	0.18	12%
2001	2000	1,265	42.9%	0.41	27%

Table 10. **Renewable Energy Production Incentive Payment History. Source: EREN 2002a.**

Section 29 Tax Credits

The major incentive assisting LFGE is the Section 29 tax credit, which was enacted to encourage the production of energy from non-conventional sources. It is currently valued at about $1.08 per MMBtu,[49] which equates to about ¢1 per kWh. Under current regulations, Section 29 tax credits can be claimed through 2007 for LFG collection facilities placed in service after December 31, 1992, and prior to June 30, 1998. Facilities placed in service before that period can only claim the credits through 2002. Section 29 expired on June 30, 1998, meaning that LFGE projects initiated since then do not qualify for the credits (see **Figure 4**).

Figure 3 shows the spike in the number of new projects that became operational in the years preceding 1998, when the tax credit expired, and the slowdown in the construction of new facilities in the following year. This suggests that Section 29 tax credits were successful in driving installation of combined collection and energy systems and thus driving a shift from the release of raw LFG all the way to collection and energy production. However, since eligibility for the tax credit is based on the date of the installation of the collection system, any systems that start taking advantage of the credit today are only shifting from collection and flaring to collection and energy production.

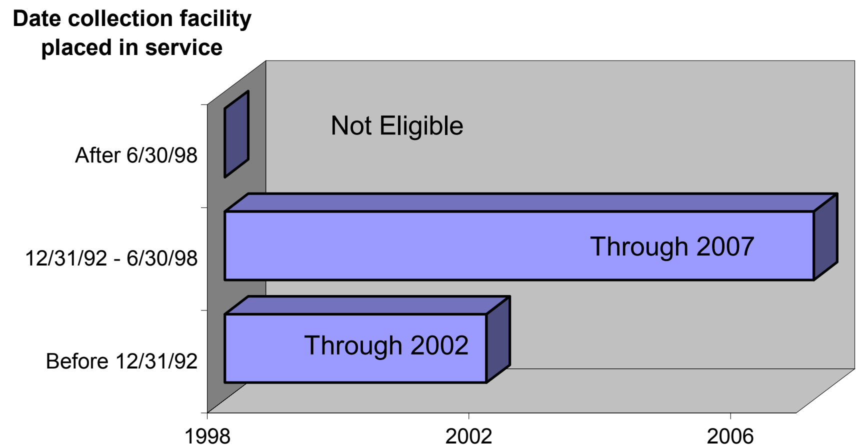

Figure 4. **Eligibility Timeline for Section 29 Tax Credit.**

Proposed Legislation

In 2002, the proposed House and Senate energy bills both included 10-year reauthorizations for REPI with provisions that eliminated the two-tier system that distinguishes between higher and lower priority energy sources. By adding more certainty to the award payment process, this legislation would substantially benefit municipally owned LFGE projects if it is approved.

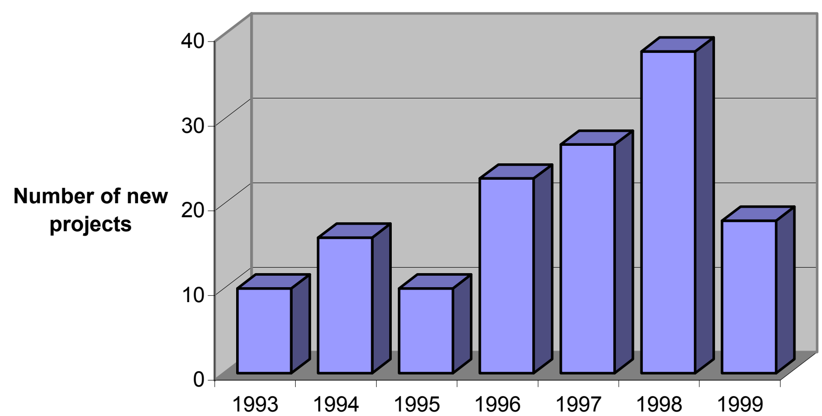

Figure 3. **New Landfill-Gas Energy Projects 1993-1999. Source: Thorneloe et al. 2000.**

In addition to the REPI reauthorization, the Senate version of the bill also included renewable portfolio standards and renewable energy federal purchase requirements that would also increase incentives for electricity generation from LFG.[50] Also pending Congressional decision are proposals that call for extensions of the Section 29 tax credit and expansion of the renewable energy production tax credit to include LFG.

One proposal in the federal energy bill could have negative consequences for future LFGE projects. Under the Public Utility Regulatory Policies Act (PURPA), electric utilities are required to interconnect with LFGE projects and pay them their avoided cost of energy (also known as the buyback rate), which is the utility's incremental cost of power production. Some versions of the energy bill proposed discontinuing PURPA, which, if approved, could make grid connection more costly and difficult for LFGE projects.

Historically, many LFGE projects have relied on incentives to operate economically. The outcome of pending federal energy legislation is likely to have tremendous influence on the future of LFGE project development.

STATE AND LOCAL INCENTIVES

Several states provide incentives for electricity generation from renewable sources. These can take the form of tax credits, rebates, loans, and renewable portfolio standards. In some instances, state incentives can outweigh federal ones. For instance, the New Renewable Resources Account in California has allocated over $28 million to 23 new LFGE projects; this represents an average incentive of ¢1.13 per kWh.[51] The $28 million of conditional funding is a greater amount than the sum of the past 8 years of annual REPI appropriations for all sources of renewable power.

The Renewable Energy Resources Program in Illinois provides generous grant funding for renewable energy projects and is partly responsible for the high number of LFG electricity projects in the state. An incredible 41 percent of the state's landfills have operational LFG electricity projects (compared to roughly 10 percent nationally), and several more are under construction or in advanced planning stages.[52]

Furthermore, many states make tax-free municipal financing available to landfills but not recycling facilities. As discussed further in the next section, this can have a value of between ¢0.4 and ¢0.7 per kWh.[53]

At the retail level, a number of green power programs market electricity to customers willing to pay a premium for energy from renewable sources. In competitive markets, power marketers sell the electricity to customers, and some utilities in regulated markets offer their retail customers a renewable-power purchase option. The premium paid by retail customers varies from program to program, as does the mix of each program's generation sources. Typically, the premium falls in the range of ¢1.5 to ¢3.5 per kWh.[54] Since a substantial portion of this amount usually goes to the green power provider (who acts as the middleman), renewable energy generators such as LFGE generally receive considerably less than the full premium amount.

The reach of green power programs is still very limited. Roughly a third of all U.S. households have access to a green power product, but of those eligible households, only about 1 percent have chosen to participate in a green power program.[55]

Some states have also adopted renewable portfolio standards which require power providers to maintain a minimum level of renewables in the mix of resources they provide customers. The subsidy provided by these programs to LFGE projects will depend on the level of competition among renewables and the amount of renewables required to meet the standard. In general, the subsidy should be less than those provided through a green power program, since different types of renewables will compete and power providers will negotiate to keep the overall cost of power low to remain competitive.

Since LFGE projects tend to be more cost-effective than other forms of renewable energy generation, LFG plays a significant role in several green power programs and state renewable portfolio standards. In fact, in some programs it represents the only source of energy. While the subsidies per kWh are quite large, the amount of power actually generated is small. Due to the limited market penetration of green power programs, these subsidies currently have little effect on LFGE economics at the national level, though this could change in the future if green power programs or renewable portfolio standards become more common.

PROJECT ECONOMICS

The cost of electricity generation from LFG is dependent on a number of factors, including the presence or absence of a gas-recovery system, the size of the landfill, and type of conversion technology employed. On top of equipment cost, project cost components typically include grid interconnection costs and a number of soft costs. The typical capital cost components of an LFGE project are listed in **Table 11**. In addition to these costs, there are operations and maintenance costs associated with both the collection system and the generation equipment.

ITEM	RANGE OF COSTS	TYPICAL COST	PERCENT
Collection System	$200,000 -$1,000,000	$200,000	13
Administrative: Fees, Planning, Legal, Environmental	$30,000 - $1,000,000	$30,000	2
Interconnection	$20,000 - $500,000	$76,000	5
Generating Equipment	$500,000 -$2,000,000	$970,000	65
Contingency		$225,000	15
TOTAL	$850,000 - $4,500,000	$1,500,000	100

Table 11. **Capital Cost of a 1 Megawatt Landfill-Gas Energy Project. Source: Jansen 1992.**

On a per kWh basis, the cost of electricity generation can range from as low as ¢3.4 per kWh to as high as ¢10 per kWh.[56] It is usually much more economical to produce energy where there is already a collection system in place. **Table 12** shows generation costs for a landfill already complying with the EPA's New Source Performance Standards (i.e. with a collection system already in place) and a non-NSPS (i.e. no collection system) landfill each with 1 million metric tons (MMT) of waste in place using a reciprocating engine.

(¢/kWh)	Generator Capital Cost	Generator O&M Cost	Collection System Cost	Collection System O&M	Total Electricity Cost
NSPS	2.3	1.8	-	-	4.1
Non-NSPS	2.3	1.8	1.2	1.2	6.5

Table 12. **Levelized Costs of Landfill-Gas Electricity Generation.** [57] **Source: Cacho & Fine 2002.**

By these calculations, generating electricity from a landfill without a collection system already in place is 56 percent more expensive. The calculations used to generate the results in **Table 12** use slightly lower capital cost and variable operations and maintenance values than those used by the EPA, so the costs in the table should be seen as lower-end estimates and are more useful for comparing relative costs of the two types of systems.

The cost of electricity generation from LFG also depends on the method by which a project is financed. If an LFGE project is owned or operated by a municipal governmental body or agency, municipal bonds are a possible source of project financing. Issuing municipal bonds to cover costs is usually less expensive than private financing using a mix of commercial debt and equity. **Table 13** compares costs of electricity generation for LFGE projects of varying sizes, conversion technologies, and sources of financing for both NSPS and non-NSPS landfills.[58]

	Internal Combustion Engine			Combustion Turbine		
Waste in Place	**1 MMT**	**5 MMT**	**10 MMT**	**1 MMT**	**5 MMT**	**10MMT**
Municipal Financing	6.7/*4.3*	5.5/*4.2*	5.2/*4.1*	7.0/*4.7*	5.6/*4.2*	5.0/*3.8*
Private Financing	7.4/*4.8*	6.0/*4.6*	5.8/*4.5*	7.9/*5.3*	6.2/*4.7*	5.6/*4.2*

Cents per kWh for total projects/*cents per kWh for energy conversion system only.*

Table 13. **Comparison of Estimated Costs of Electricity Generation. Source: EPA 1996.**

From these estimates, it appears that municipal financing can lower the cost of generating electricity by ¢0.4 to ¢0.7 per kilowatt-hour; in most cases, this represents savings of greater than 10 percent. If, as is often the case, municipal financing is not equally available to recycling facilities as it is to landfills, than this cost differential is more accurately thought of as a subsidy.

While the presence of a gas collection system is the most influential factor affecting cost, the amount of waste in place at a landfill is also a significant cost determinant. Generally, the larger an LFGE project, the more favorable the economics. Today, it is clear that small landfills often do not generate enough methane to make energy recovery economic; of the 698 landfills in the EPA's Landfill Methane Outreach Program database with less than one million tons of waste in place, only eight currently have operational LFG electricity generation projects. However, as collection and generation technology improves and becomes more affordable, the number of small landfills with economic project potential may increase.

THE BREAKEVEN POINT

Ultimately, the economic feasibility of an LFGE project is predicated on whether the revenue from electricity sales exceeds the cost of producing electricity. However, as discussed earlier, it is crucial to decide if the cost of the gas collection is legitimately part of the cost of producing energy or a baseline cost of operating a landfill. Given that LFG is an inevitable result of burying organic materials, the costs of mitigating the health and environmental damage caused by LFG should be internalized as part of the cost of landfilling. Where collection systems are part of the cost of doing business, subsidies that cover part of the cost of the collection system are subsidies for landfilling. In the case of landfills covered by the EPA's NSPS rules, which require a collection system, a collection system and its costs are already clearly part of the baseline. Referring back to **Table 13**, the per kWh cost of electricity from a privately financed landfill with a collection system ranges from ¢4.2 to ¢5.3 depending on the landfill size.

Given that LFG is an inevitable result of burying organic materials, the costs of mitigating the health and environmental damage caused by LFG should be internalized as part of the cost of landfilling.

