SIERRA CLUB
CALIFORNIA

July 13, 2010

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California Energy Commission
Dockets Office, MS-4
Re: Docket No. 10-BAP-1
1516 Ninth Street
Sacramento, CA 95814-5512
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Sierra Club California would appreciate the California Energy Commission's serious consideration of the comments below during the preparation of the state's 2010 Bioenergy Action Plan.

We generally support bioenergy as an integral part of a future with multiple renewable technologies feeding the grid and providing onsite power generation. In moving bioenergy forward, however, we must be conscious that each energy feedstock has its own set of impacts and efficiencies. We recommend applying four key considerations to the evaluation of any technology and feedstock:

I. Emissions - Does the technology or feedstock reduce greenhouse gas emissions based on a lifecycle assessment of emissions?
II. Efficiency - Does the technology and/or feedstock provide a reasonable efficiency on its net return of energy based on a life-cycle assessment.
III. Optimal Use - Does the technology, facility and/or waste feedstock put the feedstock to its highest and best use or create a demand to create waste?
IV. Impacts - Does the technology or feedstock generate other environmental impacts that outweigh its energy benefit, or are there other alternative sources that, in line with a precautionary approach, provide similar benefit with fewer impacts?

Sierra Club California provides the following specific recommendations for the 2010 Bioenergy Action Plan:

1. Do not give "renewable energy" credits to landfill gas (unless capture rates over the entire landfill and destruction efficiencies are scientifically demonstrated and continually monitored to ensure they are equal to or exceed those of a flare, or they are installed earlier than the NSPS requirements). Based on the attached articles "*Landfill Gas-to-Energy Projects May Release More Greenhouse Gases Than Flaring*," Jim R. Stewart, PhD, and "*Putting the Landfill Energy Myth to Rest*," Sally Brown, BioCycle, May 2010, capturing landfill gas from an active landfill can, in some cases, increase the fugitive emissions compared to landfills using flares. Also see the Sierra Club's national policy on *Landfill Gas to Energy Facilities* Policy (attached).
2. Promote the use of anaerobic digestion as a source for energy and soil amendments. SCC limits its support to sealed digestion units to maximize the capture of emissions. Furthermore, it is necessary to consider the viability of the feedstocks and the impact that has

on the disposition of the digestate. Contaminates must be removed prior to processing to assure they are not released into the general environment. Furthermore, waste feedstocks should be screened for highest and best use, as outlined in the four criteria listed above.

3. Support the use of waste feedstocks for a variety of technologies with the following caveats:
   a. The highest and best use of a waste should be considered. It may "cost" more, in energy, emissions, environmental impact, and dollars to replace a product using a virgin feedstock than using a recycled feedstock. Therefore, it necessary to consider the highest use for a waste feedstock before selecting it for energy production.
   b. When discussing highest and best use, acknowledge the use of organics as a soil amendment as a high use, including but not limited to compost and digestate.
   c. Technologies or facilities that solely rely upon a waste feedstock may generate a demand for waste. Creating less waste is the highest tier of the waste hierarchy. Establishing a facility that creates a demand for waste may reverse the waste management hierarchy in an area. Why preserve the waste hierarchy over energy generation? Not creating a waste entirely avoids the use and waste of energy that would go into the creation of that product and/or the energy costs of handling of it as a waste.
   d. Dangerous contaminates need to be removed or appropriately addressed before processing, or the digester residue needs to be treated as hazardous waste.
4. When burning biofuels, require co-generation and combined heat and power (CHP) facilities wherever possible to ensure maximum efficiency. Seek the input of CPUC's Policy and Planning Division, specifically policy analyst Michael Colvin, whose singular experience with CHP issues could be valuable in this regard.
5. Fund research into cellulosic biofuels using the principles of lifecycle analysis emissions, efficiency, optimal use and impacts to guide the value of any particular feedstock.
6. Create consistent definitions for universal use in California for feedstocks that include:
   a. Identification of what specific materials are included in a particular feedstock. This is particularly relevant for waste feedstocks.
   b. An emissions index based on lifecycle assessment.
   c. An efficiency index based on lifecycle assessment.
   d. Identification of associated impacts associated with the feedstock.
   e. Identification of potential contaminates associated with the feedstock.
7. Establish standardized contracts for funding bioenergy that would:
   a. Establish a rate of reimbursement that encourages investment in bioenergy.
   b. Provide reliable revenues in order for projects to obtain necessary funding.
   c. Provide standards for interconnections to facilitate quick and pre-determined interconnection to the grid.
8. Create permitting regulations specific to bioenergy technologies. The permitting process should coordinate permits from all agencies to remove conflicting requirements. These regulations must be developed with appropriate public input in order to assure all stakeholders views and evidence have been reflected.

9. Identify specific tasks with associated responsibility parties and a schedule within the 2010 Bioenergy Action Plan to assure accountability in the implementation of the plan. This includes, but is not limited to, those issues that require supporting legislation to be realized.
10. Identify and outline steps to eliminate barriers to the use of anaerobic methane digesters to capture methane from organic wastes and use it to supplant fossil fuel consumption while also delivering top quality compost to enrich depleted soils. This technology should be especially be promoted for dairies. One test case is Strauss Family Dairy in Marin County. Look at Europe for other examples: Sierra Club understands there are at least 5000 such facilities in Germany and Austria alone compared to just a handful operating in California. Special feed-in tariffs for dairies reportedly have spurred this growth in Europe and presumably would have a similar effect if used in California. The high GHG factor for methane (latest values are 34 times CO2 over 100 years and 105 times CO2 over the critical next 20 years[1]) means that that it is important to include avoided GHG impacts in feed-in tariffs for dairies. Additionally, barriers to methane digesters have already been outlined in a comprehensive research paper CEC may wish to draw from on barriers to methane digesters: Methane Digesters: A Case for Cross-Media Environmental Decision Making.[2] The CEC and the state's refurbished Bioenergy Plan must untangle the currently dysfunctional mosaic of regulatory, statutory and operational barriers hampering the widespread adoption of methane digesters in order to reach our AB 32 climate goals. An example of promising landfill digester technology is a proposal at Palo Alto Landfill supported by a City Council-appointed Blue Ribbon Task Force and supported by the citizen's group Palo Alto Green Energy, "Dry Anaerobic Digestion (DAD)". By evaluating such technologies and eliminating barriers to their dissemination and adoption, CEC would make a solid contribution to mitigation of the looming impact of atmospheric methane on the global climate.

We support California's proactive approach to bioenergy through its 2010 Bioenergy Action Plan. It is clear, however, based on the lack of implementation of the 2006 Action Plan, that it is necessary to add accountability to the plan to assure its realization. Furthermore, whatever legislative initiatives may be necessary to realize the plan need to be explicitly identified with deadlines necessary to meet the timelines established within the 2010 Action Plan.

Sierra Club California appreciated the CEC's invitation to participate in the Bioenergy Workshop on June 3, 2010, and we welcome the chance to be an active contributor to development of the Plan going forward.

Sincerely,

Bill Magavern

Bill Magavern
Director

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[1] Drew T. Shindell, *et al.*, "Improved Attribution of Climate Forcing to Emissions," *Science* **326**, 716 (2009).

[2] http://berc.berkeley.edu/system/files/BERC_BISBiogasCrossMedia210.pdf

SIERRA CLUB REPORT ON LANDFILL-GAS-TO-ENERGY

Prepared by the Sierra Club LFGTE Task Force
January 5, 2010

Executive Summary

The Landfill Gas to Energy (LFGTE) Task Force was asked to evaluate whether LFGTE facilities decrease or increase net greenhouse gas (GHG) emissions. We have unanimously concluded that reliance on landfill gas to generate electricity results in increased net GHG emissions. This is clearly the case when considering the fate of new wastes that could be diverted to waste management facilities more appropriate than landfills, and is almost certainly true for wastes already buried in landfills that collect landfill gas and flare it.

Our conclusions reinforce existing Sierra Club policy that supports diversion of the organic fraction of our discards from landfills so that uncontrolled methane is not generated in the first instance. They also suggest that, in existing landfills with or without LFGTE facilities, regulations should be significantly strengthened to reduce methane emissions as much as possible.

Modern solid waste landfills generate and release significant amounts of methane, a potent contributor to global warming. When decomposable organic trash (e.g., food scraps, yard waste, and more) break down under the oxygen poor conditions in today's covered landfills, a complex mixture of combustible gases is produced. About half of that gas mixture is methane and, left undisturbed, much of it seeps out of the ground and is released to the environment over time.

More than a decade ago, the Environmental Protection Agency began requiring most larger solid waste landfills to install landfill gas collection and flaring systems, in part as a way to reduce methane emissions and their contribution to climate change. Collection and flaring of landfill gas, they reasoned, may result in some reduction in human contributions to climate change if they result in reduced fugitive releases of methane to the environment and in effective conversion of captured methane to carbon dioxide, a less potent greenhouse gas (GHG).

Enterprising landfill operators, encouraged by an EPA outreach program, are using the collected landfill gases to generate electricity and to produce additional revenue by selling that electricity to power companies. Conventional wisdom suggests that LFGTE facilities should also help to reduce global warming impacts by reducing the need to produce electricity from coal and other dirtier fuels.

Our analysis leads us to conclude that conventional wisdom is mistaken.

Findings

1) **For new wastes, disposal of decomposable organic wastes in landfills, including those with associated LFGTE facilities, clearly results in the release of substantially more greenhouse gases (and other environmental pollutants) than diversion of these wastes from land filling to other**

treatments.

When organic wastes are buried in today's landfills, methane is always produced and a substantial portion of that methane leaks into the environment.

2) **Management practices commonly employed in conjunction with LFGTE systems tend to increase fugitive methane emissions, to shift their timing toward the present (compared with standard landfill gas collection and flaring), and to reduce collection efficiency.** (See Background #5)

In particular, raising the moisture content of the landfill, the "wet cell" method, accelerates the decomposition of wastes, making room for more wastes and increasing the volume and concentration of methane produced. It also shifts methane generation forward in time, which is counterproductive to achieving the near-term reductions in GHG emissions that many scientists believe are necessary for successful control of climate change. (Some landfills that do not employ LFGTE also use the wet cell method to create space for more wastes.)

4) **Contrary to conventional wisdom, it appears the relatively small CO_2 reduction benefit that might be achieved by replacing fossil fuel electricity with LFGTE electricity is greatly outweighed by the increase in fugitive methane emissions resulting from altered landfill management practices.**

That makes LFGTE facilities counterproductive as part of a climate change mitigation strategy.[1] Because the very things necessary to reduce methane emissions from LFGTE facilities conflict with incentives to maximize revenue from the generation of electricity, it does not appear likely that landfill managers will improve practices sufficiently in the foreseeable future to result in a net GHG benefit from LFGTE. (See Background #7)

5) **While efforts to divert organic discards from landfills are developed and implemented, methane will continue to be generated from wastes that are already in place, and from future organic discards that those programs fail to divert.**

While the site is actively managed, several operational changes should immediately be made at landfills to (1) increase the amount of landfill gases that are captured, (2) avoid measures intended to augment the concentration of methane in landfill gas, and (3) cease using methods that shift overall gas generation from the future to the present unless a high percentage of that gas can be captured. (See APPENDIX B.). More research is needed on how to manage landfills to stabilize the site so that fugitive methane emissions do not continue after active maintenance ends (the "second wave", which greatly increase lifetime emissions), That should not be at the price of significantly increasing fugitive methane emissions in the critical near term when we

[1] For LFGTE to result in any net GHG emission benefit, the management system would have to be improved dramatically so that virtually no methane or hazardous air and water pollutants escape and new monitoring methods would have to be employed to verify fugitive emission levels. Even then the amount of credit for LFGTE should be based on the net reduction of GHG emissions on a life-cycle analysis basis, taking account of the degree that fossil fuels are actually displaced by the energy from LFGTE.

confront a tipping point. (Present proposals directed at the second wave are discussed further in Background #9)

6) **Current landfill regulation does not deal adequately with methane emissions or with other pollutants, including toxics that are generated in landfills and are either poorly regulated or not regulated at all.** Specific recommendations for improvements in Club policy and in federal and state landfill regulations require further exploration and should be aggressively pursued. (See Background #8)

7) **The contribution of methane emissions from landfills and other sources to global climate change has typically been underestimated.**

   If mitigation strategies are to achieve the near-term large reductions necessary to prevent catastrophic climate change impacts, then curbing methane emissions is an important opportunity for near-term mitigation of those impacts and should be given a high priority. This opportunity is not fully recognized in Kyoto Protocol procedures and in most current mitigation programs. The latest Intergovernmental Panel on Climate Change's scientific report does explain the greater role of methane and indicates that globally the climate impact of current methane emissions over the next 20 years is almost as great as CO_2 emissions. (See Background #4)

Recommendations

While there remain a number of unresolved questions about LFGTE, the Task Force believes there is more than sufficient evidence for the Club to take action in the following areas:

***Recommendation No. 1* – The Sierra Club should resist legislative and policy initiatives that encourage LFGTE projects or that allow LFGTE facilities to receive credit in GHG emission reduction programs. Club policies and initiatives should be examined and revised as appropriate to be consistent with that objective.**

The Task Force recommends amendment of the *2006 Energy Resources Policy* (which currently does not address LFGTE) by adding a new subsection under "*VII. Resources for the Transition to a Clean Energy Future, E. Resources Opposed by the Sierra Club*".

***Recommendation No. 2* – The Sierra Club should continue to advocate the elimination of organic discards from landfills as a long-term solid waste management goal *and* as a component of our global climate change campaigns. The Sierra Club should explore and support solid waste management policies, laws, regulations, strategies and technologies that could help to facilitate that transition.**

This recommendation reinforces and expands upon the general principles in the Club's

Zero Waste: Cradle-to-Cradle Principles for the 21st Century Policy of Feb. 2008. It also suggests the need for Club guidance and perhaps policy dealing with treatment methods for organics in the waste stream as alternatives to land disposal. The draft *Zero Waste Guidance on Landfills* does not deal with all of those issues and this Task Force has had only preliminary discussions of those options. .

***Recommendation No. 3* – Because separate collection and management of decomposable organic wastes is not fully achievable in the near term and does not help with wastes already in the ground, the Sierra Club should pursue improvement of landfill management regulation and practices aimed at reducing emissions of methane and other pollutants.**

This is a recommendation for action and does not require a policy change. Specific recommendations for Club policies and guidance that address the most feasible and desirable ways to achieve reductions should be pursued on a priority basis. As a first step, Appendix B lists some changes in landfill regulations that would help to reduce fugitive emissions of methane.

***Recommendation No. 4* – The Sierra Club should seek to elevate the attention given to curbing methane generation and release from landfills and other sources as part of our global warming and energy campaigns.**

This recommendation reaches beyond the scope of the Board's charge to this Task Force, but it is clear to us that methane emission reductions could and should be an integral part of any effective GHG emissions reduction strategy.