Unfortunately at smaller landfills the baseline is much less clear. Given that the EPA's rules do not cover 95 percent of landfills and about two-thirds of LFG, even though collection system costs should be part of the baseline, that clearly is not the status quo. Thus at smaller landfills, it becomes a valid question as to whether subsidies that cover part or all of the cost of collection are a good investment of public dollars. **Table 13** gives a range of per kWh costs of electricity from a privately financed landfill without a collection system of ¢5.6 to ¢7.9 again depending on size.

The revenue that a project generates is determined by local electricity prices and the per kWh subsidies available. Local electric prices vary dramatically in different regions of the country and fluctuate according to season and even time of day. As qualifying facilities under the Public Utility Regulatory Policies Act (PURPA), LFG electricity projects can usually sell the energy they produce to utilities for their avoided cost (also known as the buyback rate, though as noted above, this may change in the future), which is the utility's incremental cost of power production. If a utility needs additional generating capacity, an LFGE developer may also receive an additional payment for the utility's avoided capacity cost, which is the utility's cost of building or buying additional capacity.

Historically, LFG electricity projects have received utility buyback rates ranging from ¢2 to ¢10 per kWh of electricity produced, averaging around ¢6 per kWh. More recently, however, LFGE developers have generally received less, usually only ¢3 to ¢4 per kWh. In the past, long-term power purchase contracts secured favorable electricity prices for qualifying facilities such as LFGE when utility buyback rates were quite high. Several of these contracts have since expired, and buyback rates are much less attractive to independent power producers today than they were 10 years ago. Furthermore, in many states that have restructured, power plants no longer sell their power to electric utilities, instead selling through competitive solicitations and commodity-like markets. The more competitive settings have also usually served to limit the price that LFGE projects can get for their electricity. Generally, significant economic potential for LFGE projects exists where buyback rates are above ¢4 per kWh,[59] but anecdotal evidence suggests that most new contracts are more likely to fall in the range of ¢2.5 to ¢3 per kWh.[60]

The electricity produced from an LFGE project can sometimes be used to displace some or all of the electricity purchases at commonly owned facilities near the project site. A municipally owned LFG project may be used to displace energy use at proximally located county facilities such as water treatment plants, correctional facilities, recycling centers, and office buildings. Retail electricity prices in 2000 averaged ¢7.36 for commercial customers and ¢4.57 for industrial customers.[61] Since the retail rates paid by such facilities to the utility can be two to three times higher than the buyback rates offered by the utility, displacing these electricity purchases can generate significant savings and greatly improve project economics. However, opportunities for such displacement are limited, as most landfills are not sited close to commonly owned facilities that consume significant amounts of energy.

As mentioned explained above, Section 29 tax credits have a value of about ¢1 per kWh, municipal financing has a value of between ¢0.4 and ¢0.7 per kWh, and state green power programs can add an addition ¢1.5 to ¢3.5 per kWh. While it is possible that none of these subsidies could be available, they have the potential to add between ¢2.9 and ¢5.2 per kWh to a project's revenues. This could bring the total revenues to between ¢5.4 and ¢6.5 per kWh.

Costs and Revenues	**Low (¢/kWh)**	**High (¢/kWh)**
Costs of Electric Generation		
NSPS with private financing	4.2	5.3
Non-NSPS with private financing	5.6	7.9
Revenues Associated with Generation		
Electricity sales	2.5	3.0
Municipal financing	0.4	0.7
Green pricing	1.5	3.5
Section 29 tax credit	~1	~1
Total revenues	2.5 - 5.4	3 - 8.2
Profit or Loss	**High Cost vs. Low Revenue**	**Low Cost vs. High Revenue**
NSPS w/ private financing	(2.8) - 0.1	(1.2) - 4
Non-NSPS w/ private financing	(5.4) - (2.5)	(2.6) - 2.6

Table 14. **Costs, Revenues, Profits, and Losses for Landfill-Gas Energy Projects.**

Table 14 compares the range of costs and potential revenues available to both NSPS and non-NSPS landfills. Based on these numbers, there are likely to be situations where even large landfills need substantial subsidies to convert from flaring to energy production, but there are also likely to be instances where this type of landfill is generating a large profit. For non-NSPS landfills, it appears that high cost, small landfills are unlikely to be driven to install a collection system and generate electricity unless virtually all the subsidies mentioned here are available. However, lower costs non-NSPS projects can also end up it generating a substantial profit. Recall though that they will be going from raw gas release to energy production; thus while these projects need greater subsidies they are reducing much larger environmental harms.

Figure 5 is based on the same data as **Table 14** but shows the relationship between landfill size and costs more explicitly. Note that in this case, the value of municipal financing is shown as a cost of relying on private financing for the generating equipment

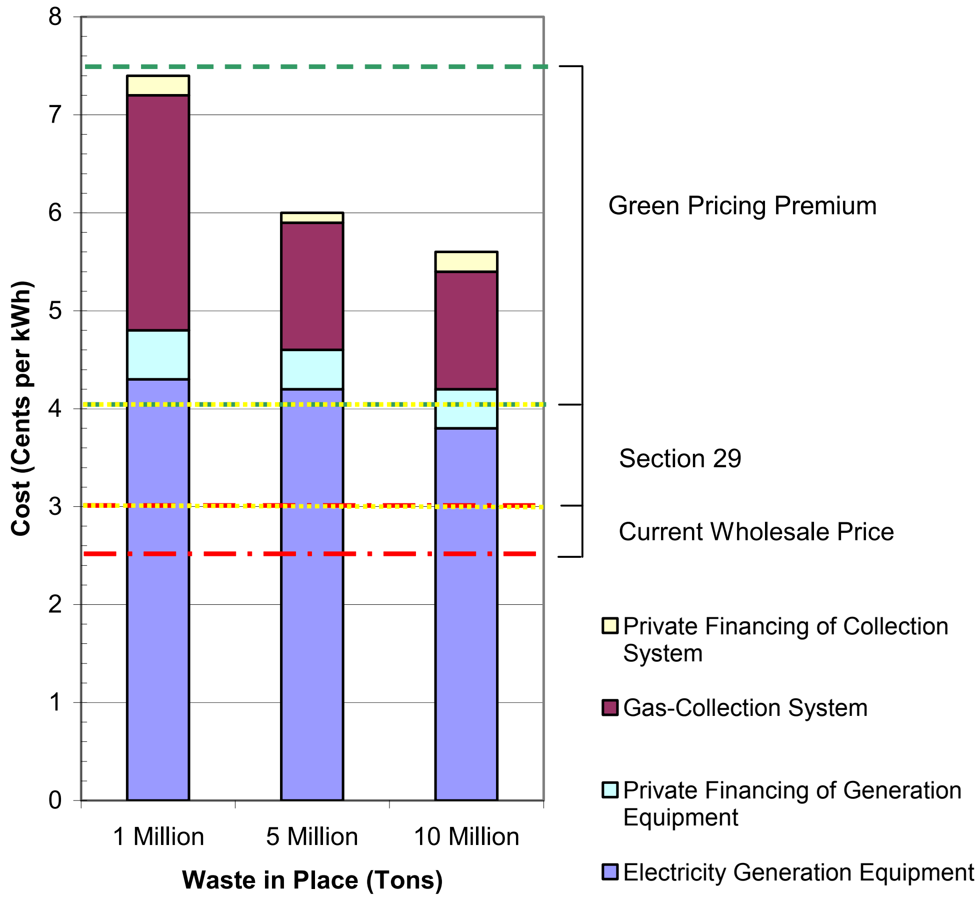

Figure 5. **Landfill-Gas Energy Production Costs vs. Electricity Sales Revenue.**

and the collection system.

The volatility and regional variation of electricity prices, project costs, and subsidies work against formulaic generalizations of cost-effectiveness of LFGE projects. In fact, the volatility and resulting uncertainty associated with electricity prices have both a direct effect on cost-effectiveness and an indirect one through increasing the cost of capital to projects. When electricity prices are at the border of cost effectiveness, a tax credit or production incentive of even a fraction of a cent per kWh can provide the necessary boost that enables a project to become a reality. **Table 15** summarizes the major cost factors affecting LFGE project economics. As discussed earlier, the collection system costs should be a cost of doing business for a landfill, but at non-NSPS landfills this is currently not the case. The data presented above strongly suggests that making collection systems mandatory would greatly reduce or eliminate the subsidies needed to drive LFGE. However, until such a policy is enacted, the "practical side of idealism" requires deciding if the subsidies needed to drive a collection system and energy production at non-NSPS landfills provides enough benefit to be a good public investment. We come back to this question in our recommendations.

MORE FAVORABLE	LESS FAVORABLE
NSPS (gas-recovery system already in place)	Non-NSPS (no gas recovery)
Large amount of waste in place	Small amount of waste in place
Municipal financing	Private financing
High buyback rates	Low buyback rates
Displacement of electricity purchases at on site	No displacement of electricity purchases

Table 15. **Factors Affecting Landfill-Gas Energy Project Economics .**

VALUING THE SUBSIDIES

Central to the debate over LFGE subsidies is the impact that these subsidies have on landfill tipping fees. As the previous section has made clear, there is considerable variability in the economics of LFGE projects. Subsidies will only affect tipping fees when they make the project more than economically viable and the excess profit flows to the owner of the landfill. Tipping fees vary greatly from state to state, ranging from $11 per ton in Colorado to around $50 per ton in Maryland.[62] The national weighted average in February 2002 was approximately $37 per ton.[63]

Renewable Energy Production Incentive

In an attempt to bound the impact of REPI subsidies, NRDC compiled detailed information on five of the six largest LFGE projects receiving REPI payments. In 2001, these five landfills received almost two-thirds of all REPI payments to LFGE facilities.[64] Dividing the amount of REPI payment by the annual waste acceptance rate at each of the landfills yields the maximum annual subsidy per ton of waste received that REPI could result in assuming the projects were cost effective without the subsidy. The maximum impact on tipping fees ranges from ¢13 to ¢78. The results are shown in **Table 16**.

NAME	LOCATION	ANNUAL ACCEPTANCE RATE (000 TONS)	AVG. ANNUAL REPI PAYMENT (1998-2001)	PAYMENT PER TON OF WASTE	TIPPING FEE PER TON
Scholl Canyon	Glendale, CA	495	$388,191	$0.78	$29.59
Central	Petaluma, CA	436	$118,380	$0.27	$50/ton
Roosevelt Regional	Goldendale, WA	1,018	$133,598(1)	$0.13	$19.75/ton
Coffin Butte	Corvalis, OR	250	$101,966	$0.41	$32/ton
Monterey Peninsula	Marina, CA	218	$83,883	$0.39	$30/ton
Total		2,417	$750,518	$0.31	$30/ton(2)

(1) Includes only payments from 2001. Before 2001, the project did not receive significant REPI funding.

(2) Weighted average.

Table 16. **Value of Renewable Energy Production Incentives Payments.**
Source: EPA 1999b, EREN 2002a.

While it is tempting to directly compare the REPI payments per ton of disposed waste to landfill tipping fees, the actual effect of the subsidies is almost impossible to quantify. Although there is some correlation between the amount of waste that an LFGE site accepts each year and the amount of electricity it produces, electricity generation (and hence the amount of REPI funding) is ultimately dependent on the amount of methane generated by the landfill. A landfill's methane generation rate depends on a number of factors, including size and depth of the landfill, the amount of waste in place, the age of the landfill, and regional climatic factors.

In addition, much of the REPI payments may go towards the capital cost and operation of the LFG recovery and utilization equipment (as is their intended purpose), leaving little or no profit for the municipality. Even in the unlikely event that 100 percent of REPI payments represent profits to landfills, these subsidies would only amount to 0.6 to 2.6 percent of the tipping fees charged by the facilities in **Table 16**. From these data, the possibility that REPI subsidies may significantly affect tipping fees in the near term appears to be negligible.

Section 29 Tax Credit

Unlike REPI payments, which affect only a small number of municipally owned landfills, Section 29 tax credits can be claimed by all landfills that fall under private ownership.[65] While REPI funding for LFGE projects has never exceeded $2.2 million per year, a report prepared for the National Recycling Coalition in 2001 calculated the potential annual aggregate value of Section 29 tax credits to be between $164 and $182 million.[66] The number of LFGE projects benefiting from Section 29 tax credits and the actual amount of the subsidy is unknown, though the credits probably affect the better part of operational LFGE facilities.