Appendix A – Background

There are eight underlying concepts that are necessary to understand these issues:

1. *Substantial volumes of methane are generated from the decomposable organic fraction of our buried discards.* Between half and two-thirds of our household and commercial discards are organic. Those wastes consist chiefly of yard trimmings, soiled paper and food scraps, with lesser quantities of pet waste, diapers, textiles and wood. When garbage and its organic fraction are buried and compacted in the ground and then covered, they decompose anaerobically (i.e. in oxygen-starved conditions), and methane (CH_4) is produced among the decomposition byproducts.

   A ton of wet organic material buried in a landfill is reflective of what one family might throw out in a year and will generate approximately 500 pounds of methane spread out over decades. Some fraction of that methane will escape from the landfill into the atmosphere, whether or not some of the methane is collected and burned. Those escaped landfill gases are commonly known as *fugitive* or *uncontrolled* emissions.

2. *Only a part of landfill gas is captured with collection systems in place.* In most large landfills, Environmental Protection Agency (EPA) regulations require the installation of gas collection systems after 5 years of first waste emplacement and continuing for a period of less than 30 years after closure. (See Figure 1) Because gas escapes from the top, sides and bottom of landfills, and because landfills often cover several hundred acres and are piled with wastes as much as several hundred feet deep, capturing all the gas is extremely challenging, even for the period when there is any gas collection. In addition, technology to measure fugitive emissions over a wide area has not been available. As a result, reliable representative measurements of the effectiveness of collection systems are not available and it has not been feasible to establish direct, enforceable methane emission limits.

   EPA estimates, without supporting data, that the best collection systems capture about 78% of the gases during the relatively small fraction of a landfill's emitting lifetime that they are installed and functional. But, the Intergovernmental Panel on Climate Change (IPCC) expressed the view that, over the long term, including the extensive times when there is little or no gas collection, the average fraction captured may be as low as 20%.

   The difference between these two values is due at least in part to the assumptions used to frame the estimates. The EPA's estimates are based on what they believe the best systems should achieve during the limited time that they operate. The IPCC's are based on average systems operating over the entire period that gas is generated.

   In particular, the major pathways for uncontrolled landfill gas emissions occur after the site is closed and set-aside funds for postclosure maintenance are gone. Based on studies that indicate moisture only reaches "23% to 34% of the

waste mass"[1], and the fact that high moisture levels are necessary for effective decomposition, most gas will be generated after the cover fails, rainfall re-enters the site, and a second major wave of gas generation ensues without any controls. Consequently, landfills are a much greater source of greenhouse gases than EPA has acknowledged.

3. *None of the alternatives to land filling presents a significant methane problem.* In contrast to substantial methane generated by landfills, some fraction of which escapes, none of the commercial alternatives to the landfilling of organic wastes produces significant volumes of uncontrolled methane. These commercial alternatives include processing the organics by windrow (composting), open vessel aerobic decomposition, enclosed aerobic chambers, enclosed anaerobic chambers with methane collection, pyrolysis, and combustion/incineration.

4. *Methane is carbon dioxide on-steroids.* The difference between releases of CH_4 (from landfills alone) and CO_2 (from almost any other alternative) holds enormous consequences for climate change. Methane emissions have at least 25 times the warming potential of CO_2 emissions when climate impacts are counted over the longer term (i.e., using the 100-year "GWP").[2] In the near term, as we confront a possible tipping point, it is arguable that methane should be counted more heavily, as much as 72 times CO_2 (using the 20-year GWP). Total methane emissions from all sources are estimated to represent about 9% of CO_2-equivalent GHG emissions in the U.S. and 14% of global GHG emissions based on the longer 100-year GWP time horizon. **But the IPCC estimates that, based on a 20-year time horizon, global methane emissions in 2000 were nearly equal to CO_2 emissions in their impact on global warming.**[3] (See Figure 2 for a graphic illustration of IPCC's analysis of the integrated impact of global emissions.) Landfills are estimated by EPA to account for about 24% of total methane emissions in the U.S. (The Task Force suspects the actual percentage may be higher.) Landfills are a much smaller percent of total methane emissions in most of the world, especially in developing nations.[4]

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[1] Debra Reinhart, *Prediction and Measurement of Leachate Head on Landfill Liners,* Florida Center for Solid and Hazardous Waste Management (Report #98-3) (1998), at p. viii. Other data from leachate recirculating landfills suggests that even in these wet cells "efficiency of the leachate recirculation system at distributing leachate throughout the waste body in the recirculation cell were [still] low." J.W.F. Morris, et al., *Findings from long term monitoring studies at MSW landfill facilities with leachate recirculation,* WASTE MANAGEMENT 23 (2003), at p. 653.

[2] The "Global Warming Potential" or GWP was adopted in the Kyoto Protocol as a method for comparing emissions of different greenhouse gases (GHG) by weight. It is an integrated measure of impact over a specified time period and 100 years was adopted in the Kyoto Protocol (the "100-year GWP"), although some policy analysts advocate shorter time periods for counting impacts such as 20 years—the "20-year GWP". A ton of methane emissions has 25 times the integrated impact on global warming as a ton of CO_2 using the 100-year GWP and 72 times using the 20-year GWP.

[3] Figure 2.22, p. 206, Chap. 2, Report of Working Group I: "Physical Basis of Climate Change", Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.

[4] Stacy C. Jackson, "Parallel Pursuit of Near-Term and Long-Term Climate Mitigation," 326 Science 526 (2009); and **Error! Main Document Only.**James Hansen, "Greenhouse gas growth rates," 101 PNAS 46 (November 16, 2004), p. 161094. For more recent information about further heightening of methane's warming potential, see, Drew T. Shindell, et al., "Improved Attribution of

5. *Changes in landfill operation linked to LFGTE increase uncontrolled methane releases.* In recent years, the landfill industry has made widespread operational changes to increase revenues from energy production but with potentially significant impacts on our climate. These unfortunate practices were never contemplated in EPA's landfill rules and have never been officially vetted for their GHG implications.

For example, many landfills with associated LFGTE facilities are recirculating leachate and adopting other management practices intended to accelerate organic waste decomposition and accelerate landfill subsidence. This is called "wet cell" operation in contrast with the traditional "dry tomb" designs. The increased moisture can result in increased methane concentrations in collected landfill gas by almost half. This operational change shifts the timing of methane generation closer to the present, when it would otherwise be spread over many decades.

Many LFGTE landfills also delay installation of the cover that keeps out rainfall and reduce negative pressure in the gas collection system as additional tactics to maintain optimum conditions for methane production. The result is landfill gas with a higher methane concentration and reduced gas collection efficiency, increasing both the volume of fugitive emissions and the methane concentration in those emissions. For citations, see footnote 4. There are alternative landfill practices that theoretically might achieve better emissions control. Potential examples include a few small publicly owned and closed landfills and a small demonstration project operated to maximize gas capture at the same time energy is generated.[5] However those methods tend to make LFGTE less profitable. Without any current way to enforce proper operation, the economic incentive on an operator would be to act in ways that wind up increasing emissions in order to restore profitability. If comprehensive and practical monitoring systems were later developed and demonstrated to reliably measure all fugitive emissions, and not just those from the surface while the unit is open, then there may be grounds for reconsideration.

6. *Landfills are responsible for significant GHG emissions*. EPA GHG emission inventories estimate landfill methane emissions at about 2% of total anthropogenic (i.e. manmade) GHG emissions in the U.S in 2005. It appears that, depending upon which assumptions are adopted (i.e. high vs. low gas collection efficiency, long vs. short term time periods for measuring impacts (GWP), and wet cell vs. dry tomb management), landfills may be responsible for a much greater impact -- up to approximately 12% of total GHG emissions. Using the latest IPCC 20-year GWP of 72 to weight methane instead of the earlier IPCC 100-year value of 21 used by EPA will, by itself, increase the estimated percentage of GHG emissions by more than three times.

Climate Forcing Emissions, 326 Science 716 (2009).

[5] Augenstein, Don, "Landfill Operation for Carbon Sequestration and Maximum Methane Emission Control: Controlled Landfilling Demonstration Cell Performance for Carbon Sequestration, Greenhouse Gas Emission Abatement and Landfill Methane Energy", Final Report, Institute for Environmental Management (IE M), February 26, 2000.

7. *Purported GW benefits of LFGTE are dubious.* The landfill industry contends that recovery of the methane from landfill gas for the generation of electricity will reduce net GHG emissions. The gain from LFGTE is alleged to occur because the electricity generated at the landfill offsets the need to generate power from dirtier combustion sources, thus avoiding the associated emissions of carbon dioxide and other harmful pollutants. That view is widely shared by politicians, EPA, and some environmental organizations. The Task Force is persuaded that this CO_2 benefit is greatly outweighed by an increase in fugitive (uncontrolled) methane emissions resulting from the altered landfill management methods apparently practiced at most LFGTE projects.

Because of the much greater potency of methane as discussed in Background #4 above, additional leakage (compared with conventional collection and flaring) of only a very small percentage of the methane generated is sufficient to overwhelm the relatively small CO_2 reduction from electricity production. When LFGTE is compared with non-landfill waste treatment options, the high leakage rates of all landfill management methods (at least 22% or more even by EPA's most optimistic estimates) makes the comparison much more unfavorable to LFGTE. An additional uncertainty is the source of electricity generation that is likely to be displaced by LFGTE, but the Task Force's conclusions do not depend on challenging the industry assumption that it would displace dirty fossil energy.

8. *Landfill gas emissions are a major source of un(der)regulated pollution.* In addition to the potent greenhouse gas, methane, landfill gases contain compounds that contribute to regional smog and hazardous pollutants harmful to human health. Because methods for measuring fugitive emissions over large non-point sources have not been available, setting emissions performance standards (which depend upon direct emissions measurements) at landfills has not been possible.

As a poor substitute for direct measurement, methane concentration levels at the surface of landfills are normally measured quarterly along a grid, at points about 100 feet apart, beginning after there is a final cover in place.[6] But, this test is effectively useless at landfills with low permeability covers because the greatest emissions are localized at a few tears in the cover and are not diffused uniformly across the surface. Conclusions based on these inadequate testing methods will fail to detect most gas leaks at landfills with composite covers.

Consequently, current regulations and emission inventories are unreliable and probably ineffective. Better empirical measurements are critical to achieving optimal improvements in regulation, although a number of feasible immediate improvements are described in Appendix B.[7]

Finally, regulations do not adequately address substantial emissions that occur after active management and regulation cease, as described below in #9.

9. *Landfills may emit substantial methane for decades after active management has ceased.* Some in industry advocate leachate recirculation

[6] 40 CFR §60.755(c).
[7] 40 CFR§ 98.343.

during active landfill operation as a way to reduce the levels of undigested waste in closed landfills, and thus reduce post-closure, "second wave" landfill gas generation and release. The result, however, is significantly increased fugitive methane emissions earlier in the life of the landfill and during the time when there is, as NASA has stated, an urgent need to reduce and not increase methane emissions.[8] Landfills that accept decomposable organic wastes should be required to begin gas collection sooner (perhaps within 2 years of the start of waste deposition, rather than the currently required five years), in order to better manage these early emissions.

In addition, lessening the effects of the second wave of landfill gas, without front-loading the system with near-term methane releases, is critical. More effective post-closure requirements and aggressive research and development efforts might be able to identify better methods for preventing second wave gas releases.

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8 James Hansen, *Greenhouse gas growth rates*, 101 PNAS 46 (November 16, 2004), p. 161094

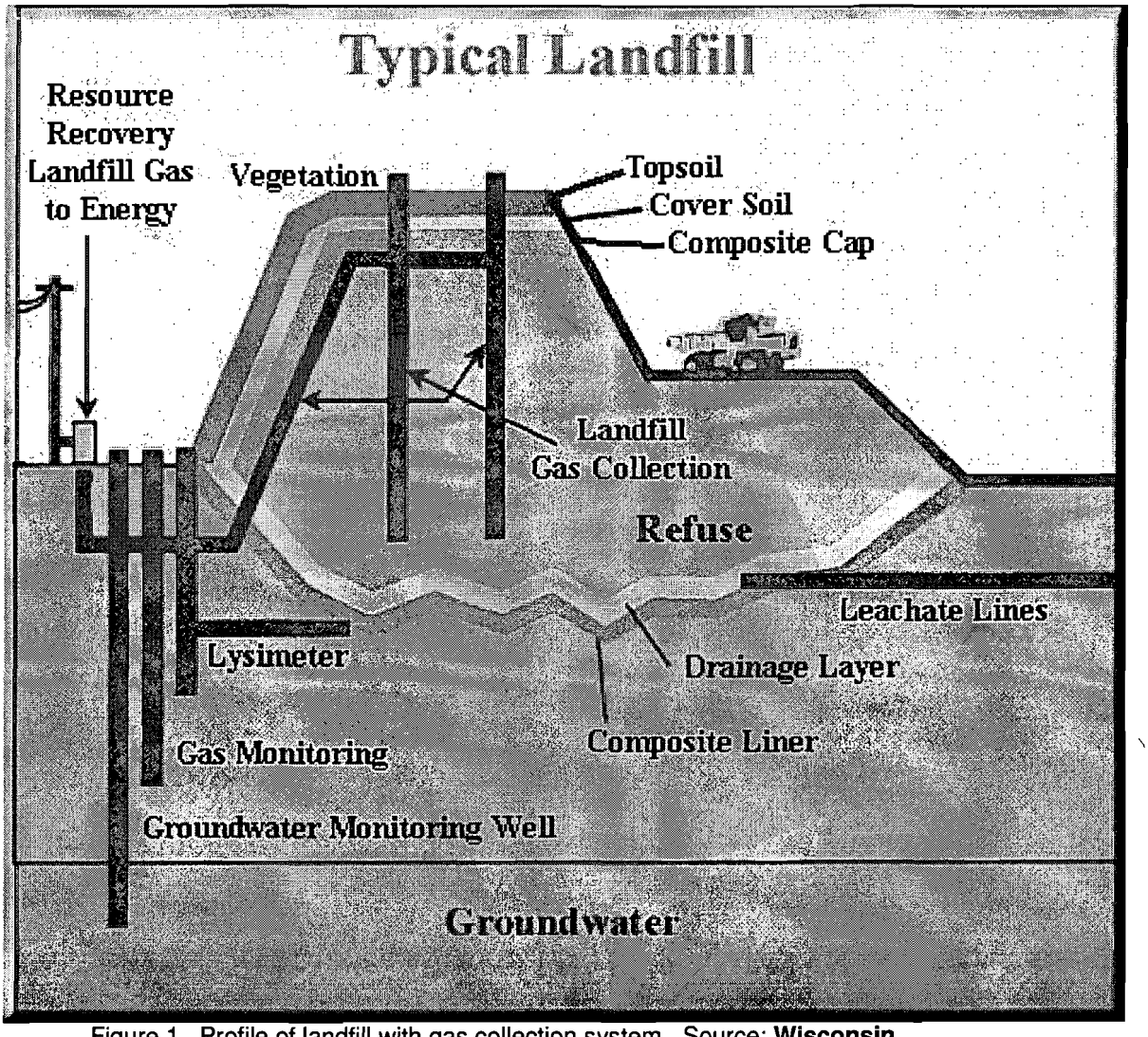

Figure 1. Profile of landfill with gas collection system. Source: **Wisconsin Department of Natural Resources.**

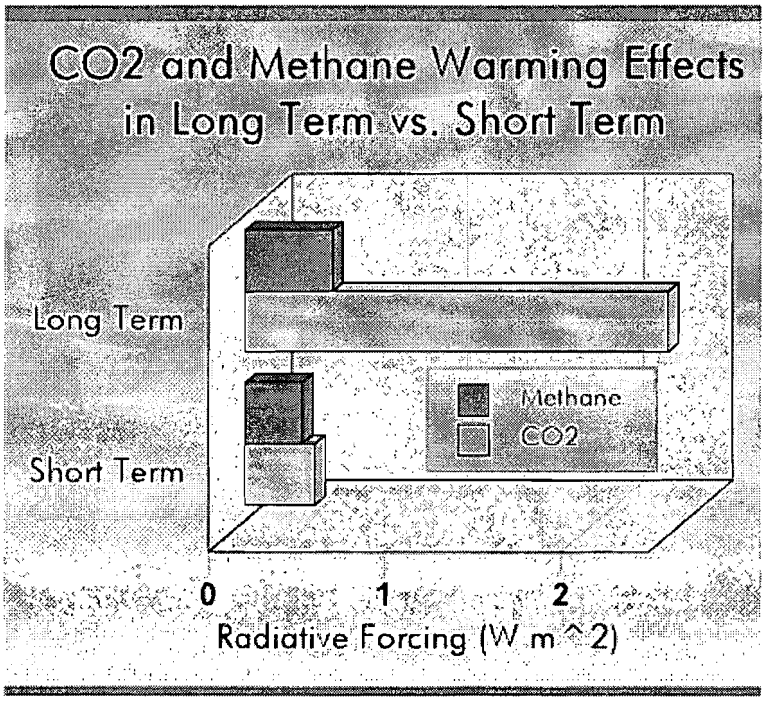

Figure 2. Integrated climate impacts of year 2000 total global emissions of $CO_2$and Methane on radiative forcing evaluated over long-term (100-year) and short-term (20-year) time horizons. "Radiative forcing" is a term used to describe the warming effect of a greenhouse gas in the atmosphere. It is the difference between the incoming radiant energy from the sun and the outgoing radiant energy in the atmosphere. Source: IPCC Fourth Assessment and Center for Competitive Waste Industry.

APPENDIX B

SOME ESSENTIAL ELEMENTS OF AN EFFECTIVE LANDFILL GAS EMISSIONS CONTROL REGULATION

Preface. The existing landfill air rule effectively leaves the detail of LF gas management design and operation to the landfill owner. Because there is no reliable system to monitor emissions, effective control of the pollutants in landfill gas requires the use of landfill management practices designed to minimize the generation and release of problem pollutants. Some of those better practices cost more to implement, and thus are often ignored.

Of course, the most effective way to avoid release of landfill gas pollutants is to divert decomposable organic wastes for responsible treatment elsewhere. As long as landfills continue to accept organic wastes, and until the organic wastes buried already are fully decomposed, landfill gas will continue to be a problem, and much better regulation of the management of landfills and landfill gas will be essential.

The Sierra Club's Landfill Gas to Energy Task Force has reviewed the technical literature, most of which is produced by the industry itself and by its consultants. The Task Force has identified those industry-recommended practices its members believe can help to improve gas collection and reduce gas emissions. They are presented here as examples of the kinds of improved practices that are supported by some in the industry and that could be viewed as a useful starting point for the development improved landfill gas regulations.

The new requirements should apply to all landfills large enough to capture gas effectively, unless a case specific showing is made that a specific requirement is not technically feasible at a particular site (independent of cost considerations), or at a separable part of that site. Before any such determination is made, adequate notice and a meaningful opportunity for public comment must be provided.

These examples are offered to assist activists and staff who are attempting to address relevant issues. They are examples based on the industry literature that highlight important regulatory and management issues, but they are not necessarily considered to be sufficient by the Sierra Club. The Sierra Club has not yet developed policy recommendations in this area, but may choose to do so in the future.

These examples are generally directed at two strategies for reducing fugitive methane emissions. The first is direct capture of more of the gases generated, and the other is reduced methane generation, especially in the near term.

INCREASED GAS CAPTURE

1. **Early Horizontal collectors.** Landfill operators should be required to

install horizontal gas collectors in active waste-receiving areas with each elevation change (usually daily) prior to installation of vertical gas wells, but delay operation of the collectors unti l there is sufficient depth and cover to apply vacuum. [SCS, A-1 and A-3 (p. 4).] Horizontal collectors should be spaced to overlap each pipe's zone of influence when negative pressures are applied under conditions without a low permeability cover. Co-utilizing horizontal collectors for gas collection and liquid recirculation should be prohibited.

> Background. *Gas is traditionally collected with rigid vertical pipes, which are perforated, and drilled into the waste mass for most of its depth. The pipes are connected with headers and lines to a fan that pulls gas from the surrounding waste mass. However, substantial gas is released before these vertical pipes can be made functional, and flexible horizontal pipes are a means to collect some of this early gas to reduce fugitive emissions.*

2. **Vertical well density.** Landfill operators should be required to reduce the spacing of vertical wells from the current 300' to 350' apart common today to not more than 150'. [SCS, A-2 (p. 4).]

> Background. *The effectiveness of gas collection systems is in significant part a function of how close the gas wells are spaced: in general, the closer they are to each other, the more gas will be collected. When gas collection began in the mid 1990s, wells were commonly about 150 feet apart. In more recent years, common spacing for gas wells has spread to 300-350 feet apart. The result has been less effective gas collection.*

3. **Multiple wells in same bore holes.** Landfill operators should be required to install multiple vertical wells for different depths in the same bore hole in order to allow for distinct and optimal negative pressures at each level. [SCS, A-5, at p. 4.]

> Background. *Landfills can often be 300 feet deep. With increasing depths, the density of the surrounding wastes increase as well, and that means more vacuum forces are needed to pull gas from the same distance from the collection pipe. However, if the same force needed to draw gas at the lower depths were used in higher depths, air would also be drawn from the surface. When more than 5% oxygen mixes with methane in landfill gas, dangerous conditions are created, which necessitates turning down the system to avoid fires and explosions, but reducing collection effectiveness as well.*

4. **Leachate collection system to gas collection system connection.** Landfill operators should be required to connect the gas collection system to the leachate collection system at the high side on bottom of landfill. .[SCS, A-4 (p. 4).]

> Background. *Landfill gas follows the path of least resistance, which can be at the bottom of the landfill through the pathways created by the leachate lines and their gravel packs intended to remove leachate. Good practice is to collect*

gas from the leachate take outs to prevent it being released into the atmosphere.

5. **Multiple seals around bore holes.** Landfill operators should be required to utilize at least three sets of seals, including bentonite, clay and well bore seal, where collection wells penetrate the final composite cover in order to minimize air infiltration and maximize vacuum forces. [SCS A-6, at p. 5.] Methane leak rates around the seals at each well head should be checked at least monthly during typical atmospheric conditions and, if methane levels are significantly above background, the seals should be repaired. [40 CFR §60.755(c)]

Background. Ironically, much of the gas that escapes does so through the seals around the gas collection wells. Continuing subsidence at the surface cracks the original seals, and they need continuing maintenance to prevent leakage.

6. **Enhanced monitoring.** The procedures intended to detect leaks provided under 40 CFR 60.755(c) should be replaced with optical remote scanning (ORS) over all surface areas of the landfill, including but not limited to areas around gas collection wells and side slopes. EPA needs to develop standards for the method.

Background. The existing method for assessing performance of the gas collection system is based upon checking quarterly for methane concentration levels at the surface at 100 foot intervals on a grid. This method is often called the "sniff test." Because gas escapes from landfills with a final cover primarily through tears and cracks in the plastic sheet, most leaks are probably missed. This deficiency is exacerbated when the area near well seals, where there most often are leaks, is avoided. New scanning systems are more effective at assessing methane levels across the flat, horizontal surface. It is important to improve the capability of optical systems for assessing leaks on the side slopes where more leaks occur than through the top face.

REDUCED METHANE GENERATION

7. **Installation of vertical collectors, maximum slopes and final cover.** Each landfill cell should be designed to reach final grade in not more than two years from first waste emplacement. The active vertical collectors should be installed at that time and connected with headers to a vacuum system. Not more than one year after reaching final grade, a final low permeability cover (less than 1×10^{-5} cm/sec.) should be installed. If a geomembrane is used to provide a low permeability barrier, exterior side slopes should not be steeper than 4:1 to facilitate stabilization of the clay and dirt layers in a final cover over the underlying geomembrane. [Oonk, at p. 11; SCS C-1 and D-6, at p 6-7; 56 Federal Register 104, at p. 2447.]

Background. Although the original proposed landfill gas management rule (1991) would have required installation of gas collection within two years, the final rule (1996) relaxed that requirement to five years in order to

accommodate the industry's desire to build larger mega-fills that often required longer to reach final grade. This created a conflict between the goals of optimizing gas collection and optimizing the operator's financial scale efficiencies. Similarly, several states have found that the industry standard used for the steepness of the side slopes (3:1 or three horizontal units to 1 vertical) cannot be stabilized in part because the overlying dirt slides off the slippery plastic cover sheet. At least three states have required more gradual side slopes (4:1) to help stabilize the dirt cover.

8. **Delay any recirculation of leachate.** Leachate recirculation should be prohibited, at least until after an expendable low-permeability cover and active gas collection system have been installed. [Augenstein, at p. 4.]

Background. *In order to induce settling, which enables the landfill owner to resell space for disposal a second time, operators have been recirculating leachate. Increased moisture levels accelerate decomposition and increase compressive forces, but the result is also increased gas generation and higher methane concentration levels during the early period of landfill operation when gas collection either is not yet installed, or is not yet fully functional. In addition, if there is no low permeability cover, the gas collection system vacuum will pull air from the surface along with methane from the surrounding wastes. Too much oxygen infiltration results in a flammable mixture. To avoid fires, the vacuum pressures must be reduced to avoid pulling air from the surface. However, this also means that the negative pressures fail to reach horizontally as far, leaving more areas of the landfill uncontrolled.*

9. **De-water flooded vertical wells.** In addition to monitoring the composition of gas collected for oxygen and nitrogen intrusion landfill operators should be required to monitor gas volumes to detect gas wells that may be flooded, and to pump out flooded wells. [SCS A-8, at p. 5.]

Background. *Moisture in landfills, especially prior to installation of the final cover, can flood the gas collection piping, which compromises the ability to collect gas. Monitoring for reduced gas flows as an indicator of this condition, and then remedying the situation is important to a properly functioning gas collection system.*

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Appendix C - Annotated Bibliography References and Contacts

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NOTE: Documents listed here were consulted by the Task Force during the course of its review. Listing does not constitute an endorsement of their contents or conclusions. Items marked with double asterisk (**) are available on the Clubhouse web site at: http://clubhouse.sierraclub.org/people/committees/lfgte/

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[*This technical summary provides the overview of contributions of methane and waste management activities to global greenhouse gas emissions and discusses mitigation policies in general terms. More detailed discussion of landfill gas is in the following document.] Available for download at: http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-ts.pdf*

IPCC, Fourth Assessment Report, Chapter 10: Waste Management, Section 10.5.1 Reducing landfill CH4 emissions, 2007. [*This section discusses emission estimates and mitigation methods for landfill gas and provides the basis for the lower end of the capture ratio cited in the Task Force Report; IPCC reports can be downloaded from the IPCC web site.] Chapter 10 on Waste Management available for downloading at: http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter10.pdf*

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*two instruments that are the basis of a new fugitive gas monitoring method.]***

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Turning a Liability into an Asset: A Landfill Gas-to-Energy Project Development Handbook (EPA 430-B-96-004(September 1996)

Office of Air Quality Planning and Standards and Office of Air and Radiation, *Emission Factor Documentation for AP-42, Section 2.4, Municipal Solid Waste Landfills* (Revised 1997)

[These are the primary EPA documents that reference landfill gas emissions.]

Persons Consulted

Susan Thorneloe, EPA Office of Research and Development, re: monitoring methods. *(mainly she just sent us references and did not answer direct questions.)*

Larry Bingham. He was on the original engineering team that designed the first landfill-gas-to-energy system at the Los Angeles County Sanitation District's Palo Verde landfill in 1974, and who operated LFGTE systems for many years.