The EPA has complete or near-complete data from 117 LFG electricity generation projects in 22 different states, which are listed in Appendix B. Of these, about a quarter have closed and are no longer accepting additional waste. Based on EPA data, NRDC calculated the annual value of the Section 29 tax credit that each would receive, assuming it were eligible. A summary of these calculations is shown in **Table 17**.[67] The aggregate value of the subsidy is much higher than the $48 million shown in the table because the table only shows the value of the subsidy to landfills for which the EPA had good data. Nevertheless, the analysis provides an upper-bound estimate of the potential impact of Section 29 tax credits on tipping fees.

SIZE (TONS OF WASTE IN PLACE)	# OF LANDFILLS	ANNUAL VALUE OF CREDIT(1)	ANNUAL VALUE PER TON OF WASTE RECEIVED(2)
<3 million	27	$3.7 million	$0.62
3-6 million	37	$8.5 million	$0.74
6-12 million	28	$12.9 million	$0.64
>12 million	24	$29.4 million	$0.89
Total	117(3)	$48.0 million	$0.76

(1) Assuming 80 percent capacity factor.

(2) Based on 88 landfills with data for annual rate of waste acceptance.

(3) Includes one landfill with unknown amount of waste in place.

Table 17. **Summary of Section 29 Tax Credit Value.**

As the table shows, when evaluated on a per ton of waste basis, the upper-bound value of the tax credit eclipses REPI payments by more than double–¢76 per ton compared to ¢30 per ton. The same disclaimer regarding the assessment of the subsidy per annual ton of accepted waste applies – while there may be some correlation between electricity production and annual waste acceptance, the amount of electricity generated is actually more dependent on the amount of waste in place and the age of a particular landfill. Indeed, some of the landfills supplying fuel for LFGE projects have been closed and are no longer accepting waste. Valuing the tax credit per ton of waste received for these landfills would make little sense, since the amount of waste they receive is zero.

With this in mind, it bears emphasis that the calculations above serve only to indicate the magnitude of these subsidies and not their actual effect on either landfill tipping fees or recycling programs. The economics of each LFGE project are unique and dependent on several factors, the foremost of which are the characteristics of the landfill (including whether it is required to collect LFG under NSPS regulations) and regional electricity prices. Some projects may be cost-effective without any subsidies, while others may depend on them for their economic survival.

Even for LFGE projects that are cost-effective without incentives, it is highly improbable that the full amount of a subsidy would be reflected in lower tipping fees. It is also worth noting that Section 29 tax credits and REPI funding are distributed to the LFGE project developer, which in most cases is a separate entity from the landfill owner. Any excess profit derived from these subsidies is shared by the landfill owner and project developer. Furthermore, in the case of a publicly owned landfill, simply qualifying for tax credits can involve substantial transaction costs. Municipal landfill owners hoping to benefit from tax credits must structure intricate contractual agreements with private third parties. Under such an arrangement, private partners retain a portion of the tax savings, with the remainder flowing back to the municipality.

Thus, while our analysis shows the upper-bound value of Section 29 tax credits to be about ¢76 per ton of waste received, the actual effect of the subsidy on tipping fees is likely much lower. However, significant potential exists for individual landfills to benefit disproportionately, particularly at landfills with very low waste acceptance rates and high methane generation.

Present Value of Excess Subsidies

Another way to evaluate the impact of subsidies is to look at the present value of the excess profits that projects could earn for electricity they generate. Looking back at **Table 14**, the potential for excess profits ranged from ¢0.1 to ¢4 per kWh. Once a ton of waste is buried in a landfill, it takes between 3 and 8 years before it starts to generate methane. At that point, it produces approximately enough methane each year to generate 7 kWh each year.[68] Assuming it takes an average of 5 years before the ton starts generating waste and all the subsidies are available for 10 years after that point, we can calculate the present value of the stream of excess profits that the ton of waste will generate. With a real discount rate of 3 percent, the ton will generate between ¢5 and \$2.06 on a present value basis. At 8 percent, a more realistic value for private companies, the methane from the ton of waste has a present value of between ¢3 and \$1.28.

Over time, policies such as this slow the development of recycling, keeping the cost high and artificially depressing the cost of burying garbage.

While \$2.06 is nearly 6 percent of the national average tipping fee, this number represents an extreme. Remember that **Table 14** indicated that many projects would need some amount of subsidy to install an energy system let alone a collection system. It is unlikely that any project would have the lowest costs, receive the best wholesale price for electricity, receive all of the subsidies, and receive this revenue for a full 10 years. Furthermore, when the ton of waste is buried, there is significant uncertainty about what revenues are generated when the waste starts to produce methane.

Based on all of these calculations, it is tempting to conclude that while there is potential for incentives for LFGE projects to have an impact on tipping fees, the real work effects are likely to be small. However, these subsidies must be judged in a broader context. Incentives for LFGE projects are additive with all the subsidies that exist for landfilling in general. There are a host of incentives and policies that currently clearly tip the scales toward landfilling despite the obvious benefits of recycling and resource reduction. For instance, in 1998 the Internal Revenue Service decided to end a tax exemption for recycling facilities still enjoyed by waste-management facilities.[69] Over time, policies such as this slow the development of recycling, keeping the cost high and artificially depressing the cost of burying garbage. Thus while it appears unlikely that REPI subsidies, Section 29 tax credits, or existing green pricing programs by themselves are causing a near term shift away from recycling towards landfilling, they must be looked at in the context of a plethora of subsidies that clearly are causing such a shift.[70]

CHAPTER 4

RECOMMENDATIONS

The ideal LFG public policy would be guided by the priorities laid out in Chapter 2 and recognize all the economic nuances discussed in Chapter 3. Such a policy would remove all incentives for landfilling over resource reduction or recycling and would simply require collection of LFG at all landfills and LFGE projects at all landfills where it was economic on a total society-cost basis. In reality, however, LFG policies are highly imperfect and likely to remain so for the indefinite future. Identifying all of the policies that favor landfilling over resource reduction and recycling is beyond the scope of this paper, but correcting this imbalance is a major goal for the Natural Resources Defense Council and should be the top priority for everyone concerned about LFG. Recognizing that this is a long-term goal and that new landfills will be opened, more biomass will be buried, and LFG will continue to be an environmental and public health threat for years to come, the recommendations presented here will focus on policies to reduce the impacts of LFG while trying to limit the number of additional incentives for landfilling.

REQUIRING COLLECTION AND ENERGY PRODUCTION

While we may not be able to achieve the ideal type of public policy, we can start by combining the priorities of Chapter 2 with the economics of Chapter 3. Recall that after avoiding landfills altogether, based on the benefits identified in Chapter 2, it was clear that while producing energy had benefits, collecting and combusting LFG was the clear top priority. According to the EPA's data, 61 percent of raw LFG being released in the United States comes from landfills with no collection system in place. The other 19 percent comes from gaps, leaks, and other inefficiencies in existing collection systems.[71] Even if collection systems are only 50 percent efficient, twice as much raw landfill gas will be released at landfills with no collection system. Thus, installing collection systems at landfills that do not currently have them should clearly be the top priority.

Table 14 and

Figure 5 in Chapter 3 show how important the presence of a collection system is to taking the additional step on energy production. If the collection system is not a simple cost of doing business as a landfill, it is very likely that the existing subsidies are not enough to drive the installation of such a system. In fact, the costs are likely to be even larger than those discussed in Chapter 3 because these landfills are also likely to be smaller. The EPA New Source Performance Standards require a collection system at larger landfills. It should not be surprising then that the approximately 400 landfills that the EPA Landfill Methane Outreach Program has identified as potential LFGE sites on average have less than half the waste in place that those sites that are operational or under construction.[72]

Relying simply on incentives is likely to be too expensive, and incentives simply shift costs of clearing up LFG away from landfills to tax roles. Thus we come to our first recommendation:

- **The EPA should expand the NSPS rules to require collection systems at all landfills that accept biomass.** When the EPA originally established the NSPS rules, the size cut off was determined based in large part on the cost-effectiveness of mitigating HAPs. The EPA did include the potential income from LFGE projects, but no financial value was placed on reducing methane emissions. Because of its global warming potential, even a very modest value for CO_2 reductions leads to large annual values for reduced LFG emissions. Even at a very modest value for CO_2 of $5 per ton, avoiding the methane emissions from a landfill that could support a 1 megawatt energy project would be worth more than $170,000 per year. Therefore, collection systems should be cost-effective at all landfills.
- **The EPA should require LFGE projects at most landfills.** While avoiding methane emissions provides the greatest value from combusting LFG, avoiding power plant emissions through a LFGE project would have an annual value of about $30,000 at a 1 megawatt project. As we noted earlier, this step would also generally, though not always, reduce emissions of NO_x, SO_2, and HG.

Even at a very modest value for CO_2 of $5 per ton, avoiding the methane emissions from a landfill that could support a 1 megawatt energy project would be worth more than $170,000 per year.

TARGETING INCENTIVES

Of course requiring collection or energy systems on the basis of avoided methane emissions requires acknowledging the threat of global warming, a step that seems unlikely under the current administration. In the meantime, we cannot afford to abandon incentives. However, we should make sure that we target them carefully. To this end, we should:

- **Favor non-NSPS landfills.** As we have already discussed, non-NSPS landfills are not currently required to have LFG collection systems, and developing energy projects at these landfills is likely to be more expensive. This means that incentives targeting these landfills are more likely to encourage a collection system as well as an energy system, and they are less like to result in inadvertently reducing tipping fees by having the incentive “leak” from the LFGE project to the landfill.
- **Favor real renewables over LFGE projects.** Incentives such as the renewable portfolio standard and the proposed revised version of the REPI pit LFGE projects against real renewables. For landfills without collection systems, there can at least be some argument for this, but for projects that are simply shifting from flaring to energy production, this is a clear loser. Real renewables provide all the carbon reduction benefits of avoiding traditional electric generation without any of the increased carbon emissions associated with landfilling. The proposed removal of the two-tier system from the REPI would be a step in the wrong direction.
- **Favor closed landfills.** Obviously, incentives to closed landfills cannot result in lower tipping at the landfill, but if the company that owns the closed landfill also owns others,

there is still some risk of incentives spilling over from the energy project to tipping fees. The risk is reduced, though, and there can still be substantial LFG emissions that can be controlled. In fact one of the ironies of the subtitle D “dry-tomb” landfills is that in the effort to control leachate by keep the buried garbage dry, they delay the entry of moisture and thus the formation of LFG until the linings start to fail.

- **Favor new LFGE projects over existing ones.** Incentives that provide on-going payments for alternative or renewable energy should prioritize new LFGE projects. Existing projects are more likely to have recouped their investments, and thus incentives paid to these projects are more likely to end up spilling over to the landfill and affecting tipping fees. We will discuss green pricing programs and renewable portfolio standards next, but these types of incentives need to be particularly aware of this.
- **Favor strict emissions standards at NSPS landfills.** To the extent that any subsidies go to NSPS landfills, as we noted above, they should only go to new conversion from flaring to energy production. They should also only go to projects that meet strict emissions standards. The emissions benefits of shifting from flaring to energy production are normally limited, thus making subsidies a questionable investment. With gas cleanup and/or tailpipe emissions controls, these benefits can be increased, and this is what subsidies should be used to do.
- **Favor incentives that competitively allocate subsidies.** Incentives such at the Section 29 tax credit and municipal financing make no distinction between LFGE projects that need large subsidies and those that don’t need any at all. As a result, these types of incentives are likely to over subsidize projects. Incentives such as green pricing programs and renewable portfolio standard, which force projects to compete, will drive projects towards the minimum amount of subsidy they need.
- **Limit the timeframe for all incentives and update economic analyses.** If incentives are fixed for too long, they are likely to become too large as the cost of developing LFGE projects fall overtime. To avoid this, incentives should only be available for short periods of time and the economics of LFGE projects should be examined anew before extending any incentives.

GREEN PRICING PROGRAMS AND RENEWABLE PORTFOLIO STANDARDS

While green pricing programs and renewable portfolio standards do not pay specific dollar amounts, they can result in substantial payments to LFGE projects, if these projects are allowed to participate. Both of these policies have a feature that makes them particularly attractive as a way to encourage LFGE. However, this same feature, if not managed carefully, can make these policies particularly bad ways to encourage LFGE. Green pricing and renewable portfolio standard, both force technologies to compete for market share. This means that any incremental payment over the market price for electricity will be minimized because if LFGE project owners ask for too much, they will lose sales to other project owners and other sources of energy altogether. This minimizes the risk that incentives will be too large and will impact tipping fees.

Existing LFGE projects at NSPS landfills do no need the subsidies provided by green pricing and renewable portfolio standard programs and do not provide enough benefit to warrant inclusion in them.