OTHER ONLINE RESOURCES

http://www.epa.gov/landfill/ & http://www.epa.gov/methane/scientific.html
[*These sites may be useful for background information on landfill methane and also to*

understand how EPA is actively positioning LFGTE as a solution (hence the need for Club action on this issue).

http://www.ilsr.org/pubs/pubswtow.html & http://www.stoptrashingtheclimate.org/
The bibliography (end note) list in the Institute for Local Self Reliance report "Stop Trashing the Climate" includes hundreds of entries, many of which re-enforce the conclusions reached by the Task Force.

www.biocycle.net 10TH ANNUAL BIOCYCLE CONFERENCE ON RENEWABLE ENERGY FROM ORGANICS RECYCLING
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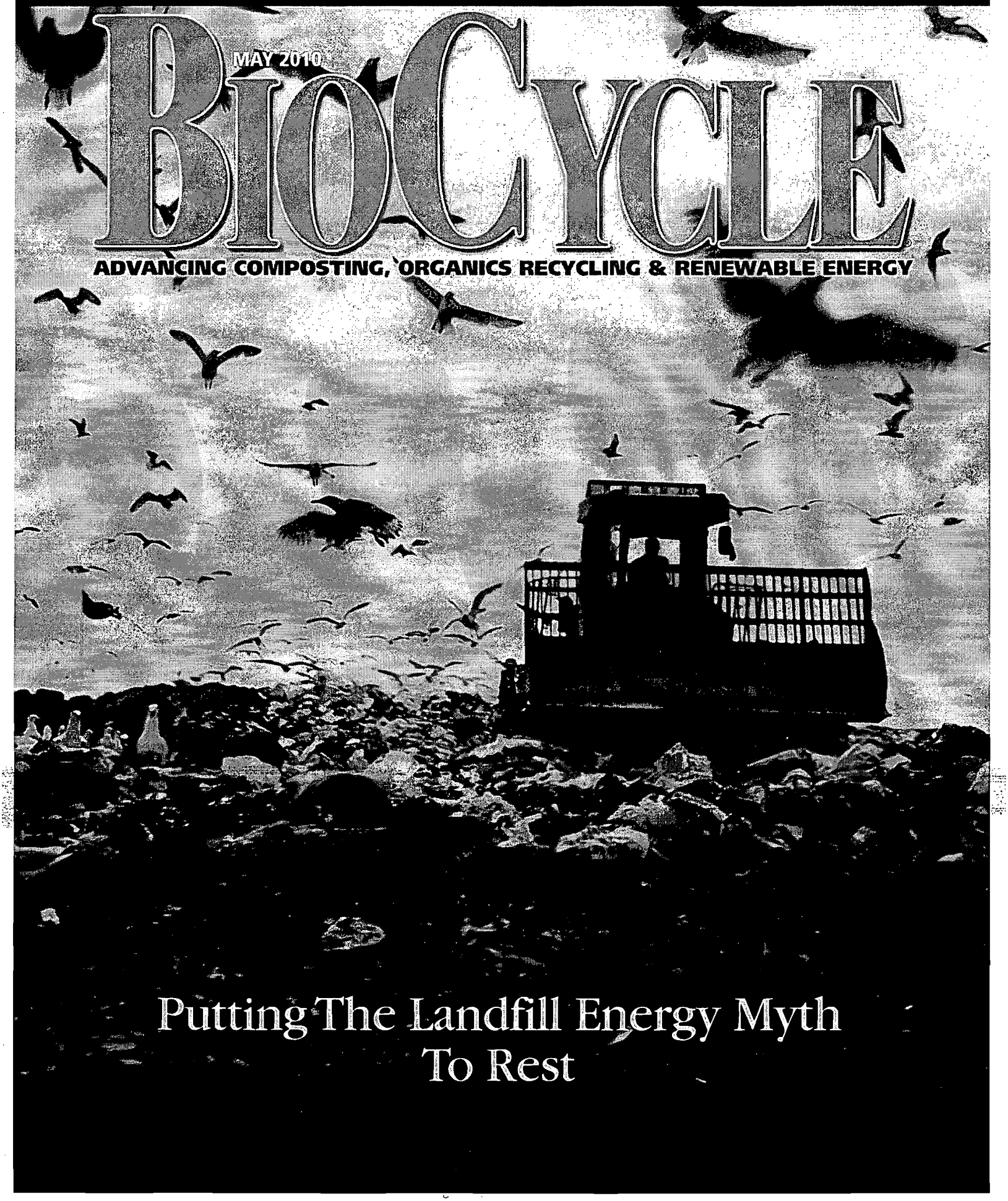

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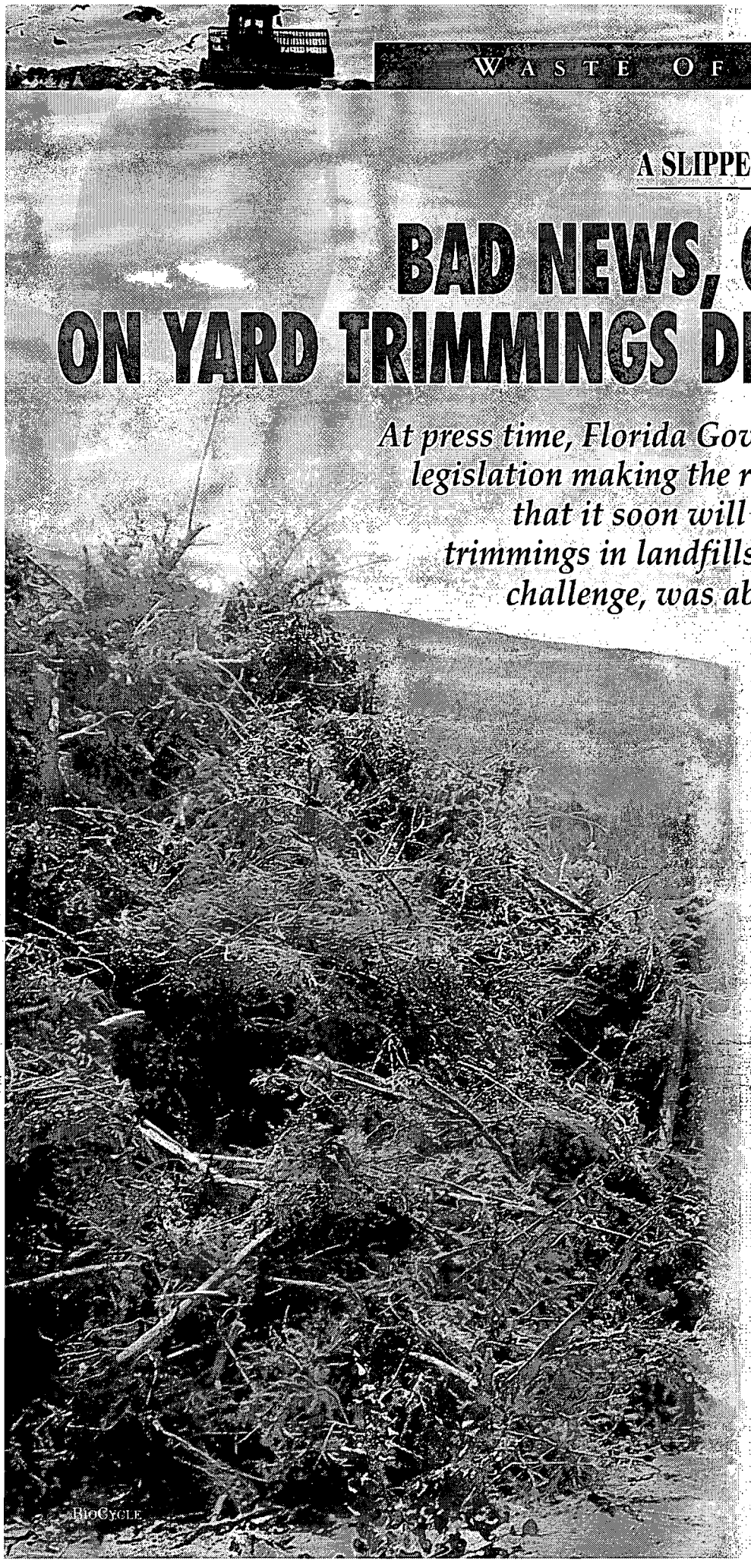

A SLIPPERY SLOPE

BAD NEWS, GOOD NEWS ON YARD TRIMMINGS DISPOSAL BANS

At press time, Florida Governor Crist had not signed legislation making the repeal official, but odds are that it soon will be legal to dispose of yard trimmings in landfills. Georgia, facing a similar challenge, was able to keep its ban in place.

Dan Sullivan

TWO OF FOUR states with pending legislation to repeal longstanding bans on landfilling yard trimmings have decided their fate. In Florida, a 20-year-old disposal ban on green waste was rescinded with the passage of HB 569 under the auspices of creating more methane for capture as renewable energy. In Georgia, controversial language that would have allowed yard trimmings in lined landfills that had methane capture systems was stripped out of HB 1059 before it passed the same day (April 29). The final bill allows these types of landfills to accept source separated yard trimmings for processing into compost and mulch. The new law also allows landfills to set up recycling operations for other separated materials such as plastic and glass after undergoing a minor permit modification.

Similar legislation to repeal decades-old bans on landfilling yard trimmings died in committee in Michigan in 2009 and at press time had not been reintroduced (a sponsor of that bill did not return phone calls for this story). And in Missouri, the composting industry — which depends heavily upon the availability of yard trimmings — is bracing for an eventual fight. "This is all about tip fees — I don't care what anybody says," suggests Patrick Geraty of St. Louis Composting. Geraty listed a litany of reasons for shrinking landfill revenues across the country, beginning with a shift 20 years ago toward composting municipal yard trimmings, to the green building movement and a greater tendency to recycle construction materials, to the current slow economy. "Land-

fills are trying to get some of that revenue back," he says.

FLORIDA REPEAL

Josh Phares of Capitol Solutions in Tallahassee, state hill lobbyists for the U.S. Composting Council (USCC), called Florida's move a step in the wrong direction. "Millions of dollars of private and public money went into that legislation," Phares said of the 20-year-old ban on yard trimmings disposal. In the footsteps of that legislation, he says, 264 companies have set up shop as composters and invested heavily in infrastructure. While supporters of the Florida repeal claim that more yard trimmings in Class 1 landfills would allow them to capture more methane, the fact is that landfills will now be able to capture the tipping fees that — while the ban was on — had gone to composters. "We're going to ask the governor to veto it," he says of the letter his boss, Patrick Bell, would be drafting on behalf of the USCC.

Florida Governor Charlie Crist, who recently declared his switch from both the GOP to the independent ticket as well as from the governor's race to a bid for U.S. Senate, may have other things on his mind. He is on record as saying he'd consider a special legislative session to deal with the state budget and other pressing issues that had not been resolved when the regular session ended May 3. Crist's own mandate that his state achieve 75 percent recycling by 2020 led to drafting of other legislation that spelled out ways in which that goal would be accomplished.

Language supporting the repeal did not make it into HB 7243, Florida's recycling bill that ultimately passed. But it remains to be seen whether a provision of that bill that gives recycling credit — one ton for each megawatt-hour produced — to renewable energy facilities using solid waste as a fuel will include landfill gas capture, as ultimately interpreted by state regulators, or whether that language will apply only to waste-to-energy combustion facilities. While the recycling bill "encourages" local governments "to recycle yard trash ... into compost," language was removed from the bill mandating that counties and municipalities within them compost at least five percent of all organic waste materials they generate.

"We believe that the establishment of yard waste processing facilities in the state was a positive result of the initial ban," says Chris Snow of Hillsborough County (Florida) Solid Waste Department, who had testified against the legislation to repeal the yard trimmings ban. "This would impact, we believe, the better and higher use for yard waste than going into the landfills, even if they had the potential for gas generation and capture, due to the inefficient manner in which it is done. We did not support changing this 20-year-old law."

Opponents of the landfill ban repeals have said that landfill gas capture is not only inefficient but that methane is a greater contributor to greenhouse gases than CO_2 by a factor of 23. "In general, we believe that the decision to place yard clippings into landfills is inconsistent with our updated solid waste policy seeking the highest and best use of solid waste materials," says Matt Flechter, Recycling and Composting Coordinator for the Michigan Department of Environmental Quality. "We don't think placing yard clippings in the landfill is their highest and best use. There is plenty of methane that should be captured from landfills without the addition of yard waste. Let's capture the methane that's already being generated without sending additional organic waste to the landfill."

Others were not so reserved. "It's scientifically and technologically completely ungrounded," says JD Lindeberg of Resource Recycling Systems in Ann Arbor, Michigan. Lindeberg says his own scientific testimony about greenhouse gases when repeal legislation was being discussed had paled in comparison to that of distraught composters who had sunk their life savings into their businesses post yard trimmings ban. "It's bad politics, it's bad for the environment and it's taking an industry that's been creating compost and topsoil and that has begun to thrive and smacking it down in order to give money to the large landfill industry, take it out of state and take it to Wall Street. I think three strikes and you're out — dumb, dumber and dumbest."

GEORGIA'S BAN PRESERVED

Georgia not only shares a border with Florida, it shared pending legislation that at one point also threatened that state's ban on landfilling yard trimmings. Although they were both decided the same day, the outcomes were vastly different. "Our goal is still to keep organics and yard trimmings out of landfills and toward their highest or best use," says Mark Smith, Land Protection Branch Chief for the Georgia Environmental Protection Division (EPD). While Georgia's ban on yard trimmings in lined landfills — by acreage the most common type of landfill across the state — dates back to 1996, the ban has never applied to construction and demolition (C&D) or inert landfills. Some in the compost industry say this allowance alone has made it difficult for Georgia composters to compete. But considering the alternative that HB 1059 had one time proposed — opening up lined landfills to municipal green waste — the compost community within the state seems at peace for now with the bill as passed.

"We can live with it," says Wayne King of ERTH Products, a Georgia composter and president of the USCC. "It allows composting at landfills, and other recycling facilities at landfills, for beneficial reuse. They did not repeal the ban on yard trimmings going into the landfill." King says state environmental officials had expressed confidence they could monitor such activity so that compost and mulching operations at landfills led to sellable, usable products

In Florida, 264 companies have set up shop as composters and invested heavily in infrastructure.

that would benefit Georgia's soil and water resources. He did express concern that the source separated green waste, or the resulting compost or mulch, might be allowed for landfill cap and cover, which could effectively circumvent the ban if such practices became common.

"I would never want to say never," Georgia EPD's Smith says, suggesting that if there was an acute odor problem or compost was being substituted for another specific raw material to bolster surface vegetation, such practices might be permissible on a case-by-case basis. "But we're not looking for significant quantities to be disposed of in the waste stream," he says.

"Our goal is still to keep organics and yard trimmings out of landfills and toward their highest or best use," says Mark Smith of Georgia EPD.

John Skinner, Executive Director of the Solid Waste Association of North America (SWANA), returned a call just as this issue was going to press. Skinner says that SWANA "conforms with the hierarchy that diversion into composting is a higher and better use," but explains that the association is opposed to mandates that require yard trimmings not go to landfills. Blanket bans can have unintended consequences such as haulers simply going over the border to another county or state, he says. "What you need to do is invest in compost infrastructure and make sure it's available at a reasonable cost. You may not even need the ban if the infrastructure is there."

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TIME TO MOVE ON

PUTTING THE LANDFILL ENERGY MYTH TO REST

Science and nature, as well as common sense, prove that "single-use" organics management via landfilling is a misuse of national resources.

Sally Brown

THE purpose of a landfill is to dispose of waste, plain and simple. That is the story. People have had landfills of some sort or another since there have been people and there has been waste. Landfills are where you put stuff when you want it to go away, when you no longer have any use for it. When I was young, I never thought about landfills except when we took the Belt Parkway to visit my relatives in Brooklyn. The big landfill was on the left, with the Starrett City apartment buildings on the right. Now that I work with organics and climate change, not a day goes by that I don't think about landfills.

Landfills are becoming a topic of more general discussion because of what goes into them and what happens to the stuff once it is there. This is part of a larger process of questioning the value of what we have traditionally considered to be waste materials and understanding the implications of different management strategies for these materials. As part of this process, the scientific community, politicians, businesses and the general public are hearing mixed messages on what are good things to do with waste materials.