However, this same feature means that if LFGE is successfully competing in green pricing programs and renewable portfolio standard, then potentially other cleaner and more sustainable sources of electricity are being driven out of the market. If, for instance, a state has a 10 percent renewable portfolio standard requirement and has 10 percent worth of real renewables and 2 percent worth of LFGE that can out compete the renewables, then that is 2 percent fewer renewables that will be driven by the renewable portfolio standard. If all of the LFGE projects are installed at landfills that otherwise would have simply been releasing raw LFG, then this is probably a pretty good tradeoff. If however, these are NSPS landfills that installed energy systems to get section 29 tax credits, then this 2 percent is actually just keeping 2 percent of real renewables from operating. Thus it is essential that these policies limit the types of LFGE projects they allow to only those that provide the most benefit.

Some would argue that LFGE should simply be excluded from green pricing programs and renewable portfolio standard. After all, LFGE is not renewable and landfills are certainly not "green." However, all states that have implemented these types of programs have made exceptions for certain clearly environmentally preferable technologies. Some states have even included garbage incineration despite the extensive environmental and public health damage these systems do.

Beyond the competitive allocation of subsidies, there are two other reasons that LFGE projects should be included in these types of policies. First and foremost, the reality is that landfills and LFG will be with us for years to come, and LFG is too toxic and too potent a greenhouse gas to not address. Here is where we must practice the "practical side of idealism" and use the tools that we have available to us. The second reason is subtler. Because LFGE is generally available in most states and often available at prices only slightly higher than traditional electricity, it can act as a pump-primer to get these types of policies in place and make them successful. Few politicians will support an renewable portfolio standard if they believe that it will drive prices up significantly, and similarly many people will not participate in green pricing programs if their bills are going to go up significantly. Landfill-gas energy provides these people with a policy they can support. The lower price of LFGE can also to draw enough customers in the early years to give these markets momentum. The alternative is a potentially debilitating chicken-and-egg problem where renewable developers wait for these policies to go into effect, and policy makers wait for renewables to be developed.

Our recommendation then is to include LFGE in green pricing and renewable portfolio standard but to also include all of the targeting recommended above. These policies should rely on LFGE from non-NSPS or closed landfills and from new LFGE projects. Existing LFGE projects at NSPS landfills do no need the subsidies provided by these programs and do not provide enough benefit to warrant inclusion in them. To the extent they are included, they should be required to meet strict emissions standards so that they clearly provide a net reduction in all air pollutants over flaring. If no projects meeting these criteria are available, then the requirements for participation in green pricing and renewable portfolio standard should shift overtime, driving the development of these more beneficial LFGE projects. Indeed the entire role of LFGE in these policies needs to be watched very closely. Once a robust market for real renewables develops, only the new LFGE projects at landfills that did not previously have collection systems in place should be allowed to participate.

CONCLUSIONS

The debate over LFGE subsidies is an example of the delicate balance that can exist between competing environmental concerns. On the one hand is the need to reduce health and environmental impacts of greenhouse gas emissions and hazardous air pollutants; on the other is the concern that subsidizing LFGE projects is delaying the crucial shift to more sustainable waste management practices by promoting landfills at the expense of recycling and waste reduction programs.

Two-thirds of the methane generated at MSW landfills is still released to the atmosphere,[73] contributing mightily to global warming and releasing significant amounts of hazardous air pollutants that are also constituents of raw LFG. While reduce, reuse, and recycle programs are the best forms of waste management, landfills will unfortunately be with us for years to come and will continue generating LFG for decades after the last one is closed. Ensuring the recovery of as much of this gas as possible should be the first priority for any policy related to LFG. Simply requiring collection and combustion at all landfills is the best way to achieve this. However, LFGE subsidies have helped achieve significant reductions in LFG emissions and until such a requirement is established, the continued provision of properly targeted subsidies will spur the development of new LFGE projects that will result in significant environmental benefits.

The data on the benefits of collection and combustion of landfill are very clear. While a small amount of dioxins are formed, the reduction in other HAPs makes collection and combustion an essential public health strategy. This is also a vital step in reducing the risks of global warming. The addition of an energy system increases the global warming benefits and generally reduces other significant air pollution including NO_x, SO_2, and HG. However, when a flare is already in place, these benefits are less, and thus LFGE projects where a flare already exists should be a lower priority for any public incentives.

The major subsidy affecting LFGE projects at the national level is the Section 29 federal tax credit, which equals about one cent per kWh of electricity produced. The Renewable Energy Production Incentive, has funded only a handful of municipally owned landfills at lower levels than Section 29 tax credits in recent years. State and local policies can also provide attractive incentives for LFGE development. Green power pricing is another incentive that has only affected a small number of LFGE projects to date. Both REPI and Section 29 tax credits are currently under review in Congress, along with other energy policies that affect the fate of LFGE subsidies. The future of LFGE development will depend partly on these decisions at the Congressional level.

The interaction between LFGE subsidies and landfill tipping fees is unclear. On average, Section 29 tax credits amount to ¢76 per ton of waste received. Assuming that the subsidy represents pure profit to a landfill and that the profits translate directly into lower tipping fees, the average Section 29 tax credit would represent a reduction in tipping fees of 2.1 percent. The present value of potential excess profits caused by the pancaking of municipal financing, Section 29 tax credits, and green pricing programs could reach as high as 6 percent of tipping fees. In reality, the effect would likely be much smaller, given the unlikelihood of landfill owners reaping such large profits from electric sales. However, LFGE incentives need to be viewed in the context of a range of incentives that encourage landfilling over recycling.

The “practical side of idealism” requires that we make the best use of the public dollars that we can marshal to address those problems that we can not immediately fix through better policies. Thus we need to be targeted with our incentives, prioritizing the types of projects that will provide the most environmental benefits with the least chance of perpetuating the status quo.

But a long-term strategy for addressing the LFG issue must emphasize the importance of recycling. From an environmental perspective, recycling, composting, and waste reduction are by far the best strategies for methane reduction. Diverting waste to recycling and composting programs and encouraging waste reduction prevent these materials from ever reaching the landfill. The ultimate solution to the LFG issue is to keep the materials that result in LFG and HAPs from getting there in the first place, and encouraging recycling and composting should be a top priority for federal, state, and local governments.

ENDNOTES

[1] EPA, 2000e.

[2] IPCC, *Third Assessment Report* (2001).

[3] Hershkowitz, 2002, pg. 202.

[4] CEC, 2002a.

[5] Hershkowitz, 2002, pp 77-80.

[6] Ibid.

[7] EPA, 2000e.

[8] IPCC, *Third Assessment Report* (2001).

[9] EPA, 2002a.

[10] Specifically, the regulations apply to sites that began construction, modification, or reconstruction on or after May 30, 1991 or that began accepting waste after Nov. 8, 1987. New or existing landfills with a design capacity greater than 2.5 million metric tons or 2.5 million m^3 must determine their annual emission rate for NMOC, and sites that exceed 50 metric tons of NMOC per year are required to install a gas control system.

[11] EPA, 2002d.

[12] WRI, 2002.

[13] Ibid.

[14] EPA, 2002e.

[15] EPA, 2003.

[16] EPA, 2002d.

[17] Anderson, 2002.

[18] EPA, 2002c.

[19] EIA, 1999.

[20] Trotti, 1998.

[21] EIA, 2002. Calculation assumes 80 percent capacity factor for LFGE.

[22] CEC, 2002, p. 8.

[23] Hershkowitz, 2002, pg. 202.

[24] In some literature, dioxins and furans are distinguished as separate groups of toxins. For the purposes of this paper, the term "dioxin" refers to a group of chemicals that includes furans.

[25] EPA, 2000b.

[26] EPA, 2000c.

[27] All concentrations are corrected to 11 percent O_2 unless otherwise noted. See Appendix A for a complete explanation of all calculations.

[28] The I-TEQ (International Toxic Equivalence) scheme is used to compare U.S. TEQ data to that of international sources. I-TEQ and TEQ data are based on slightly different concentrations and probably vary only a few percent.

[29] EPA, 2000c.

[30] Hill & Caponi, 2000.

[31] We arrived at 9.65 billion m^3/yr of combusted LFG using the EPA's estimate of 4,874 Gg of recovered and combusted methane in 2000 and assuming that the content of LFG is 50 percent methane and 50 percent CO_2 by weight.

[32] Using a value of 3255 g for total dioxin emissions (EPA, 2001).

[33] EPA, 2000d.

[34] If we use a lower-bound dioxins emission estimate of 0.01 ng TEQ/dscm, the toxicity of raw LFG becomes 47 times greater than that of combusted LFG.

[35] See note on data quality in Appendix A.

[36] Huitric et al, 2001.

[37] CARB, 2002.

[38] EPA, 2000e.

[39] Lee & Jones, 1994.

[40] EPA, MACT standard.

[41] EPA, 2002e

[42] Ibid.

[43] Anderson, 2002.

[44] Lee, 2002.

[45] EPA as cited in Lee, 2002.

[46] Lee, 2002 & Lee & Jones-Lee, 1994.

[47] Anderson, 2003.

[48] EREN, 2002a.

[49] CEC, 2002a.

[50] Library of Congress, 2002.

[51] CEC, 2002.

[52] EPA, 1996.

[53] Ibid.

[54] EREN, 2002b.

[55] Bird, 2002.

[56] CEC, 2002a.

[57] Assumes an installed generator cost of $1,283/kW, LFG collection system installed cost of $638/kW, capital charge rate of 13.6 percent (capital charge rate assumes 20-year life, project finance with an 80/20 debt/equity ratio, 9 percent interest on debt, a 15 percent return on equity, and 10-year depreciation).

[58] The private financing scenario uses the same assumptions as in Table 11. For the municipal finance scenario, a capital charge rate of 0.111 was used, which is based on tax-exempt municipal bonds at an interest rate of 6.5 percent.

[59] EPA, 1996, p. 5-6

[60] Thorneloe et al, 2000.

[61] EIA, 2002a.

[62] Goldstein & Madtes, 2001.

[63] Chartwell Information, 2002.

[64] EREN, 2002a.

[65] Some municipally owned landfills also benefit from Section 29 tax credits by establishing complex partnerships with third-party private entities.

[66] Koplow, 2001. These calculations also included all potential LFGE projects identified by the EPA LMOP.

[67] EPA, 1999b.

[68] Koplow, 2003.

[69] Hershkowitz, 2002, pp 77-80.

[70] Ibid.

[71] EPA, 2002e.

[72] EPA, 2002c.

[73] EPA, 2002f.

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APPENDIX A: EXPLANATION OF CALCULATIONS

Explanation of Toxicity Calculations

We used default concentrations of various organic compounds in raw LFG from AP-42 (EPA 2002e) and the cancer effect toxicity of these compounds based on data from ARB (CARB 2002) to calculate the toxicity of raw LFG. In AP-42, the EPA ranks the reliability of its default emissions factors on a scale from A to E, where A is "excellent" and E is "poor." The quality data available for each compound is listed in the table below. On average the data ranks about a C+ or slightly above "average."

The complete table below also presents default concentrations suggested by the Waste Industry Coalition. As noted in the report, these numbers are generally lower than those in AP-42, and the implied overall lower toxicity of raw LFG makes the dioxins that are formed appear more significant. However, LFG combustion exhaust is still many times less toxic than raw LFG.

The calculation for the toxicity of LFG combustion exhaust assumes that 98 percent of the VOCs are destroyed during combustion and 0.198 ng/DSCM TEQ of dioxins are formed. As noted in the body of the report, this rate of dioxin formation is the highest recorded in available EPA data.

The first step in this process is to put all of the data into a uniform metric. We chose to use pounds per MWh. For raw gas and flares, which do not produce energy, this entailed calculating a given amount of raw gas. We chose to look at the amount of gas that would be needed to generate 1 MWh from a reciprocating engine, which is, as noted in the body of the report, the most common way to use LFG. The two key assumptions in this calculation are the higher heating value of LFG and the efficiency of a reciprocating engine. All of our calculations assume LFG has a HHV of 500 Btu/ft^3 and that a reciprocating engine has an efficiency of 36 percent.

Given these assumptions, the formula for converting the ppmv concentrations given by the EPA to lbs/MWh-equivalent is:

$$ppm \times \frac{1p}{10^6\,ppm} \times molecular\_weight\left(\frac{g}{mol}\right) \times \frac{lb}{g} \times \frac{mol}{dsft^3} \times \frac{1}{HHV\left(Btu_{input}/ft^3\right)} \times \frac{Btu}{kWh} \times \frac{kWh}{MWh} \times \frac{1}{efficiency\left(output/input\right)} = \frac{lbs}{MWh_{out}}$$

To calculate the dioxin-based ng TEQ of LFG for the comparison with exhaust, we convert the ARB cancer risk factors to a dioxin-based TEQ by dividing the cancer risk factor for each toxin by the risk factor of 2,3,7,8-TCDD. These dioxin-based factors are then multiplied by the toxin concentrations determined above to yield their respective dioxin-based lb TEQ/MWh.

The table below presents the raw LFG and exhaust concentrations, TEQ concentrations, and at the end, the total cancer risk values and relative reduction accomplished though combustion.

Compound	1998 AP-42 Values				WIAC-1 Proposed Alternative Values			
	Raw LFG on a lb/MWh-equiv basis.[1]	Dioxin based TEQ of LFG[2]	Exhaust lb/MWh.[3]	Dioxin based TEQ of exhaust	Raw LFG on a lb/MWh-equiv basis.[1]	Dioxin based TEQ of LFG[2]	Exhaust lb/MWh.[3]	Dioxin based TEQ of exhaust
1,1,1-Trichloroethane (methyl chloroform)	3.384E-03	0.000E+00	6.767E-05	0.000E+00	1.184E-03	0.000E+00	2.369E-05	0.000E+00
1,1,2,2-Tetrachloroethane	9.845E-03	1.515E-08	1.969E-04	3.029E-10	6.208E-04	9.551E-10	1.242E-05	1.910E-11
1,1-Dichloroethane (ethylidene dichloride)	1.229E-02	5.388E-10	2.458E-04	1.078E-11	3.875E-03	1.699E-10	7.750E-05	3.398E-12
1,1-Dichloroethene (vinylidene chloride)	1.024E-03	0.000E+00	2.049E-05	0.000E+00	4.713E-04	0.000E+00	9.425E-06	0.000E+00
1,2-Dichloroethane (ethylene dichloride)	2.144E-03	1.154E-09	4.288E-05	2.309E-11	6.275E-04	3.379E-10	1.255E-05	6.758E-12
1,2-Dichloropropane (propylene dichloride)	1.075E-03	0.000E+00	2.149E-05	0.000E+00	1.373E-04	0.000E+00	2.746E-06	0.000E+00
2-Propanol (isopropyl alcohol)	1.591E-01	0.000E+00	3.183E-03	0.000E+00	2.512E-02	0.000E+00	5.024E-04	0.000E+00
Acetone	2.151E-02	0.000E+00	4.303E-04	0.000E+00	1.880E-02	0.000E+00	3.760E-04	0.000E+00
Acrylonitrile	1.775E-02	0.000E+00	3.549E-04	0.000E+00	1.009E-04	0.000E+00	2.019E-06	0.000E+00
Bromodichloromethane	2.710E-02	0.000E+00	5.419E-04	0.000E+00	8.982E-02	0.000E+00	1.796E-03	0.000E+00
Butane	1.545E-02	0.000E+00	3.090E-04	0.000E+00	2.985E-03	0.000E+00	5.970E-05	0.000E+00
Carbon disulfide	2.333E-03	0.000E+00	4.666E-05	0.000E+00	1.251E-03	0.000E+00	2.502E-05	0.000E+00
Carbon monoxide	2.087E-01	0.000E+00	4.174E-03	0.000E+00	4.736E-04	0.000E+00	9.472E-06	0.000E+00
Carbon tetrachloride	3.252E-05	3.752E-11	6.503E-07	7.504E-13	5.690E-05	6.566E-11	1.138E-06	1.313E-12
Carbonyl sulfide	1.555E-03	0.000E+00	3.111E-05	0.000E+00	5.809E-04	0.000E+00	1.162E-05	0.000E+00
Chlorobenzene	1.487E-03	0.000E+00	2.974E-05	0.000E+00	1.350E-03	0.000E+00	2.700E-05	0.000E+00
Chlorodifluoromethane	5.940E-03	0.000E+00	1.188E-04	0.000E+00	1.622E-03	0.000E+00	3.244E-05	0.000E+00
Chloroethane (ethyl chloride)	4.262E-03	0.000E+00	8.523E-05	0.000E+00	8.148E-04	0.000E+00	1.630E-05	0.000E+00
Chloroform	1.893E-04	2.766E-11	3.785E-06	5.532E-13	1.325E-04	1.936E-11	2.650E-06	3.873E-13

Chloromethane	3.228E-03	0.000E+00	6.456E-05	0.000E+00	6.643E-04	0.000E+00	1.329E-05	0.000E+00
Dichlorobenzene	1.631E-03	5.019E-10	3.262E-05	1.004E-11	1.248E-02	3.841E-09	2.496E-04	7.681E-11
Dichlorodifluoromethane	1.003E-01	0.000E+00	2.006E-03	0.000E+00	1.119E-02	0.000E+00	2.237E-04	0.000E+00
Dichlorofluoromethane	1.425E-02	0.000E+00	2.850E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Dichloromethane (methylene chloride)	6.418E-02	1.728E-09	1.284E-03	3.456E-11	1.524E-02	4.102E-10	3.048E-04	8.205E-12
Dimethyl sulfide (methyl sulfide)	2.567E-02	0.000E+00	5.135E-04	0.000E+00	2.235E-02	0.000E+00	4.471E-04	0.000E+00
Ethane	1.413E+00	0.000E+00	2.825E-02	0.000E+00	1.262E-02	0.000E+00	2.524E-04	0.000E+00
Ethanol	6.623E-02	0.000E+00	1.325E-03	0.000E+00	2.888E-01	0.000E+00	5.776E-03	0.000E+00
Ethyl mercaptan (ethanethiol)	7.485E-03	0.000E+00	1.497E-04	0.000E+00	4.452E-03	0.000E+00	8.903E-05	0.000E+00
Ethylbenzene	2.586E-02	0.000E+00	5.172E-04	0.000E+00	3.808E-02	0.000E+00	7.617E-04	0.000E+00
Ethylene dibromide	9.928E-06	1.909E-11	1.986E-07	3.818E-13	4.567E-04	8.782E-10	9.133E-06	1.756E-11
Fluorotrichloromethane	5.517E-03	0.000E+00	1.103E-04	0.000E+00	2.374E-03	0.000E+00	4.748E-05	0.000E+00
Hexane	2.992E-02	0.000E+00	5.984E-04	0.000E+00	1.058E-02	0.000E+00	2.117E-04	0.000E+00
Hydrogen sulfide	6.393E-02	0.000E+00	1.279E-03	0.000E+00	4.246E-02	0.000E+00	8.492E-04	0.000E+00
Mercury (total)	3.095E-06	0.000E+00	6.191E-08	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Methyl ethyl ketone	2.702E-02	0.000E+00	5.403E-04	0.000E+00	2.858E-03	0.000E+00	5.715E-05	0.000E+00
Methyl isobutyl ketone	9.897E-03	0.000E+00	1.979E-04	0.000E+00	6.838E-03	0.000E+00	1.368E-04	0.000E+00
Methyl mercaptan	6.330E-03	0.000E+00	1.266E-04	0.000E+00	3.033E-03	0.000E+00	6.066E-05	0.000E+00
Pentane	1.254E-02	0.000E+00	2.509E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Perchloroethylene (tetrachloroethylene)	3.268E-02	5.280E-09	6.537E-04	1.056E-10	1.045E-02	1.689E-09	2.091E-04	3.377E-11
Propane	2.586E-02	0.000E+00	5.172E-04	0.000E+00	3.438E-02	0.000E+00	6.876E-04	0.000E+00
t-1,2-dichloroethene	1.455E-02	0.000E+00	2.909E-04	0.000E+00	2.612E-04	0.000E+00	5.225E-06	0.000E+00
Trichloroethylene (trichloroethene)	1.958E-02	1.054E-09	3.916E-04	2.109E-11	4.728E-03	2.546E-10	9.457E-05	5.092E-12
Vinyl chloride	2.424E-02	5.035E-08	4.848E-04	1.007E-09	3.557E-03	7.387E-09	7.114E-05	1.477E-10

Xylenes	6.788E-02	0.000E+00	1.358E-03	0.000E+00	9.302E-02	0.000E+00	1.860E-03	0.000E+00
Polychlorinated dibenzo-p-dioxins (2,3,7,8-TCDD)	0	0.000E+00	1.648E-09	1.648E-09	0.000E+00	0.000E+00	1.648E-09	1.648E-09
Total cancer effect toxicity (lb TEQ/MWh-equiv.)		7.583E-08		3.17E-09		1.601E-08		1.9686E-09
				% change				% change
				95.83%				87.70%
	Raw LFG is	24.0	times more toxic than exhaust		Raw LFG is	8.1	times more toxic than exhaust	

[1] Exhaust-equivalent concentration is measured in lb/MWh-equiv, based on the efficiency of a lean burn recip engine. This unit is needed to allow comparison between available data on dioxins in exhaust gas from LFG flaring and LFG to energy projects with the concentrations of pollutants in raw LFG.

[2] Dioxin base TEQ is calculated by dividing the ARB-OEHHA cancer risk value by the dioxin risk value for each compound where a risk value is available. This is not the formal toxic equivalency (I-TEQ) method.

[3] Exhaust concentrations are measured in lbs/MWh exhaust and assume 98 percent destruction rate for toxics in LFG. PDD is based on 0.198 ngTEQ/DSQM exhaust, the EPA inventory value for total dioxins in LFG combustion exhaust.

Explanation of Other Emissions Calculations

In addition to the toxicity calculation, we also had to convert a wide range of data to a uniform metric. Again we use the lbs/MWh. In addition to the assumptions we made above we used those presented in the table below.

ASSUMPTION		NOTES
LFG dry-F	9350 ft^3/MMBtu	
LFG CH4 content	55%	EPA, AP-42
LFG CO_2 content	40%	EPA, AP-42
LFG N2 content	5%	EPA, AP-42
Oxygen in lean burn exhaust	15%	
Oxygen in boiler exhaust	3%	
Oxygen in lean burn turbine exhaust	15%	
Lean burn reciprocating engine efficiency	36%	
Lean burn turbine efficiency	27%	
Boiler efficiency	80%	
Generator efficiency	95%	

Using these assumptions, to convert ppmv in exhaust we use the following formula:

$$ppm \times \frac{1p}{10^6\,ppm} \times molecular\_weight\left(\frac{g}{mol}\right) \times \frac{lb}{g} \times \frac{mols}{dsft^3} \times dry\_f\left(\frac{dsft^3}{MMBtu_{input}}\right) \times \frac{\%O_2\_in\_air}{\%O_2\_in\_air - \%O_2\_in\_exhaust} \times \frac{MMBtu}{MWh} \times \frac{1}{efficiency\left(\frac{output}{input}\right)} = \frac{lbs}{MWh_{out}}$$

To convert from ng/dsm^3, we used the following formula:

$$\frac{ng}{dsm^3} \times \frac{10^{-9}g}{ng} \times \frac{lb}{g} \times \frac{m^3}{f^3} \times dry\_f\left(\frac{dsf^3}{MMBtu_{input}}\right) \times \frac{\%O_2\_in\_air}{\%O_2\_in\_air - \%O_2\_in\_exhaust} \times \frac{MMBtu}{MWh} \times \frac{1}{efficiency\left(\frac{output}{input}\right)} = \frac{lbs}{MWh_{out}}$$

To convert from g/m^3 of CH_4, we used the following formula:

$$\frac{g}{m^3 CH_{4in}} \times \frac{CH_4}{LFG} \times \frac{lb}{g} \times \frac{m^3}{ft^3} \times \frac{1}{HHV\left(\frac{Btu_{input}}{ft^3}\right)} \times \frac{Btu}{kWh} \times \frac{kWh}{MWh} \times \frac{1}{efficiency\left(\frac{output}{input}\right)} = \frac{lb}{MWh_{out}}$$

To convert from lbs/MMBtu, we used the following formula:

$$\frac{lb}{MMBtu_{input}} \times \frac{MMBtu}{MWh} \times \frac{1}{efficiency\left(\frac{output}{input}\right)} = \frac{lbs}{MWh_{out}}$$

And finally to convert from g/bhp-hr, we used the following formula:

$$\frac{g}{bhp-hr} \times \frac{1}{generator\_efficiency} \times \frac{lb}{g} \times \frac{bhp-hr}{MWh} = \frac{lb}{MWh_{out}}$$

What follows is an extensive set of emissions concentrations drawn from eight difference sources. The sources are keyed to the following table.