Part of the reason that these messages are mixed is that we are at the beginning of a process to understand how to manage materials in a carbon-based economy where resources are limited. We are coming into this process as a culture that has always had landfills and a waste industry that has effectively and profitably managed them. Our rules and regulations for managing waste materials have focused on public health. Requirements to manage materials are centered on the goal of minimizing the potential for any negative impacts upon that public health. Now we have to consider waste materials using multiple lenses, including greenhouse gas emissions, demand for renewable energy and a growing scarcity of natural resources.

This new focus has led to a reexamination of the benefits/detriments of traditional waste management. Landfills have become more than a place to dispose of waste. Depending on one's perspective, landfills are now generally viewed as: 1) A place to produce green energy and sequester carbon or 2) An inappropriate way to dispose of resources and a source of greenhouse gases. It is likely that neither perspective is completely correct or completely off base.

In order to understand whether landfilling is a viable way to manage residuals it is important to understand what the residuals are, the potential benefits associated with these materials and how to best realize these benefits. It is also important to understand how landfills function and, relative to that understanding, what conditions exist within and at the surface of a landfill. The focus of this discussion will be on the organic components of solid waste. For cans and bottles, an excellent discussion of benefits associated with recycling is provided at US EPA WARM (http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html).

WASTE CHARACTERIZATION

Waste characterization studies have been conducted to figure out what type of organics actually go into landfills. Waste going to a landfill will vary based on location, season and available diversion programs. The US EPA WARM model provides a breakdown of different components of MSW (municipal solid waste) by percent weight. Table 1 provides generation and disposal numbers for

Table 1. MSW generation and disposal — organic waste components (USEPA, 2009)

	% of Total Generated	*% of Total Discards*
Paper & paperboard	31	20.7
Yard waste	13.2	7
Food scraps	12.7	18.6
Wood waste	6.6	8.9

Table 2. Washington State biomass inventory data for King and Yakima Counties (dry tons)

	King County	Yakima County
Corn stover		10,200
Mint slugs		36,700
Hops residue		4,300
Dairy manure	24,400	115,200
Cattle manure	4,700	43,850
Horse manure	26,900	30,200
Poultry manure	300	22,700
Land clearing debris	70,000	2,400
Cull fruit		17,000
Apple pomace		10,100
Grape/fruit pomace		11,000
Cheese whey	2,400	11,300
Beef processing	600	7,000
Animal mortalities	150	1,200
Fish waste	650	
Food waste	67,000	7,100
Yard non wood	147,000	22,000
Other organics	15,500	800
Paper	729,000	78,500
Grease	11,500	1,400
Biosolids	30,000	2,200
Total (dry tons)	1,130,100	435,150

the components (organic fractions) discussed in this special report.

It is best to look at these numbers as gross approximations. For areas where yard trimmings are accepted into landfills, this number is likely to be significantly higher. The number will also be higher in places with long growing seasons. In areas with successful yard trimmings diversion programs, food scraps and soiled paper are likely to make up a significantly larger fraction of MSW. For example, a waste characterization study done in California found a higher food waste content (14.6%) and a low leaves and grass content (4.2%) (Cascadia Consulting Group, 2004). The Washington State Department of Ecology in cooperation with Washington State University completed a statewide biomass inventory (Frear *et al.*, 2005). Inventories for King and Yakima counties are shown in Table 2. King County is the most urban county in the state, and Yakima is a primarily rural county with large dairy and tree-fruit industries.

ORGANIC MATERIALS CHARACTERISTICS

Now that you have some idea of what the different components of organic waste are, the next step is to describe in greater detail the characteristics of these materials.

Food wastes are generally wet materials. A ballpark moisture content for food scraps is 70 to 80 percent. The amount of soiled paper included in the food scraps will influence the moisture content as paper tends to be dry. Things like spoiled lettuce on the other hand, are very wet. One way to characterize food waste is to use the U.S. Department of Agriculture (USDA) food pyramid, which divides foods into the following categories: Grains; Vegetables, dry beans and peas; Fruits; Milk group; Meat and bean group; Oils; Solid fats and sugars. The chemical composition of a range of foods is also available from the USDA (http://www.nal.usda.gov/fnic/foodcomp/search/). The basic chemical content of select examples from each of the food pyramid groups is shown in Table 3.

We are at the beginning of a process to understand how to manage materials in a carbon-based economy where resources are limited.

Food scraps generally have high energy values (just look at that Almond Joy), and food scraps from a balanced diet will have high nutrient value (see the protein content). This is why, after all, we eat food in the first place. Different studies have characterized food waste from different sources in Korea, Germany and India. Moisture content in these studies varies from 74 to 90 percent, the ratio of volatile solids/total solids ranges from 80 to 97 percent and the C:N (carbon to nitrogen) ratio varies from 14.7 to 36.4 (Zhang *et al.*, 2006). A study of source separated municipal organic waste from cities in Denmark tested the importance of dwelling type, season and collection system on waste composition (Hansen, *et al.*, 2007). Fat and protein content were consistent across all parameters. The calorific value of the material ranged from 19.7 Mj/kg to 20.8 Mj/kg organic fraction of dry matter.

Yard trimmings vary in content by both season and location. In general, the wetter material in yard trimmings will also have the highest nutrient content. Take grass for example. A chemical analysis of rye grass is shown in Table 4. This is why ruminant animals like cows eat grass — it is good for them and low in fat.

Trees, wood and branches on the other hand are not so good as a food source. The chemical composition of wood will vary based on the type of tree, but wood generally consists of about 40 percent cellulose, 20 to 30 percent hemicellulose and 25 to 30

Table 3. Basic chemical content of various foods from USDA food pyramid

Food Group	Water	Carbohydrate	Protein	Fat	Energy
	%				kcal per 100 g
Fruit					
Apples	86	13.8	0.26	0.19	52
Vegetables					
Broccoli raw	90.7	5.25	2.98	0.35	28
Cereal					
Rice (cooked)	73	23.5	2.32	0.83	112
Meat					
Pork (cooked)	51.8	0	21.9	25.4	323
Dairy					
Cheddar cheese	36.75	1.28	24.9	33.1	403
Fats					
Olive oil	0	0	0	100	884
Sweets					
Almond Joy	8.2	59.5	4.1	26.9	479
Prepared foods					
Stouffers salisbury steak in gravy + macaroni and cheese	80	7.47	6.4	5.2	102

Table 4. Chemical analysis of rye grass (Mähnert et al., 2005)

	Total Solids % Fresh Matter	Volatile Solids % TS	C:N	Crude Protein	Crude Fiber % TS	Crude Fat
Perennial ryegrass	17.6	90.1	16.4	14.7	24.8	2.1

percent lignin. The energy value of wood is high, about 73 kcal per 100 g or 13 million BTUs/ton. The moisture content of wood will vary from >50 percent for green wood to <25 percent for older, seasoned or dead wood. Wood is hard to digest, with very high C:N ratios typically greater than 100:1 (and those splinters would wreak havoc on your intestines).

Paper, being made from wood, is similar to wood in energy value and with a generally lower moisture content. To make paper, wood is pulped to remove lignin, leaving primarily cellulose and hemicellulose. It also has a low nutrient content.

So this is the background you need to understand what is in these organics. The next step is to understand what they are good for (i.e., their value).

BENEFITS OF ORGANICS

Two components of organic residuals have value: the carbon content and the nutrient content. For this analysis, I am not considering the potential to utilize these organic residuals to make new products, e.g., making animal feed from food scraps and particleboard from wood waste.

The carbon content has value as an energy source and as fixed carbon. Remember that all of these organics we are talking about derive from plant material, with carbon taken from the atmosphere as CO_2 and transformed into proteins, fats and lignin beginning with photosynthesis. This is the same starting point for fossil fuels and coal. Thousands and thousands of years ago, the oil that you put in your gas tank and the coal that makes electricity started out as leaves and branches from photosynthesis.

We are concerned about climate change because we have released more fixed carbon than we should have in balance with the annual natural process of plant growth, carbon fixation and decomposition. Without us interfering, this material would be part of the shorter-term carbon cycle, eaten by other creatures and turning back to CO_2 to be fixed through photosynthesis for the next time around. We can use this carbon for energy and so reduce our dependency on fossil and coal reserves, or we can attempt to keep this carbon fixed and sequestered. That is the simple version. In an ideal world, we can do both: get energy from the carbon and use the remaining material to sequester carbon and even fix more through enhanced plant growth.

Nutrients in the organic residuals have value for plants and animals. These mineral nutrients (here meaning not carbon-based) are required by all living beings. Plants get them from soil and we get them from plants. The nutrients in these residuals can potentially be separated from the carbon and recycled. However, with our current level of technology, we can only use these nutrients by applying the residuals to soils where the nutrients will become available for plant uptake.

The nutrient-rich organics, including food scraps and nonwoody yard trimmings, will contain a well-balanced set of nutrients. These nutrients are important to recycle for several reasons; the two big ones are nitrogen (N) and phosphorus (P). Nitrogen, although plentiful in the atmosphere, is energy intensive to convert to a mineral form. Phosphorus, required by plants and animals in large quantities, is normally derived from phosphate rock, and our reserves of phosphate rock are due to run out in the near future. Before we mined phosphorus from rocks, the biggest commercial source was from bird poop or guano. There would have to be a lot of birds out there to meet current demands for this nutrient.

TAPPING THE ENERGY BENEFITS

So what have we learned so far? A wide range of organic residuals exist, and they vary based on energy content, nutrient content and water content. These variables also tell us the best things to do with these materials. The energy content (normally expressed in BTUs) is related to the carbon content. The best way to capture this energy is based on the moisture content of the materials. The nutrient content gives an indication of the value of the material as a fertilizer. Approximate BTU, moisture and nutrient contents of the different residuals being discussed in this report are listed in Table 5.

So here you are, looking at that pile of organics and starting to salivate because of the BTU value. You are seeing a mountain of green energy instead of food scraps, oily pizza boxes and wood. Three ways that you can turn that pile of organics into renewable energy are:

- Combustion
- Anaerobic digestion
- Pyrolysis/gasification

Combustion

Combustion is an alternate term for burning stuff. Standard combustion reactions require oxygen and convert carbon bonds in the organic material to heat energy. Combustion reactions do not take place if there is too much moisture in the substrate. Any moisture in the organics has to be evaporated prior to or during the combustion reaction. Water has a high specific heat, meaning that a lot of energy is required to transform the water into steam. In plain and simple terms, *it is not energy efficient to burn wet stuff.* If you use high

Food scraps generally have high energy values (just look at that Almond Joy); food scraps from a balanced diet will have high nutrient value.

moisture materials in combustion reactions, a large portion of the energy in the feedstocks is spent evaporating the water.

Combustion is a chemical reaction. Carbon bonds are broken, releasing carbon as CO_2. Other elements also will be transformed to gases during combustion. Any nitrogen in the feedstocks will be lost as nitrogen gases during combustion. Elements that won't volatilize will be left as ash residue. The percent ash will vary based on the feedstock but can range from 10 to 30 percent of the dry weight of the original material. The feedstock may have value as a soil amendment. Phosphorus won't volatilize, so the ash will contain all of the phosphorus that was in the feedstocks.

Trace elements such as calcium, cadmium, zinc and lead can also be concentrated in the ash. If concentrations of some of these are high enough (lead and cadmium, for example) the ash may be considered a hazardous waste. Other elements, like zinc and calcium, are necessary plant nutrients, so the ash may have value as a fertilizer.

Table 5. Energy, moisture and nutrient content of various organic residuals

	BTU	*Moisture*	*Nutrients*
Paper & paperboard	High	Dry	Low
Yard waste	High		
Woody material	High	Medium to dry	Low
Green waste	High	Very wet	High
Food scraps	High		
Fats, oils and grease	Very high	Wet/dry[1]	Low
Vegetables and meats	Pretty high	Very wet	Very high
Wood waste	High	Medium to dry	Low

[1]FOG is a liquid, can contain contaminants, often in the liquid waste stream, however, in a pure state it can either be burned or digested thus could be characterized as wet or dry.

Combustion reactions also produce emissions. These emissions include particulates and can also include nitrogen oxides (NOx) and sulfur oxides (SOx). Burning high sulfur coal was the source of acid rain before regulations required emissions controls to limit release of NOx and SOx from these facilities. Nitrous oxide can also be released from combustion reactions that include high nitrogen substrates.

Bottom Line: Combustion is the most efficient way to generate energy from dry feedstocks with low nutrient content.

Anaerobic Digestion

Anaerobic digestion is a microbially mediated transformation of fixed carbon compounds to methane (CH_4) and CO_2 that takes place in the absence of oxygen. This is a biological reaction, the goal of which is to provide energy for the microorganisms. The methane produced through anaerobic digestion is also known as biogas or natural gas. When landfills make energy from methane, they do this via anaerobic digestion. Anaerobic digestion is less efficient and much more finicky than aerobic digestion (how we eat). This occurs in three stages: hydrolysis, fermentation and methanogenisis.

Each of these reactions has its own byproducts and feedback loops. Hydrolysis reactions are chemical transformations of compounds that involve water and are carried out by extra-cellular enzymes. Fermentation reactions transform the products of hydrolysis reactions to fatty acids, alcohols, ammonia, acetate and hydrogen gas. Methane is produced during methanogenisis in one of three ways: Hydrogen gas can be oxidized (the oxidation is the energy source in the reaction) with the electrons from this reaction transferred to CO_2 to produce water and CH_4; acetate can be degraded into CO_2 and CH_4; and, finally, methyl groups are removed from methyl-bearing compounds and released as CH_4 with the released electrons transferred to hydrogen gas.

A wide variety of organics can be used as feedstocks for anaerobic digestion. A partial list of potential feedstocks is shown in Table 6 (Totzke, 2009). Studies have been conducted to determine the maximum CH_4 generation potential of these different feedstocks. The volatile solids (VS) content of each substrate is often used as a means to predict the maximum methane that can be generated by anaerobic digestion (Davidsson *et al.*, 2007; Hansen *et al.*, 2004). To determine volatile solids, you heat the substrate for a fixed amount of time at a fixed temperature. All organic carbon that can transform from solids to gas during this process is defined as the volatile solids (VS).

While VS defines the maximum amount of methane that can be generated from a substrate, measured methane concentrations from anaerobic digestion often fall below the predicted maxima. Hansen *et al.* (2004) used lab-scale digesters to measure CH_4 generation from different components of household food scraps; paper bags were included. Substrates for this study were blended in a high-speed blender, mixed with water to reach a solids content of about 10 percent and added to thermophilic reactors (55°C) along with microbial inoculum from an operating biogas plant. Methane was measured over a 50-day period with most of the gas released within the first 12 days. The reactors were stirred, but no attempt was made to adjust the environment in the reactors to maximize CH_4 production during the incubation. Results from the incubation are shown in Figure 1.