SOURCE KEY	SOURCE
1a	EPA *AP-42*, Tabe 2.4-1. Default Concentrations for LF Constituents. November, 1998.
1b	Based on EPA *AP-42*, Tabe 2.4-1. Default Concentrations for LFG Constituents. November, 1998.
1c	*AP-42* Chapter 2.4 Table 2.4-4
1d	Calculated based on EPA *AP-42* LFG make up (55% CH4, 40%CO2
2a	*AP-42* as cited in EEA Inc., *Rational for Waste Fuel or…*, NRDC, Dec. 2002.
2b	BACT/LAER Clearinghouse as cited in EEA Inc., *Rational for Waste Fuel or…*, NRDC, Dec. 2002.
2c	CARB as cited in EEA Inc., *Rational for Waste Fuel or…*, NRDC, Dec. 2002.
2d	SCAQMD as cited in EEA Inc., *Rational for Waste Fuel or…*, NRDC, Dec. 2002.
3	Cheminfo Services, *Emissions Reductions Benefits of LFG Combustion, Environment* Canada, Feb., 2002.
4	*Emissions Database of Electric Generation*, 2000
5	Frank R. Caponi, Ed Wheless & David Frediani, *Dioxin and Furan Emissions From Landfill Gas-Fired Combustion Units*, 98-RP105A.03.
6	Huitric, Sullivan, & Tinker, *Waste Industry Air Coalition Comparison of Recent Landfill Gas Analyses with Histroic AP-41 Values*, January 2001.
7	Laur, M., "Summary of Readily Available Information and Conclusions Drawn Regarding the By-product Production of Dioxin from the Combustion of Landfill Gas (Docket No. A-98-28)," Undated Memorandum to Air and Radiation Docket and Information Center, U.S. EPA.
8	Resource Systems Group, *EPI Index*.

Emission	Point Source	Reported Quantity	Reported Unit	Standardized Quantity	Standardized Unit	Source	Notes
CO	LFG Boil	90	mg/dscm CH4	0.0	lbs/MWh-equiv	1c	Data reliability rank E
CO	LFG combustion exhaust	13	g/m^3 CH4 (LFG)	8	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
CO	LFG Flare	0.73	lbs/MMBtu	6.9	lbs/MWh-equiv	2a	
CO	LFG Flare	12000	mg/dscm CH4	7.8	lbs/MWh-equiv	1c	Data reliability rank C
CO	LFG Flare	0.1	lbs/MMBtu	0.9	lbs/MWh-equiv	2b	
CO	LFG Flare	0.18	lbs/MMBtu	1.7	lbs/MWh-equiv	2b	
CO	LFG Flare	0.3	lbs/MMBtu	2.8	lbs/MWh-equiv	2b	
CO	LFG Recip	1.6	g/bhp-hr	5.0	lbs/MWh	2a	Lean burn specified
CO	LFG Recip	2.9	g/bhp-hr	9.0	lbs/MWh	2b	Lean burn specified
CO	LFG Recip	2.3	g/bhp-hr	7.2	lbs/MWh	2b	Lean burn specified
CO	LFG Recip	2.5	g/bhp-hr	7.8	lbs/MWh	2c	Lean burn specified
CO	LFG Recip	2.5	g/bhp-hr	7.8	lbs/MWh	2d	Lean burn specified
CO	LFG Turbine	0.1	lbs/MMBtu	1	lbs/MWh	2a	0.1-0.4 range cited; lean burn specified
CO	LFG Turbine	7500	mg/dscm CH4	4.9	lbs/MWh	1c	Data reliability rank C
CO	LFG Turbine	3600	mg/dscm CH4	3.1	lbs/MWh	1c	Data reliability rank E
CO	LFG Turbine	0.44	lbs/MMBtu	5.6	lbs/MWh	1c	Data reliability rank A; HHV 400btu/ft3 @60deg. F.
CO	LFG Turbine	0.75	lbs/MMBtu	9.5	lbs/MWh	2b	Lean burn specified
CO	LFG Turbine	130	ppm	4.25	lbs/MWh	2d	Lean burn specified
CO	Raw LFG	0.088	g/m^3 CH4 (LFG)	0.057	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
NOx	All electric generation	2.96	lbs/MWh	2.96	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
NOx	All electric generation	2.79	lbs/MWh	2.79	lbs/MWh	8	Total MWh based on EDEG 2000 data.

Emission	Point Source	Reported Quantity	Reported Unit	Standardized Quantity	Standardized Unit	Source	Notes
NOx	Average Coal	4.81	lbs/MWh	4.81	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
NOx	Average Coal	4.56	lbs/MWh	4.56	lbs/MWh	8	
NOx	Average Gas	1.59	lbs/MWh	1.59	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
NOx	Average Gas	2.14	lbs/MWh	2.14	lbs/MWh	8	
NOx	Just Fossil Generation	4.14	lbs/MWh	4.14	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
NOx	Just Fossil Generation	4.02	lbs/MWh	4.02	lbs/MWh	8	
NOx	LFG Boil	530	mg/dscm CH4	0.2	lbs/MWh-equiv	1c	Data reliability rank D
NOx	LFG Combustion Exhaust	3.1	g/m^3 CH4 (LFG)	2.0	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
NOx	LFG Flare	0.039	lbs/MMBtu	0.37	lbs/MWh-equiv	2a	
NOx	LFG Flare	650	mg/dscm CH4	0.4	lbs/MWh-equiv	1c	Data reliability rank C
NOx	LFG Flare	0.05	lbs/MMBtu	0.5	lbs/MWh-equiv	2b	
NOx	LFG Flare	0.06	lbs/MMBtu	0.6	lbs/MWh-equiv	2b	
NOx	LFG Flare	0.08	lbs/MMBtu	0.8	lbs/MWh-equiv	2b	
NOx	LFG Flare	0.06	lbs/MMBtu	0.6	lbs/MWh-equiv	2d	
NOx	LFG Recip	0.8	g/bhp-hr	2.5	lbs/MWh	2a	Lean burn specified
NOx	LFG Recip	4000	mg/dscm CH4	2.6	lbs/MWh	1c	Data reliability rank D
NOx	LFG Recip	1	g/bhp-hr	3	lbs/MWh	2b	Lean burn specified
NOx	LFG Recip	2	g/bhp-hr	6	lbs/MWh	2b	Lean burn specified
NOx	LFG Recip	0.6	g/bhp-hr	1.9	lbs/MWh	2c	Lean burn specified

Emission	Point Source	Reported Quantity	Reported Unit	Standardized Quantity	Standardized Unit	Source	Notes
NOx	LFG Recip	0.6	g/bhp-hr	1.9	lbs/MWh	2d	Lean burn specified
NOx	LFG Turbine	1400	mg/dscm CH4	1.2	lbs/MWh	1c	Data reliability rank D
NOx	LFG Turbine	0.14	lbs/MMBtu	1.8	lbs/MWh	1c	Data reliability rank A; HHV 400btu/ft3 @60deg. F.
NOx	LFG Turbine	38	ppm	2.0	lbs/MWh	2b	38-75 range cited; lean burn specified
NOx	LFG Turbine	75	ppm	4.0	lbs/MWh	2b	38-75 range cited; lean burn specified
NOx	LFG Turbine	25	ppm	1.3	lbs/MWh	2c	Lean burn specified
NOx	LFG Turbine	25	ppm	1.3	lbs/MWh	2d	Lean burn specified
NOx	New Gas	0.072	lbs/MWh	0.072	lbs/MWh	8	Based on data from Hermiston Generation Plant, Hermiston, OR.
NOx	Raw LFG	0.003	g/m^3 CH4 (LFG)	0.002	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
PM	All Electric Generation	0.14	lbs/MWh	0.14	lbs/MWh	8	PM-10 specified; total MWh based on EDEG 2000 data.
PM	Average Coal	0.24	lbs/MWh	0.24	lbs/MWh	8	PM-10 specified
PM	Average Gas	0.04	lbs/MWh	0.04	lbs/MWh	8	PM-10 specified
PM	Just Fossil Generation	0.20	lbs/MWh	0.20	lbs/MWh	8	PM-10 specified
PM	LFG Boil	130	mg/dscm CH4	0.0	lbs/MWh-equiv	1c	Data reliability rank D
PM	LFG Flare	270	mg/dscm CH4	0.2	lbs/MWh-equiv	1c	Data reliability rank D
PM	LFG Recip	770	mg/dscm CH4	0.5	lbs/MWh	1c	Data reliability rank E
PM	LFG Turbine	350	mg/dscm CH4	0.3	lbs/MWh	1c	Data reliability rank E
PM	LFG Turbine	0.023	lbs/MMBtu	0.29	lbs/MWh	1c	Data reliability rank B; HHV 400btu/ft3 @60deg. F.

Emission	Point Source	Reported Quantity	Reported Unit	Standardized Quantity	Standardized Unit	Source	Notes
PM	New Gas	0.048	lbs/MWh	0.048	lbs/MWh	8	Based on data from Hermiston Generation Plant, Hermiston, OR.
SO2	All Electric Generation	6.28	lbs/MWh	6.28	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
SO2	All Electric Generation	5.96	lbs/MWh	5.96	lbs/MWh	8	Total MWh based on EDEG 2000 data.
SO2	Average Coal	11.05	lbs/MWh	11.05	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
SO2	Average Coal	10.77	lbs/MWh	10.77	lbs/MWh	8	
SO2	Average Gas	0.24	lbs/MWh	0.24	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
SO2	Average Gas	0.37	lbs/MWh	0.37	lbs/MWh	8	
SO2	Just Fossil Generation	8.86	lbs/MWh	8.86	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
SO2	Just Fossil Generation	8.58	lbs/MWh	8.58	lbs/MWh	8	
SO2	LFG Combustion Exhaust	0.037	g/m^3 CH4 (LFG)	0.024	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
SO2	LFG Turbine	0.045	lbs/MMBtu	0.57	lbs/MWh	1c	Data reliability rank C; HHV 400btu/ft3 @60deg. F.
SO2	New Gas	0.00438	lbs/MWh	0.00438	lbs/MWh	8	Based on data from Hermiston Generation Plant, Hermiston, OR.
SO2	Raw LFG	0	g/m^3 CH4 (LFG)	0	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Total Particulate Matter (TPM)	LFG Combustion Exhaust	0.042	g/m^3 CH4 (LFG)	0.027	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane

Emission	Point Source	Reported Quantity	Reported Unit	Standardized Quantity	Standardized Unit	Source	Notes
Total Particulate Matter (TPM)	Raw LFG	0	g/m^3 CH4 (LFG)	0	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
VOC	All Electric Generation	0.025	lbs/MWh	0.025	lbs/MWh	8	Total MWh based on EDEG 2000 data.
VOC	Average Coal	0.032	lbs/MWh	0.032	lbs/MWh	8	
VOC	Average Gas	0.041	lbs/MWh	0.041	lbs/MWh	8	
VOC	Just Fossil Generation	0.035	lbs/MWh	0.035	lbs/MWh	8	
VOC	LFG Combustion Exhaust	0.018	g/m^3 CH4 (LFG)	0.012	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
VOC	LFG Flare	0.05	lbs/MMBtu	0.5	lbs/MWh-equiv	2b	
VOC	LFG Flare	0.03	lbs/MMBtu	0.3	lbs/MWh-equiv	2b	
VOC	LFG Recip	0.25	g/bhp-hr	0.78	lbs/MWh	2b	Lean burn specified
VOC	LFG Recip	0.375	g/bhp-hr	1.17	lbs/MWh	2b	Lean burn specified
VOC	LFG Recip	0.6	g/bhp-hr	1.9	lbs/MWh	2c	Lean burn specified
VOC	LFG Recip	0.8	g/bhp-hr	2.5	lbs/MWh	2d	Lean burn specified
VOC	LFG Turbine	0.013	lbs/MMBtu	0.16	lbs/MWh	1c	Data reliability rank B; HHV 400btu/ft3 @60deg. F.
VOC	LFG Turbine	0.07	lb/MWh	0.07	lbs/MWh	2b	Lean burn specified
VOC	New Gas	0.01486	lbs/MWh	0.01486	lbs/MWh	8	Based on data from Hermiston Generation Plant, Hermiston, OR.
VOC	Raw LFG	0.92	g/m^3 CH4 (LFG)	0.60	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
CH4	LFG Combustion Exhaust	0	g/m^3 CH4 (LFG)	0	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
CH4	Raw LFG	654	g/m^3 CH4 (LFG)	426	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane

Emission	Point Source	Reported Quantity	Reported Unit	Standardized Quantity	Standardized Unit	Source	Notes
CO_2	All Electric Generation	1417.38	lbs/MWh	1417	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
CO_2	All Electric Generation	1351	lbs/MWh	1351	lbs/MWh	8	Total MWh based on EDEG 2000 data.
CO_2	Average Coal	2210.11	lbs/MWh	2210	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
CO_2	Average Coal	2,182	lbs/MWh	2,182	lbs/MWh	8	
CO_2	Average Gas	1170.50	lbs/MWh	1171	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
CO_2	Average Gas	1,181	lbs/MWh	1,181	lbs/MWh	8	
CO_2	Just Fossil Generation	1989.86	lbs/MWh	1990	lbs/MWh	4	Based on selected data eliminating suspect emissions and efficiencies
CO_2	Just Fossil Generation	1951	lbs/MWh	1951	lbs/MWh	8	
CO_2	LFG Boil	1266	lbs/MWh	1266	lbs/MWh	1d	
CO_2	LFG Combustion Exhaust	3,878	g/m^3 CH_4 (LFG)	2526	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
CO_2	LFG Engine	2814	lbs/MWh	2814	lbs/MWh	1d	
CO_2	LFG Turbine	50	lbs/MMBtu	632	lbs/MWh	1c	Data reliability rank D; HHV 400btu/ft3 @60deg. F.
CO_2	LFG Turbine	3752	lbs/MWh	3752	lbs/MWh	1d	
CO_2	New Gas	860.7	lbs/MWh	860.7	lbs/MWh	8	Based on data from Hermiston Generation Plant, Hermiston, OR.
CO_2	Raw LFG	1,345	g/m^3 CH_4 (LFG)	876	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane

Emission	Point Source	Reported Quantity	Reported Unit	Standardized Quantity	Standardized Unit	Source	Notes
1,1,2,2-Tetrachloroethane	Raw LFG	1.11	ppm	0.0098	lbs/MWh-equiv	1a	Compounds for which ARB-OEHHA risk values are available
1,1,2,2-Tetrachloroethane	Raw LFG	0.07	ppm	6E-04	lbs/MWh-equiv	6	Compounds for which ARB-OEHHA risk values are available
1,1-Dichloroethane (ethylidene dichloride)	Raw LFG	2.35	ppm	0.0123	lbs/MWh-equiv	1a	Compounds for which ARB-OEHHA risk values are available
1,1-Dichloroethane (ethylidene dichloride)	Raw LFG	0.741	ppm	3.88E-03	lbs/MWh-equiv	6	Compounds for which ARB-OEHHA risk values are available
1,2-Dichloroethane (ethylene dichloride)	Raw LFG	0.41	ppm	2.1E-03	lbs/MWh-equiv	1a	Compounds for which ARB-OEHHA risk values are available
1,2-Dichloroethane (ethylene dichloride)	Raw LFG	0.12	ppm	6.3E-04	lbs/MWh-equiv	6	Compounds for which ARB-OEHHA risk values are available
Benzene	LFG Combustion Exhaust	0.0013	g/m^3 CH4 (LFG)	0.00085	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Benzene	Raw LFG	0.0044	g/m^3 CH4 (LFG)	0.0029	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Carbon tetrachloride	Raw LFG	0.004	ppm	3E-05	lbs/MWh-equiv	1a	Compounds for which ARB-OEHHA risk values are available
Carbon tetrachloride	Raw LFG	0.007	ppm	6E-05	lbs/MWh-equiv	6	Compounds for which ARB-OEHHA risk values are available
Chloride (as HCl)	LFG Combustion Exhaust	0.061	g/m^3 CH4 (LFG)	0.040	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Chloride (as HCl)	Raw LFG	0	g/m^3 CH4 (LFG)	0	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Chloroform	Raw LFG	0.03	ppm	2E-04	lbs/MWh-equiv	1a	Compounds for which ARB-OEHHA risk values are available

Emission	Point Source	Reported Quantity	Reported Unit	Standardized Quantity	Standardized Unit	Source	Notes
Chloroform	Raw LFG	0.021	ppm	1.3E-04	lbs/MWh-equiv	6	Compounds for which ARB-OEHHA risk values are available
Dichlorobenzene	Raw LFG	0.21	ppm	1.6E-03	lbs/MWh-equiv	1a	Compounds for which ARB-OEHHA risk values are available
Dichlorobenzene	Raw LFG	1.607	ppm	1.249E-02	lbs/MWh-equiv	6	Compounds for which ARB-OEHHA risk values are available
Dichloromethane (methylene chloride)	LFG Combustion Exhaust	0.00015	g/m^3 CH4 (LFG)	0.00010	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Dichloromethane (methylene chloride)	Raw LFG	0.014	g/m^3 CH4 (LFG)	0.0091	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Dichloromethane (methylene chloride)	Raw LFG	14.3	ppm	0.0642	lbs/MWh-equiv	1a	Compounds for which ARB-OEHHA risk values are available
Dichloromethane (methylene chloride)	Raw LFG	3.395	ppm	0.01525	lbs/MWh-equiv	6	Compounds for which ARB-OEHHA risk values are available
Dioxins & Furans	LFG Combustion Exhaust	7.70E-13	g/m^3 CH4 (LFG)	5.01E-13	lbs/MWh-equiv	3	Reported Assuming 47% of LFG is methane, converted @ 55%.
Dioxins & Furans	LFG Engine	19.6	pg I-TEQ/Nm3 @ 11% O2	2.29E-10	lbs/MWh	5	Mean shown, 0.04-318 reported range, stnd dev 54.5
Dioxins & Furans	LFG Flare	13.6	pg I-TEQ/Nm3 @ 11% O2	1.59E-10	lbs/MWh-equiv	5	Mean shown for shrouded flares, 0.22-156 reported range, Stnd Dev 33.0
Dioxins & Furans	Raw LFG	0	g/m^3 CH4 (LFG)	0	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Dioxins (Polychlorinated Dibenzo-P-Dioxins (2,3,7,8-TCDD))	LFG Boil	0.02	ng TEQ/dscm exhaust	7E-11	lbs/MWh-equiv	7	Using 1989 TEFs and corrected for 7% O2. Assumes non detects = 1/2 detection limit.

Emission	Point Source	Reported Quantity	Reported Unit	Standardized Quantity	Standardized Unit	Source	Notes
Dioxins (Polychlorinated Dibenzo-P-Dioxins (2,3,7,8-TCDD))	LFG Boil	0.04	ng TEQ/dscm exhaust	1E-10	lbs/MWh-equiv	7	Using 1989 TEFs and corrected for 7% O2. Assumes non detects = 1/2 detection limit.
Dioxins (Polychlorinated Dibenzo-P-Dioxins (2,3,7,8-TCDD))	LFG Combustion Exhaust	0	ng TEQ/dscm exhaust	0E+00	lbs/MWh-equiv	7	Using 1989 TEFs and corrected for 7% O2. 0.00-0.09 range given
Dioxins (Polychlorinated Dibenzo-P-Dioxins (2,3,7,8-TCDD))	LFG Combustion Exhaust	0.09	ng TEQ/dscm exhaust	7E-10	lbs/MWh-equiv	7	Using 1989 TEFs and corrected for 7% O2. 0.00-0.09 range given
Dioxins (Polychlorinated Dibenzo-P-Dioxins (2,3,7,8-TCDD))	LFG Engine	0.07	ng TEQ/dscm exhaust	6E-10	lbs/MWh	7	Using 1989 TEFs and corrected for 7% O2.
Dioxins (Polychlorinated Dibenzo-P-Dioxins (2,3,7,8-TCDD))	LFG Engine	0.08	ng TEQ/dscm exhaust	7E-10	lbs/MWh	7	Using 1989 TEFs and corrected for 7% O2. .08-.1 range given
Dioxins (Polychlorinated Dibenzo-P-Dioxins (2,3,7,8-TCDD))	LFG Engine	0.1	ng TEQ/dscm exhaust	8E-10	lbs/MWh	7	Using 1989 TEFs and corrected for 7% O2. .08-.1 range given
Dioxins (Polychlorinated Dibenzo-P-Dioxins (2,3,7,8-TCDD))	LFG Flare	0.02	ng TEQ/dscm exhaust	2E-10	lbs/MWh-equiv	7	Using 1989 TEFs and corrected for 7% O2.
Ethylene dibromide	Raw LFG	0.001	ppm	1E-05	lbs/MWh-equiv	1a	Compounds for which ARB-OEHHA risk values are available
Ethylene dibromide	Raw LFG	0.046	ppm	4.6E-04	lbs/MWh-equiv	6	Compounds for which ARB-OEHHA risk values are available
Fluoride (as HF)	LFG Combustion Exhaust	0.091	g/m^3 CH4 (LFG)	0.059	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane

Emission	Point Source	Reported Quantity	Reported Unit	Standardized Quantity	Standardized Unit	Source	Notes
Fluoride (as HF)	Raw LFG	0	g/m^3 CH4 (LFG)	0	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Hexachlorobenzene (HCB)	LFG Combustion Exhaust	1.10E-08	g/m^3 CH4 (LFG)	7.16E-09	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Hexachlorobenzene (HCB)	Raw LFG	5.70E-08	g/m^3 CH4 (LFG)	3.71E-08	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
HG	All Electric Generation	2.66E-05	lbs/MWh	2.66E-05	lbs/MWh	8	Total MWh based on EDEG 2000 data.
HG	Average Coal	4.92E-05	lbs/MWh	4.92E-05	lbs/MWh	8	
HG	Average Gas	3.86E-06	lbs/MWh	3.86E-06	lbs/MWh	8	
HG	Just Fossil Generation	3.83E-05	lbs/MWh	3.83E-05	lbs/MWh	8	
HG	LFG Turbine	2.92E-04	ppm	4.13E-06	lbs/MWh	1b	Assumes HG is not destroyed in combustion.
HG	New Gas	1.81E-06	lbs/MWh	0.000001 805	lbs/MWh	8	Based on data from Hermiston Generation Plant, Hermiston, OR.
HG	Raw LFG	2.92E-04	ppm	3.10E-06	lbs/MWh-equiv	1a	
Perchloroethylene (tetrachloroethylene)	LFG Combustion Exhaust	0.00019	g/m^3 CH4 (LFG)	0.00012	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Perchloroethylene (tetrachloroethylene)	Raw LFG	0.0096	g/m^3 CH4 (LFG)	0.0063	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Perchloroethylene (tetrachloroethylene)	Raw LFG	3.73	ppm	0.0327	lbs/MWh-equiv	1a	Compounds for which ARB-OEHHA risk values are available
Perchloroethylene (tetrachloroethylene)	Raw LFG	37.456	ppm	0.32841	lbs/MWh-equiv	6	Compounds for which ARB-OEHHA risk values are available
Polycyclic Aromatic Hydrocarbons (PAHs)	LFG Combustion Exhaust	0.00001	g/m^3 CH4 (LFG)	7E-06	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane

Emission	Point Source	Reported Quantity	Reported Unit	Standardized Quantity	Standardized Unit	Source	Notes
Polycyclic Aromatic Hydrocarbons (PAHs)	Raw LFG	0.052	g/m^3 CH4 (LFG)	0.034	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Toluene	LFG Combustion Exhaust	0.0047	g/m^3 CH4 (LFG)	0.0031	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Toluene	Raw LFG	0.15	g/m^3 CH4 (LFG)	0.10	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Trichloroethylene (trichloroethene)	LFG Combustion Exhaust	0.00004	g/m^3 CH4 (LFG)	0.00003	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Trichloroethylene (trichloroethene)	Raw LFG	0.0038	g/m^3 CH4 (LFG)	0.0025	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Trichloroethylene (trichloroethene)	Raw LFG	2.82	ppm	0.0196	lbs/MWh-equiv	1a	Compounds for which ARB-OEHHA risk values are available
Trichloroethylene (trichloroethene)	Raw LFG	0.681	ppm	4.73E-03	lbs/MWh-equiv	6	Compounds for which ARB-OEHHA risk values are available
Vinyl chloride	Raw LFG	7.34	ppm	0.0242	lbs/MWh-equiv	1a	Compounds for which ARB-OEHHA risk values are available
Vinyl chloride	Raw LFG	1.077	ppm	3.559E-03	lbs/MWh-equiv	6	Compounds for which ARB-OEHHA risk values are available
Vinyl chloride monomer (VCM)	LFG Combustion Exhaust	0.00021	g/m^3 CH4 (LFG)	0.00014	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Vinyl chloride monomer (VCM)	Raw LFG	0.0091	g/m^3 CH4 (LFG)	0.0059	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Xylenes	LFG Combustion Exhaust	0.00041	g/m^3 CH4 (LFG)	0.00027	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane
Xylenes	Raw LFG	0.13	g/m^3 CH4 (LFG)	0.085	lbs/MWh-equiv	3	Reported quantity assumes 47% of LFG is methane

APPENDIX B: SECTION 29 TAX CREDIT CALCULATIONS

The following table presents the landfills used in our calculations of the value of section 29 tax credit and the values calculated.