The authors suggest that the difference between optimal (theoretical) and observed CH_4 generation likely were related to negative feedback loops for each of the substrates. For fats, for example, accumulation of volatile fatty acids likely reduced the pH to below acceptable conditions for the methanogens in one of the reactors. For protein, excess ammonia buildup likely halted the reactions. Decomposition of paper bags was also below predicted values. Other studies have suggested that the

Table 6. Potential feedstocks (partial listing) for anaerobic digestion

Aircraft deicing fluid	Grease trap pump out
Beet pulp	Meat processing wastes
Brewery waste	Organic fraction of MSW
Cheese whey	Outdated beverages
Chicken manure	Outdated food products
Clarifier skimmings	Restaurant wastes
DAF float	Snack food waste
Processed algae	Thin stillage
Fermentation wastes	Various spent grains
Glycerin	Vegetable wastes
Grass clippings	

transformation of cellulose to sugars during hydrolysis is the rate-limiting reaction for high-cellulose materials such as paper bags and pizza boxes.

Many of these negative feedback loops can be controlled and adjusted to optimize gas production in dedicated digesters. For example, new digester designs include separating the fermentation reactions from the methanogen reactions to help control substrate pH. Research is being conducted to determine what microbes are able to digest what substrates and the best ways to keep these bugs "fat and happy." It is known that digestion works best at temperatures between 33°C to 55°C. Digestion can be carried out in both wet (solids content <10%) and dry (solids content <25%) facilities. Adding appropriate microbial inocula, maintaining temperatures and pH and adjusting organics loading rates also appear to be key factors for maximum energy production. A well-run digester can achieve VS destruction efficiencies of close to 73 percent in the mesophilic temperature range and 80 percent in the thermophilic temperature range.

Anaerobic digestion also produces a solid residual in addition to CH_4 and CO_2. This residual will contain recalcitrant carbon compounds and a suite of nutrients. The nutrient content of materials coming out of wastewater digesters generally has 5 to 7 percent N and 2 to 3 percent P. This will be similar to materials from manure digesters and dedicated food waste digesters. Land application of residuals from anaerobic digesters is a well-studied practice. These soil amendments have been shown to increase plant yields, provide plant available nutrients, increase soil carbon reserves, improve soil tilth (structure) and increase soil water-holding capacity (Cogger *et al.*, 1999; Cogger *et al.*, 2001; Evanylo, 2003; Khaleel *et al.*, 1981; Lindsey and Logan, 1998; Sukkariyah *et al.*, 2005, Wallace *et al.*, 2009).

Bottom Line: Anaerobic digestion is the best way to extract energy from wet feedstocks (Matteson and Jenkins, 2007). It is also a very good technology to derive energy from organics while conserving nutrients and a portion of the carbon for returning to the soil.

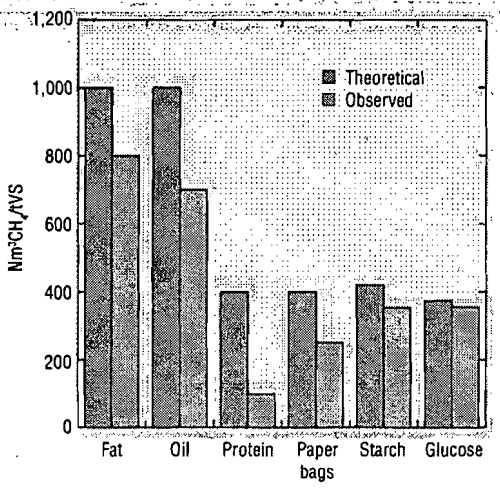
Pyrolysis / Gasification

Pyrolysis and gasification are two versions of a similar process. They have been receiving a lot of attention recently as an alternative means to treat organic residuals. Pyrolysis is a type of combustion reaction that takes place under conditions of limited oxygen and elevated pressure. This type of combustion produces three end products: char, a solid high-carbon material commonly known as charcoal; syngas, a synthetic gas rich in volatile carbon compounds that can be used for combustion and "synfuel"; and a liquid material also rich in carbon compounds that can be burned for energy.

The conditions in a pyrolysis reaction can be managed to optimize production of one of the three end products resulting in higher production of char, syngas or liquid fuel. Substrates for pyrolysis need to have low moisture content. Material should also be processed prior to the reaction to have similar particle size. Pyrolysis is a great concept because of the potential to produce three end products, each with an associated end use and value. It can be viewed as more of a transformation reaction that produces materials that can then be used for energy production. Drawbacks are the requirements for low-moisture substrates, homogenous feedstocks and high energy requirements to generate the three end products.

Bottom Line: Making syngas uses a substantial fraction of the energy contained in the substrates. If high net energy is your goal, pyrolysis is not the process for you.

Figure 1. Theoretical and observed CH_4 generation in lab-scale digester



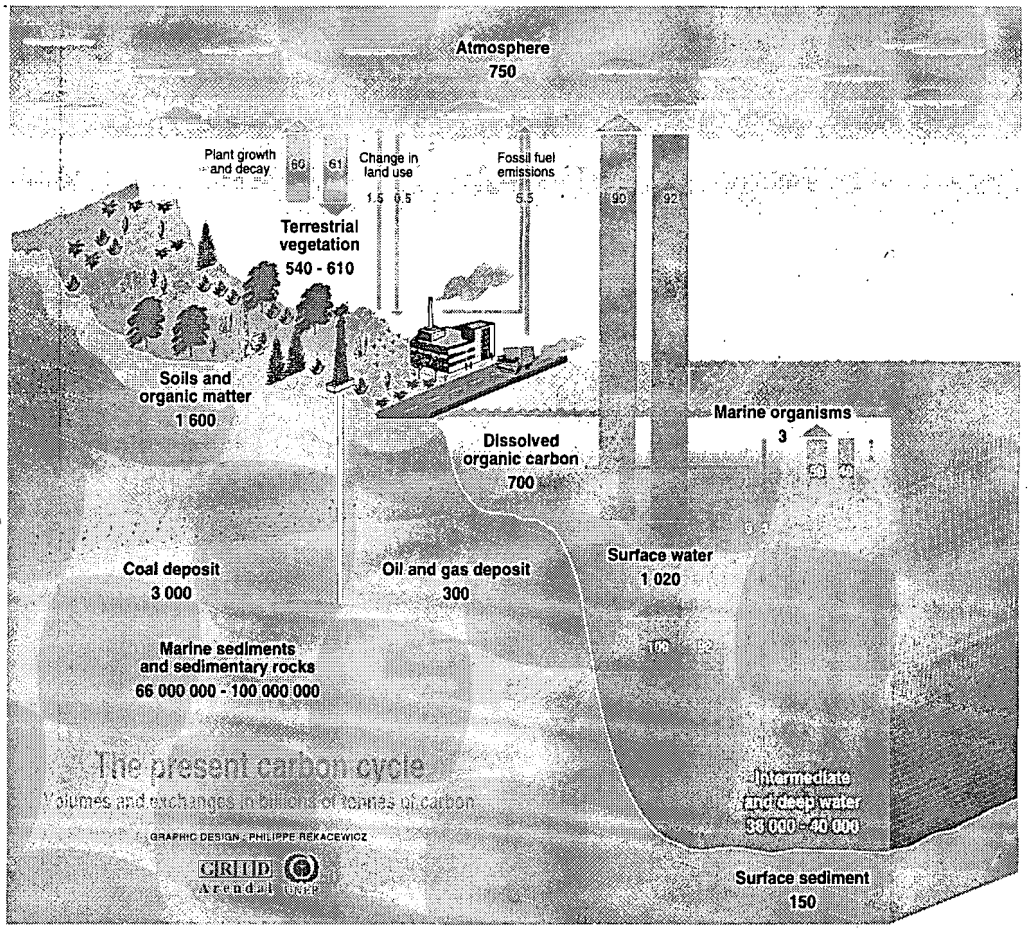
THE FIXED CARBON VALUE

Energy is not the only value of the fixed carbon in organic residuals. This is carbon taken out of the atmosphere. If this fixed carbon had stayed in the atmosphere, it would be floating around as CO_2. Each ton of carbon in the soil would make up 3.6 tons of CO_2 in the atmosphere. The whole goal of the Kyoto Protocol and our attempts to reduce carbon emissions are to keep carbon in a fixed form rather than releasing it back

We are concerned about climate change because we have released more fixed carbon than we should have in balance with the annual natural process of plant growth, carbon fixation and decomposition.

In plain and simple terms, it is not energy efficient to burn wet stuff. Anaerobic digestion is the best way to extract energy from wet feedstocks.

Figure 2. The present carbon cycle



Sources: Center for climatic research, Institute for environmental studies, university of Wisconsin at Madison; Okanagan university college in Canada, Department of geography; World Watch, November-December 1998; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change. UNEP and WMO, Cambridge press university, 1996.

Courtesy of UNEP/GRID-Arendal (http://maps.grida.no/go/graphic/the-carbon-cycle)

into the atmosphere. So your pile of organic residuals also presents an opportunity to do just that: keep it fixed here at or below the surface rather than releasing it as CO_2.

There are two ways to do this: 1) Bury the carbon in a tomb so it won't decompose; or 2) Add it to soils to enrich soil carbon reserves. The answer you are going to get here is from a chef turned soil scientist, so realize that my view on the best approach may carry some personal prejudice and bias.

First you have to realize how carbon cycles. Basically, carbon is stored on the earth in several different pools. The largest is the oceanic pool with 38,000 Pg of carbon (Pg = petagram = 1×10^{15} g = 1 billion metric tons), followed by the geologic pool (comprised of fossil fuel) containing 5,000 Pg (4,000 Pg of coal, 500 Pg of oil, and 500 Pg of gas), the soil/pedologic pool containing 2,300 Pg to 1-meter depth (comprised of 1,550 Pg of soil organic carbon (SOC) and 750 Pg of soil inorganic carbon or (SIC)), the atmospheric pool containing 760 Pg, and, finally, the biotic pool containing 600 Pg of live mass and detritus material (Batjes & Sombroek 1997). Figure 2 is an illustration of the carbon cycle, using information from various studies to generate the values. It is helpful as a visual aid when reading the next few paragraphs.

Carbon exchanges between each of these different pools occur at different rates. The geologic pool, for example, lived in isolation with only very small deposits from the atmospheric pool until we got into the picture. The biotic and soil pools, on the other hand, exchange carbon with the atmosphere all of the time. Ten percent of atmospheric carbon passes through terrestrial ecosystems each year — just like a cup of sugar between neighbors. This is almost ten times the addition rate from fossil-fuel burning (Raich and Potter, 1995). Mean residence time (MRT) for carbon in soils is generally in the range of 20 to 30 years (Lal, *et al.*, 1995; Post *et al.* 1992). If we tilt this balance just a little bit, leaving more of the carbon stored in soils and plants, we can make a major dent in atmospheric carbon concentrations. This is a very good thing. *This is the best, easiest and cheapest way we know to sequester carbon.*

It is important to realize that while a majority of the CO_2 in the atmosphere is from the fossil pool, a very significant minority is from the terrestrial pool. Activities like urbanization, deforestation and large-scale in-

dustrialized agriculture have depleted these soil carbon reserves. Our soils contain much less organic matter than they used to. The potential soil C sink is close to historic soil organic carbon losses, about 55 to 78 Pg (Lal 2004), which is approximately 7.3 to 10.3 percent of the current estimated atmospheric pool. *This means that our soils would drink up added carbon.* The fact that we have depleted this pool over time means that soils have the potential to be a large carbon sink. They are well below equilibrium carbon concentrations, and so much of the carbon that is added to them (assuming good management practices) will stay there.

For example, a graduate student and I recently surveyed a wide range of soils from farms, turf grass, highway right of way and mine sites. All of these soils had been amended with biosolids or composts anywhere from two to 30 years prior to our sampling. In the healthy soils (no-till turf grass in an area of high rainfall), each ton of compost yielded 0.01 to 0.06 tons of added carbon to the soil. In more disturbed soils (e.g., mine sites, tilled farms), each ton of amendment yielded 0.2 to 0.5 tons of stored soil carbon. Considering that the carbon content of these amendments is about 30 to 40 percent, that is a pretty good return.

A primary focus of carbon sequestration is to keep the carbon under lock and key so that it has no potential to interact with the atmospheric pool and revert back to CO_2. One example of this is deep-well injection of liquid CO_2 a few miles into the earth. This type of project is being funded by the Department of Energy using carbon from coal-fired power plants. The wells are very expensive to drill, and where you put them is also a concern. It is not clear if the carbon that is injected will stay down below or gradually filter up into the atmosphere.

Landfill proponents argue that a portion of the organics that are landfilled will effectively remain under lock and key. The landfill that I talked about way back in the beginning of this report is now under a Target Store so maybe that carbon is under lock and key with an English bull terrier standing guard on top.

This type of carbon storage accomplishes one thing and one thing only — it stores carbon. I would argue that this is a short-sighted approach. When carbon is added to soil systems, a whole range of additional benefits occur. Some of these were mentioned briefly in the discussion of anaerobic digestion. These principles are also generally well recognized by people who have used organic soil amendments such as composts and biosolids. This is such a critical part of the discussion that I'm going to provide a little more information.

Organic amendments can increase SOC concentrations by increasing organic matter inputs directly through application and indirectly by associated increases in net primary productivity. That means that plants grow better in soils with higher organic matter. Not only are there greater inputs to soil carbon with high organic matter soils, you get more food. This is a direct contradiction of the saying, "you can't have your cake and eat it too," but it really happens (Izaurralde *et al.*, 2001).

Figures 3 and 4 contain some data to show how it works. This is data from biosolids applied to dryland wheat in eastern Washington State. Figure 3 shows wheat yield and Figure 4 shows changes in soil carbon over time. This is an area where moisture is generally the most limiting factor for plant growth. In years where there was enough rainfall, the plots with biosolids grew more wheat than the plots with N fertilizer or the controls. You can also see how the carbon in the soil that received biosolids has increased over time. The green highlights in Figure 3 indicate when fertilizers and biosolids were applied to the fields. I should also mention that when these plots were sampled in 2008, the soils that had received the high rate of biosolids held 10 percent more water than the control or fertilized soils. This can mean a lot when it only rains 12 inches a year or when you consider that 80 percent of the water used in California is for crop irrigation.

You can get organic soil amendments

Figure 3. Wheat yield on control and amended plots

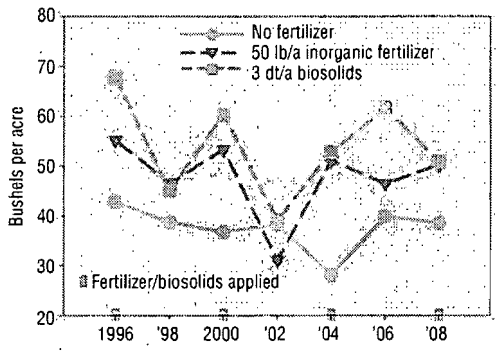
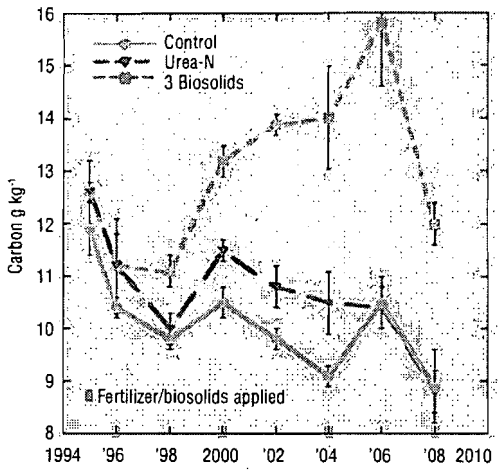


Figure 4. Changes in soil carbon over time (1995-2008)



The potential soil C sink is close to historic soil organic carbon losses. This means that our soils would drink up added carbon.

The landfill is now under a Target so maybe that carbon is under lock and key with an English bull terrier standing guard on top.

from organic residuals in two ways — direct application (generally done after composting) or application of materials after anaerobic digestion. In both cases you conserve the majority of the nutrients in the materials. In both cases you conserve a portion of the carbon in the materials. In both cases you get increased soil carbon, improved soil properties and increased plant yield. And with anaerobic digestion, you get some of the energy benefits, too.

So now you know all about residuals and energy, residuals and carbon sequestration and residuals and nutrient conservation. Now it is time to talk about landfills. Finally you say, I've been reading this nonsense for page after page, just waiting to hear about landfills. Well, here goes.

SANITARY LANDFILLS

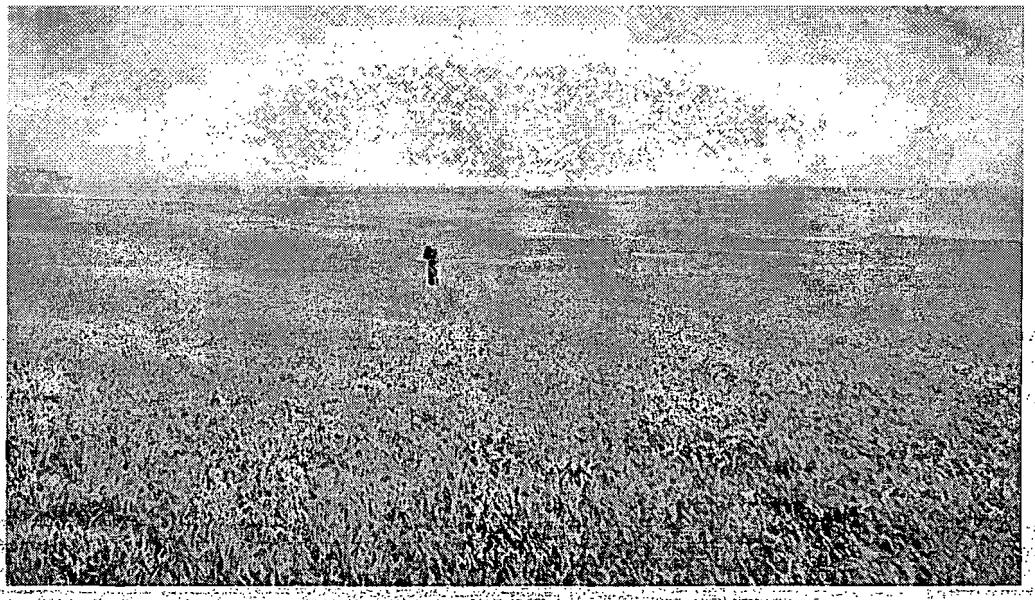
The United States has some of the best-managed landfills in the world. Legislation has required that modern landfills be constructed as sanitary landfills. That means waste is put into a lined cell, compacted and covered. Gas collection systems are mandated in these sanitary landfills if the landfill is big enough. Approximately 66 percent of the landfilled waste in the U.S. is disposed in landfills with gas collection systems (Sullivan, 2010). Collection systems are put into place as the landfill is constructed and begin operation from between one to five years from the time waste is first put into a cell. This collection continues for the active life of the landfill and for a period of time after closure. When you close a landfill you have to put a final cover over the surface. This is several feet thick and is designed to stop gases from escaping from the surface.

In the whole debate on where organics belong and whether landfills are environmental allies or enemies, you see a range of values for landfill gas capture efficiencies and a range of values for how much carbon is stored in a landfill. The U.S. EPA had traditionally set landfill gas capture efficiency at 75 percent across the lifespan of the landfill. This value is in the process of being changed to reflect varying collection efficiencies during the different stages of the life of a landfill.

The Solid Waste Industry for Climate Solutions issued values for collection efficiencies at these different stages (SWICS, 2009):

- 50 to 70 percent for the part of a landfill that is under daily cover and has an operating gas collection system;
- 55 to 95 percent for the part of the landfill that has an intermediate soil cover with an active gas collection system; and
- 90 to 99 percent for landfills under final cover with active gas collection systems.

Capture efficiencies are not provided for the periods when gas capture systems are not operating — those first few years during waste collection and the decades following the end of legal requirements for collection. However, one study reported that gas collection efficiencies were reduced by 79 percent when the gas collection system was not operating (Lohila *et al.*, 2007). In other words, when the gas collection system isn't operating (e.g., in the first 1-5 years that waste is put into a cell), the gas collection efficiency is pretty low.



Biosolids were applied to fields planted in dryland wheat (above) in eastern Washington State over a period of years. Yields and soil carbon were measured, as compared to plots with only N fertilizer addition and a control with no fertilizer.

Nitrous oxide (N_2O) emissions also need to be considered. In a recent report on the importance of landfill gas collection, no mention is made of N_2O emissions, although several studies have reported N_2O emissions from the surface of sanitary landfills where gas collection systems are operating. Börjesson and Svensson (1997) measured N_2O emissions from landfills in Sweden where soil or municipal biosolids were used for cov-

Table 7. Temperature, moisture and methane onset in landfill cells

	Waste Quantity (tons)	Temperature	Moisture (%)	CH_4 Onset
Levebre *et al.*, 2000	200,000	40 °C	20-50	Day 20
Bäumler and Kögel-Knabner, 2008	893,000	20°C at surface 50°C at depth	.6-42, primarily 10-35	n/a
Zhao *et al.*, 2008	32,400	ambient	25-60	Day 70

er soil. Nitrous oxide emissions from the mineral soil ranged from -0.0017 to 1.07 mg N_2O-N/m²/h. Emissions from the areas covered with biosolids ranged from -0.011 to 35.7 mg N_2O-N/m²/h. Other studies have reported N_2O emissions from landfills ranging from -0.102 to 6.0 mg N $m^{-2}h^{-1}$ (Rinne *et al.* 2005; Zhang *et al.*, 2009).

These results, and there are plenty more that I haven't mentioned, suggest that depending on where and when you measure, landfills likely emit both CH_4 and N_2O. The periods when these emissions (both CH_4 and N_2O) are highest are in the initial stages of waste deposition when no gas collection systems are operating. They are likely lowest, potentially near zero, when final cover is in place and gas collection is operational. Needless to say, emissions are also likely higher in landfills without gas collection systems — those landfills where 33 percent of our wastes are disposed. It is also likely that engineering solutions can be identified to further improve gas collection. It would likely be a challenge to install and operate piping systems in cells where waste is actively being deposited, but I am sure it can be done. This would likely add to the expense associated with managing landfills, which in turn would add to the cost of disposing of material in these landfills.

LANDFILLS AS ENERGY GENERATORS

The next question is how good are these landfills at making biogas? Remember that landfills make biogas via anaerobic digestion, that finicky process discussed earlier. The answer to that question depends on what it is like inside one of those sanitary cells. A few studies have measured conditions in a landfill cell. Their findings are shown in Table 7. Compared to dedicated anaerobic digesters, the temperature in the landfills studied seems pretty good, except for that small one. And methane formation, even in the colder landfill, seems to get going fairly quickly, within a few weeks to a few months.

In fact, a different study suggested that a minimum of 50 percent of the potential methane in landfill feedstocks can be generated within the first year of residence in a landfill (Themelis and Ulloa, 2007). However, conditions seem too dry for optimal gas generation. Remember that in dedicated digesters, dry digestion is defined as having a moisture content of 75 percent.

The same study that noted that much of the methane is likely produced during the first year of residence time in a landfill (Themelis and Ulloa, 2007) also reported CH_4 capture rates in comparison to modeled rates of CH_4 generation and found efficiencies ranging from 6 percent to 100 percent with a mean value of 35 percent. That means either much of the gas has gone missing or that it was never made in the first place. Three studies suggest that the latter hypothesis is correct, at least for certain of the feedstocks:

Sormunen *et al.* (2008) sampled wastes of different ages from two landfills in Finland. One landfill had been operating for 17 years and the other for 48 years. The younger landfill had a higher ratio of volatile solids:total solids (VS:TS). Biological CH_4 potential (BMP) and the ratio of VS:TS was highest in the middle and top layers. The percent of wood was similar across all depths. The authors noted that the proportion of paper and cardboard was lowest at the bottom depth, indicating that these materials had decomposed. There was no detection of food-related residuals at any depth.

Ximenes *et al.* (2008) sampled landfills in Sydney, Australia and also found that wood products persist in a landfill environment. In this study, different types of wood from three landfills that had been closed for 19, 29 and 46 years were sampled. Moisture content of the wood ranged from 41.6 to 66.8 percent. The total carbon, cellulose, hemicellulose and lignin concentrations of specific wood types from the landfills were measured and compared to fresh samples of the same species. There was no evidence of decomposition in the two younger landfills. In the oldest landfill sampled (46 years), up to 18 percent of the original carbon content of the wood had decomposed.

Bäumler and Kögel-Knabner (2008) analyzed waste from a number of landfills in Germany for chemical composition. The authors found high concentrations of cellulose in waste material of different ages and interpreted this to mean that paper waste does not readily decompose in a landfill. (I've also heard anecdotally about a study in which a newspaper from 1974 was recovered from an Arizona landfill with the crossword puzzle still legible.)

These results suggest that for a majority of organic feedstocks (paper and woody materials), anaerobic degradation rates in landfills are very slow. Like gas capture,

When the gas collection system isn't operating, e.g., the first 1-5 years that waste is put into a landfill cell, the gas collection efficiency is pretty low.

we can probably make them better if we want to. Morton Barlaz of North Carolina State University suggested that landfills managed as bioreactors with leachate recirculation will have much more efficient methane generation than those left to make gas on their own time. Data from a laboratory decomposition study where moisture and nutrients were added to all feedstocks was used to develop decay rates for waste materials in conventional and bioreactor landfills (Barlaz, personal communication). As you can see in Table 8, things go much faster when there is enough water around. It should be noted that the food waste used for this study consisted primarily of cellulose and lignin, stuff that we can't digest. It appears that all that was left of the pizza used for this trial was the box.

Results of these various studies suggest that landfills do produce methane, some more than others. They also suggest that landfills release gases, some more than others and more at some stages than others. And they suggest that there are ways to make landfills generate more gas and ways to collect more of the gas that is generated.

Bottom Line: What these studies also suggest — and this is the most important detail — is that landfills are best suited as a place to throw stuff away rather than to optimize the carbon, energy and nutrient values of organics.

CONCLUSIONS — PLAIN AND SIMPLE

So what does this all mean? This means that landfills have done an excellent job of providing us with a place to dump stuff. As we understand the implications of dumping stuff, these landfills can be engineered to also release less CH_4 and produce more biogas. If we want to continue to dump stuff, this might be an okay way to go (and I fully admit that there is some stuff that I am more than happy to dump).

However, we are entering a new era where resources are limited and carbon is king. In this new era, dumping stuff may cease to be an option, because that stuff has value and that value can be efficiently extracted for costs that are comparable to or lower than the costs — both environmental and monetary — associated with dumping. This can be done best at places that are constructed specifically to manage resources rather than places to dump waste. These are places like dedicated digesters, composting facilities and combustion facilities. However much you engineer a landfill, it will never be as efficient at making and capturing gas and energy as a dedicated digester or a combustion facility. That landfill may, through its inefficiencies, end up sequestering a portion of the carbon that is dumped in it. However, this carbon will never serve any valuable function, help to feed us or make plants grow better. All the nutrients trapped with the carbon will be sequestered too.

> A different study suggested that a minimum of 50 percent of the potential methane in landfill feedstocks can be generated within the first year of residence in a landfill.

It is true that you can detect CH_4 and N_2O emissions from different composting operations, just like you can from landfills. But you can detect a whole lot more from poorly managed composting systems than from well-managed systems (Brown and Subler, 2007). For all that we do, we will have to learn how to do things to make the lowest imprint and to optimize our resources. You can't separate the argument on landfill efficiencies from a real discussion on how we need to manage those resources. This means not throwing them away — and landfills are for throwing things away. ■

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Table 8. Decay rates for waste materials in conventional and bioreactor landfills

Component	Conventional Landfill Decay Rate (First order decay rate constant (k))	Bioreactor Landfill Decay Rate (First order decay rate constant (k))
MSW	0.04	0.1
Leaves	0.25	0.63
Grass	0.31	0.77
Branches	0.12	0.30
Old news print	0.04	0.11
Old corrugated containers	0.03	0.08
Magazines	0.16	0.40
Food waste	0.11	0.28

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Landfill Gas-to-Energy Projects May Release More Greenhouse Gases Than Flaring

Prepared by Jim R. Stewart, PhD,[1] for Sierra Club California, updated June 29, 2010[2]

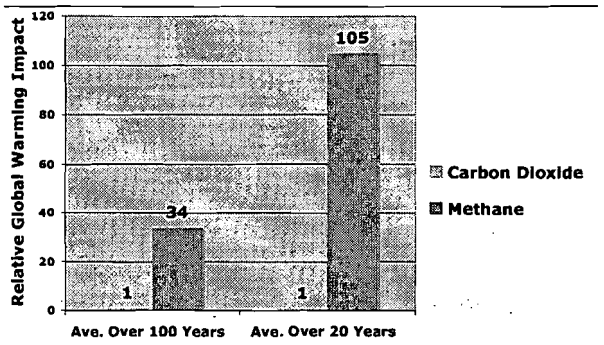
Executive Summary

This paper compares the net greenhouse gas (GHG) effects of most landfill-gas-to-energy projects with the traditional practice of burning the captured methane in a flare. Based on studies by government agencies, consultants to the waste industry, and academic institutions, a potential result is **3.8 - 7.8 times more net GHG emissions for energy recovery projects compared to flaring**. This outcome is based on the larger fugitive emissions from "wet" landfills used for energy recovery compared to those from "dry" landfills used for flaring. Since the GHG savings from replacing fossil fuel with the landfill methane could be negated by GHG impacts of the fugitive emissions, "renewable energy" credits should not be given to landfill gas, except when operators can demonstrate no more emissions than flaring.