Name	State	Public?	NSPS	WIP (million tons)	Gas utilization rate (mmBtu/hr)	Value of credit ($/year)	Acceptance rate (thousand tons/year)	$/ton
Huntsville	AL	Y	N	4.8	2	$ 15,137	266.7	$ 0.057
Fred Weber	MO	N	Y	5.4	6	$ 45,412	316.1	$ 0.144
CDT	IL	N	N	5.5	10	$ 75,686	504.0	$ 0.150
Twin Bridges	IN	?	N	9.3	21	$ 158,941	1001.6	$ 0.159
Sycamore	CA	Y	Y	9.2	21	$ 158,941	900.0	$ 0.177
Sunbeam Road	FL	N	N	2.3	8	$ 60,549	328.9	$ 0.184
Flying Cloud	MN	N	N	4.8	15	$ 113,530	514.8	$ 0.221
Tazewell County	IL	?	N	5.4	17	$ 128,667	576.9	$ 0.223
Pioneer Crossing	PA	N	N	2.4	4	$ 30,275	133.6	$ 0.227
Santa Clara	CA	?	N	2.7	13	$ 98,392	429.0	$ 0.229
Olinda Alpha	CA	Y	Y	33.0	63	$ 476,824	2002.0	$ 0.238
Greene Valley	IL	?	N	27.1	125	$ 946,080	3304.8	$ 0.286
Smithtown	NY	Y	N	1.7	13	$ 98,392	314.6	$ 0.313
Woodland	IL	?	N	7.0	42	$ 317,883	987.8	$ 0.322
Chestnut Ridge	TN	N	Y	5.0	25	$ 189,216	583.4	$ 0.324
Prairie View	IN	?	N	7.2	19	$ 143,804	435.3	$ 0.330
Lake View	PA	N	N	8.0	32	$ 240,683	688.3	$ 0.350
Otay	CA	N	Y	10.1	42	$ 317,883	860.0	$ 0.370
Sunset Farms-Austin	TX	N	N	2.8	27	$ 204,353	533.1	$ 0.383
Altamont	CA	N	Y	34.8	83	$ 628,197	1508.1	$ 0.417
Mead Valley	CA	Y	N	2.3	10	$ 75,686	175.1	$ 0.432
Keystone	PA	N	N	9.7	52	$ 393,569	893.5	$ 0.441
Monterey Peninsula	CA	Y	N	5.5	13	$ 98,392	217.5	$ 0.452
Grows	PA	Y	N	16.8	83	$ 628,197	1388.6	$ 0.452
Pottstown	PA	N	N	10.1	46	$ 348,157	760.2	$ 0.458
Moore Livingston	NY	N	N	5.2	33	$ 249,765	505.6	$ 0.494
Kankakee County	IL	N	Y	2.0	13	$ 98,392	198.8	$ 0.495

Name	State	Public?	NSPS	WIP (million tons)	Gas utilization rate (mmBtu/hr)	Value of credit ($/year)	Acceptance rate (thousand tons/year)	$/ton
High Acres	NY	N	N	7.1	19	$ 143,804	284.2	$ 0.506
Des Moines	IA	?	N	22.2	29	$ 219,491	429.0	$ 0.512
Lake	IL	?	N	10.0	167	$ 1,263,963	2447.2	$ 0.517
Newby Island	CA	N	N	3.7	63	$ 476,824	849.4	$ 0.561
Seneca Meadows	NY	N	N	10.0	60	$ 454,118	800.0	$ 0.568
Settler's Hill	IL	Y	N	15.9	87	$ 658,472	1126.1	$ 0.585
Bailard	CA	N	N	7.2	25	$ 189,216	310.2	$ 0.610
Orange County	FL	Y	N	7.7	62	$ 469,256	768.0	$ 0.611
Greater Lebanon	PA	Y	N	0.5	6	$ 45,412	73.9	$ 0.615
Austin Road	CA	Y	N	3.0	10	$ 75,686	123.1	$ 0.615
Henderson County	NC	Y	N	2.1	6	$ 45,412	73.0	$ 0.622
WMI-BJ	GA	?	N	5.9	30	$ 227,059	343.8	$ 0.661
Coffin Butte	OR	N	Y	4.2	22	$ 166,510	250.0	$ 0.666
Brown Station	MD	Y	N	3.7	23	$ 174,079	260.0	$ 0.670
SPSA Regional	VA	Y	Y	6.4	38	$ 287,608	410.0	$ 0.701
Tullytown	PA	N	N	13.9	114	$ 862,825	1184.9	$ 0.728
Miramar	CA	Y	Y	29.0	135	$ 1,021,766	1400.0	$ 0.730
North Central	FL	Y	Y	4.1	35	$ 264,902	348.0	$ 0.761
122nd Street	IL	N	N	?	21	$ 158,941	200.0	$ 0.795
West Contra Costa	CA	N	N	11.2	30	$ 227,059	281.7	$ 0.806
United Waste	MA	N	N	1.9	10	$ 75,686	93.6	$ 0.809
Ocean County	NJ	N	N	13.3	48	$ 363,295	430.0	$ 0.845
Al Turi	NY	Y	N	4.1	42	$ 317,883	351.5	$ 0.904
Sangamon Valley	IL	?	N	5.4	33	$ 249,765	274.5	$ 0.910
Browning Ferris	IL	?	N	9.9	46	$ 348,157	379.9	$ 0.916
Central Disposal	FL	N	N	27.9	141	$ 1,067,178	1144.0	$ 0.933
Elliot	TX	Y	N	5.3	56	$ 423,844	423.9	$ 1.000

NAME	STATE	PUBLIC?	NSPS	WIP (MILLION TONS)	GAS UTILIZATION RATE (MMBTU/HR)	VALUE OF CREDIT ($/YEAR)	ACCEPTANCE RATE (THOUSAND TONS/YEAR)	$/TON
Santa Cruz City	CA	Y	N	2.5	10	$ 75,686	75.0	$ 1.009
Short Mountain	OR	Y	Y	3.4	33	$ 249,765	240.0	$ 1.041
Crazy Horse	CA	Y	N	3.2	21	$ 158,941	150.7	$ 1.054
Orange County	NY	Y	N	4.0	42	$ 317,883	295.0	$ 1.078
Brooks Site	KS	Y	N	11.8	83	$ 628,197	555.2	$ 1.132
Wilder's Grove	NC	Y	N	5.6	42	$ 317,883	268.4	$ 1.184
Central	CA	Y	N	14.4	71	$ 537,373	436.0	$ 1.233
Mohawk Valley	NY	Y	N	1.2	17	$ 128,667	100.0	$ 1.287
Guadalupe	CA	N	N	5.5	31	$ 234,628	180.0	$ 1.303
Cid	IL	N	N	23.4	125	$ 946,080	720.3	$ 1.313
Peoria City/County	IL	?	N	9.2	75	$ 567,648	431.1	$ 1.317
Lycoming County	PA	Y	N	5.3	46	$ 348,157	260.2	$ 1.338
Yolo County	CA	Y	N	9.2	27	$ 204,353	143.0	$ 1.429
Edgeboro Disposal MCUA	NJ	Y	N	48.8	146	$ 1,105,021	773.2	$ 1.429
Double Butte	CA	Y	N	2.0	8	$ 60,549	42.2	$ 1.433
New Milford	CT	Y	N	7.3	58	$ 438,981	300.0	$ 1.463
Perdido	FL	Y	Y	4.9	42	$ 317,883	200.2	$ 1.588
Monmouth County	NJ	Y	N	10.7	99	$ 749,295	471.7	$ 1.589
Northern Disposal Incorporated	MA	N	N	3.3	83	$ 628,197	390.0	$ 1.611
Cumberland County	NC	Y	N	3.3	38	$ 287,608	178.5	$ 1.611
City of Winstom-Salem	NC	Y	N	5.7	58	$ 438,981	258.6	$ 1.697
Puente Hills	CA	Y	Y	62.5	785	$ 5,941,382	3415.0	$ 1.740
Pitt County	NC	Y	N	2.8	29	$ 219,491	125.3	$ 1.752
1-95 Lorton	VA	Y	N	29.0	69	$ 522,236	286.0	$ 1.826
Lowell	MA	Y	N	1.3	25	$ 189,216	85.8	$ 2.205
Buncombe County	NY	Y	N	3.9	29	$ 219,491	96.8	$ 2.269
Tomoka Farms Road	FL	Y	N	7.9	104	$ 787,139	284.6	$ 2.766

NAME	STATE	PUBLIC?	NSPS	WIP (MILLION TONS)	GAS UTILIZATION RATE (MMBTU/HR)	VALUE OF CREDIT ($/YEAR)	ACCEPTANCE RATE (THOUSAND TONS/YEAR)	$/TON
Milam	IL	?	N	10.0	21	$ 158,941	55.5	$ 2.864
Scholl Canyon	CA	Y	N	25.1	188	$ 1,422,904	495.2	$ 2.874
Pine Bend	MN	?	N	19.1	79	$ 597,923	181.4	$ 3.297
Aacme	CA	N	Y	10.7	38	$ 287,608	37.0	$ 7.773
Bedford	OR	?	N	2.8	42	$ 317,883	20.1	$ 15.802
East Pennsboro	PA	Y	N	0.4	2	$ 15,137	0	N/A
Agawam	MA	Y	N	1.0	13	$ 98,392	0	N/A
Hamm's	NJ	N	N	1.7	15	$ 113,530	0	N/A
Tripoli	NY	Y	N	1.7	10	$ 75,686	0	N/A
Saratoga Springs	NY	Y	N	2.1	10	$ 75,686	0	N/A
Lancaster	NY	N	N	2.4	81	$ 613,060	0	N/A
Old Bethpage	NY	?	N	2.8	17	$ 128,667	0	N/A
BFI-Halifax	MA	N	N	2.9	33	$ 249,765	0	N/A
Amity	PA	N	N	3.0	15	$ 113,530	0	N/A
L&D	NJ	N	N	3.3	35	$ 264,902	0	N/A
Conshocken	PA	N	N	3.6	19	$ 143,804	0	N/A
Temescal Road	CA	Y	N	4.0	8	$ 60,549	0	N/A
American Canyon	CA	Y	N	4.2	21	$ 158,941	0	N/A
Gude	MD	Y	N	4.8	33	$ 249,765	0	N/A
Sheldon-Arleta	CA	Y	N	5.5	31	$ 234,628	0	N/A
Oceanside	NY	Y	N	6.5	35	$ 264,902	0	N/A
Kinsley	NJ	N	N	7.3	27	$ 204,353	0	N/A
Penrose	CA	?	N	9.0	63	$ 476,824	0	N/A
Mountaingate (2)	CA	N	N	10.0	83	$ 628,197	0	N/A
Spadra	CA	N	N	12.5	104	$ 787,139	0	N/A
Toyon Canyon	CA	Y	N	16.0	73	$ 552,511	0	N/A
San Marcos	CA	Y	N	16.4	21	$ 158,941	0	N/A

Name	State	Public?	NSPS	WIP (million tons)	Gas utilization rate (mmBtu/hr)	Value of credit ($/year)	Acceptance rate (thousand tons/year)	$/ton
Coyote Canyon	CA	Y	Y	25.0	146	$ 1,105,021	0	N/A
Mountaingate	CA	N	N	29.0	104	$ 787,139	0	N/A
County Line	CO	Y	N	30.0	6	$ 45,412	0	N/A
BKK	CA	N	Y	46.0	450	$ 3,405,888	0	N/A
Palo Alto	CA	Y	N	2.7	19	$ 143,804	0	N/A
Mazzaro	PA	N	N	3.0	21	$ 158,941	0	N/A
City of Santa Clara	CA	Y	N	3.5	19	$ 143,804	0	N/A
Menlo Park	CA	Y	N	5.0	31	$ 234,628	0	N/A
Total				1,103	6,343	$ 48,006,370	47,517.1	$ 0.76