Introduction

All decomposing organic materials in landfills release methane,[3] a greenhouse gas (GHG) much more potent than carbon dioxide. The Intergovernmental Panel on Climate Change (IPCC) estimated in 1995[4] that the global warming effect of methane was 21 times that of CO2, averaged over a 100-year period, or 75 times CO2, averaged over a 20-year period. The latest research from NASA in 2009 shows the impact of methane to be 34 times that of carbon dioxide over 100 years and 105 times over 20 years.[5] The next 20 years are critical because of the imminent danger of releasing billions of tons of Arctic methane clathrates,[6] which could lead to irreversible runaway global heating.

Figure 1. Global Warming Impact of Carbon Dioxide (set arbitrarily at 1) compared with Methane over a hundred year period and over a twenty year period



The Sierra Club Report on Landfill Gas to Energy[7] says the priority is to **divert all organics** from landfills. This practice would end new methane emissions from landfills. An additional concern is the fact that such a large fraction of the emissions from wet organics occur in the first three years, usually before the gas cap and capture systems are put in place, as shown in Figure 2.[8] The reason for the delay putting on the cover is the operator is still adding waste to that section of the landfill.

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[1] Dr. Stewart earned a PhD in Physics from Yale University and teaches at the University of the West in Rosemead, CA, Jim@EarthDayLA.org, 213-487-9340.

[2] An earlier version was presented to the Northern California Recycling Association Conference, March 23, 2010.

[3] Methane is emitted from the bacterial process known as anaerobic digestion, which requires liquids, organic materials, and absence of oxygen.

[4] IPCC Second Assessment Report: Climate Change 1995 (not available on line – replaced by the 2007 report).

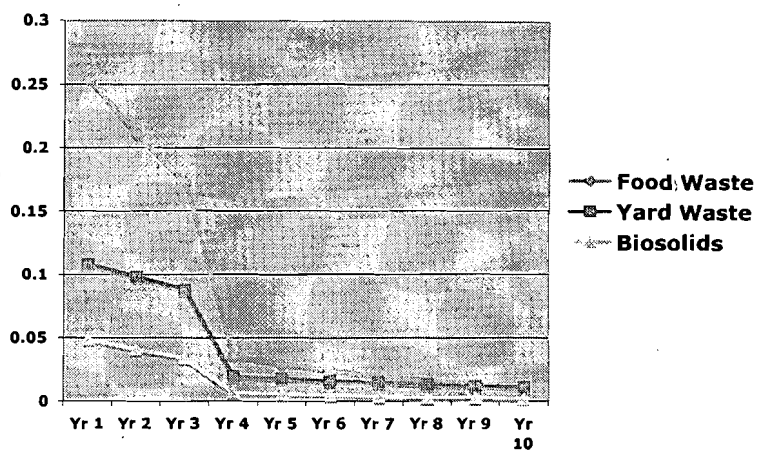
[5] Drew T. Shindell, *et al.*, "Improved Attribution of Climate Forcing to Emissions," *Science* **326**, 716 (2009).

[6] Climate Progress, Vast East Siberian Arctic Shelf methane stores destabilizing and venting, March 4, 2010 (http://climateprogress.org/2010/03/04/science-nsf-tundra-permafrost-methane-east-siberian-arctic-shelf-venting)

[7] Sierra Club Report on Landfill Gas to Energy, 2010 (http://sierraclub.org/policy/conservation/landfill-gas-report.pdf)

[8] Chicago Climate Exchange, Avoided Emissions from Organic Waste Disposal, Offset Project Protocol, 2009 (www.chicagoclimatex.com/docs/offsets/CCX_Avoided_Emissions_Organic_Waste_Disposal_Final.pdf) Note this report does not show the later wave of gas generation expected decades hence, after the landfill closes, maintenance ends, the protective cover begins to leak, and rain water stimulates more anaerobic digestion.

Figure 2. Much Methane Escapes in the First 3 Years, Usually Before Capping

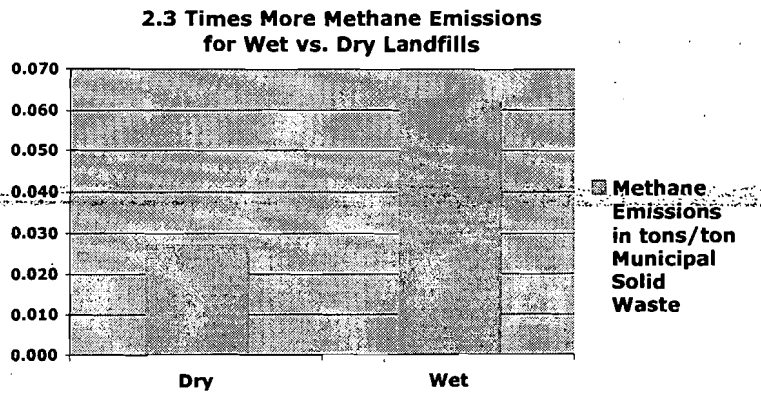


To get the above data, the Chicago Climate Exchange uses a decay model to calculate GHG emissions from a landfill, which is described in detail in their paper.[9] The bottom line is, if there are <u>any</u> organics in the landfill, we need to deal with the ongoing methane emissions from the remaining waste. For many years people installed impermeable caps and gas collection systems to capture the methane and put it into a flare to burn it. Every ton of methane captured and burned avoids the effect of adding 104 tons of CO2 to the atmosphere (calculated over a 20-year period).[10]

Wet vs. Dry Landfills

But then people thought, why waste that biomethane burning it in a flare? Why not use it to replace fossil fuels? It sounded like a good idea, except, if you take the methane from a dry landfill and try to burn it in an engine or turbine, it is inefficient. The normal methane flow from a "dry tomb" landfill is so slow and impure, that the operator doesn't make enough money to pay for the additional capital and operating expenses of an engine or turbine. So they need more moisture in the landfill. As the chart below from research done for the U.S. EPA shows, **wet** landfills generate 2.3 times more methane than **dry** ones (based only on measuring the <u>collected</u> gas, not the total emitted, which was not measured in these studies).[11] If the collection efficiency were the same in both cases, the result is up to **2.3 times more GHG emissions** for energy recovery sites.[12]

Figure 3. Moisture Greatly Increases Methane Emissions



[9] Chicago Climate Exchange, Avoided Emissions from Organic Waste Disposal, Offset Project Protocol, 2009 (www.chicagoclimatex.com/docs/offsets/CCX_Avoided_Emissions_Organic_Waste_Disposal_Final.pdf)

[10] Calculated from methane global warming factor 105 minus the 1 part CO_2 from the flare burning the methane.

[11] Reinhart, D.R. et al. First-Order Kinetic Gas Generation Model Parameters for Wet Landfills, report prepared for US EPA, 2005, p. 4-5. (http://www.epa.gov/nrmrl/pubs/600r05072/600r05072.pdf). See also Sally Brown, "Putting the Landfill Energy Myth to Rest," BioCycle, May 2010, p. 5.

[12] We note that these data are from experimental sites; some energy recovery sites may not be this wet.

Since it is supposed to be illegal to deliberately add water to a landfill, waste engineers came up with a variety of ideas to increase the gas production in the short term and decrease costs so they could make more money, including such methods as[13]:

- Leaving the cap off as long as possible so more water from rain and snow can enter.
- Regrading the slopes to drain rain into the landfill.
- Recirculating the liquid leachate flowing from the bottom of the landfill back into the top.[14]
- Turning off gas collection wells on a rotating basis in order to give each field time to recharge moisture removed by the gas extraction process itself.
- Reducing the vacuum pump pull on gas collection wells when imperfections in the landfill cover allow air to be drawn into the waste mass. Pulling lower amounts into the collection system allows more methane to escape. (Note: While landfills that just flare gas can accept 3%-5% oxygen infiltration before risking igniting fires, those recovering energy are restricted to as low as 0.1% because a high rate of methane production depends upon having an oxygen-starved environment.)
- Installing more gas collection wells at the center of the landfill, where methane ratios are greatest, and less at the periphery, which could allow more gas to escape with no wells to capture it.

Result of Increasing Moisture is More Uncollected, Fugitive Emissions

The problem is the result of these aids to more profitable "energy recovery" is much more uncaptured methane. A report for the US EPA analyzed fugitive emissions for three types of approaches: (1) normal dry tomb landfill, (2) closed landfill, but circulating leachate to provide moisture for energy recovery, and (3) active landfill circulating leachate to provide moisture for energy recovery. The results are shown in Figure 4. The closed, but wet landfill had 1.9 times more escaping emissions, while the active wet landfill designed for maximum energy production had 4.7 times more emissions.[15]

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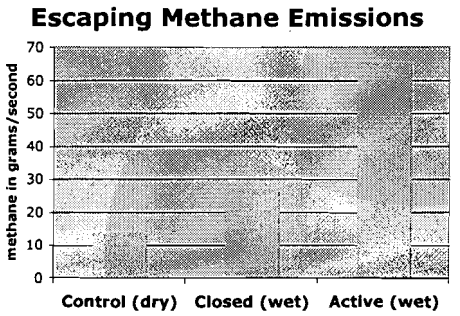
[13] List compiled in March 2010 by Peter Anderson, RecycleWorlds Consulting, based on these publications:
- Augenstein, Don, "Landfill Operation for Carbon Sequestration and Maximum Methane" (http://www.osti.gov/bridge/purl.cover.jsp?purl=/795745-EMfXDz/native)
- "Emission Control: Controlled Landfilling Demonstration Cell Performance for Carbon Sequestration, Greenhouse Gas Emission Abatement and Landfill Methane Energy", Final Report, Institute for Environmental Management (IEM), February 26, 2000.
- Don Augenstein, et. al., Improving Landfill Methane Recovery - Recent Evaluations and Large Scale Tests (2007) (http://4.36.57.37/expo_china07/docs/postexpo/landfill_augustein_paper.pdf)
- Hans Oonk, Expert Review of First Order Draft of Waste Chapter to IPCC's 4th Assessment Rpt, 2008 (http://scp.eionet.europa.eu/publications/wp2008_1/wp/wp1_2008)
- SCS Engineers, Technologies and Management Options for Reducing Greenhouse Gas Emissions From Landfills,2008 (http://www.calrecycle.ca.gov/publications/Facilities/20008001.pdf).
- U.S. Environmental Protection Agency, 40 CFR Part 60 WWW (proposed and final rule).
- Sierra Club LFGTE Task Force, Sierra Club Report on Landfill-Gas-to-Energy, January 2010 (http://sierraclub.org/policy/conservation/landfill-gas-report.pdf)

[14] "[Director of Butte County's solid waste program] Mannel explained that in this process, liquid is introduced into the sealed "waste cells" in the landfill. The addition of the liquid improves the production of methane up to five times more than the unaugmented process." Chico Enterprise-Record, 6/14/2010 (chicoer.com/news/ci_15292646)

[15] Mark Modrak, et al., Measurement of Fugitive Emissions at a Bioreactor Landfill (2005) (available at http://clubhouse.sierraclub.org/people/committees/lfgte/docs/ measurements_fugitivieemissions.pdf)

Figure 4. Moisture Increases Fugitive Methane Emissions from a Landfill, by up to 4.7 times



The IPCC estimated that, over the long term, including the extensive times (before and after the installation of the gas capture systems) when there is little or no gas collection, the average total fraction captured may be as low as 20%.[16] U.S. EPA's *Compilation of Air Pollutant Emission Factors* (AP-42) assumes a range from 60 to 85 percent, with 75 percent as "typical" for sites having a well-designed active collection control system in place.[17] EPA gives no estimates of the amounts lost before the installation of the gas capture system and after landfill maintenance ends, which often are very large.[18]

A report prepared by consultants for the solid waste industry[19] provides their view of the ranges of gas collection values: 50-70% for an active landfill, 54-95% for a inactive landfill or portions of a landfill that contain an intermediate soil cover, or 90-99% for closed landfills that contain a final soil and/or geomembrane cover systems. Their view is stated as, "The **high ends** of the range of these values are proposed for sites with NSPS or similar **quality LFG collection** systems which are designed for and achieve compliance with air quality regulations and surface emissions standards." "The **low end** of the range would be for full LFG systems that are installed and operated for other purposes, such as **energy recovery**, migration control, or odor management; . . ." (emphasis added). Our interpretation of these statements is the high ends of the ranges apply to sites using flaring, while the low ends apply to those doing energy recovery.

However, we note that the Palos Verdes landfill study in the 1990's, which was cited by SCS Engineers for its "capture efficiencies above 95%,"[20] was for a landfill that had been closed for nearly 20 years and had a 5-foot thick clay cap installed. That study was recently reevaluated by the California Air Resources Board, which found a collection rate of only 85%.[21] Thus for closed landfills with a final cover, 85% capture is a more substantiated upper limit, meaning that more than 15% is escaping.

In any event, the SCS report indicates the waste industry recognizes the potential losses in the collection efficiency of energy recovery compared to state of the art flaring. This means that an active landfill (shown in the left two columns in Figure 5) using an energy recovery system could have a collection efficiency as low as 50%, compared to about 70% for one using flaring, which implies 1.6 times more methane is likely escaping when a landfill is used for energy recovery. A study of Dutch landfills[22]

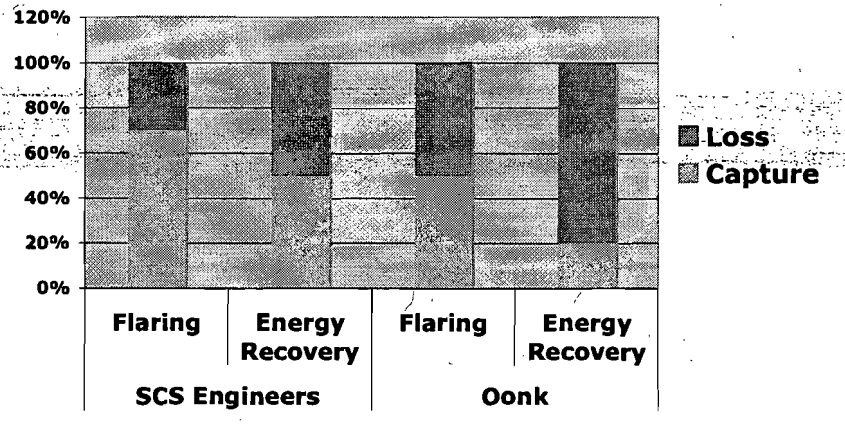
[16] Intergovernmental Panel on Climate Change, *Fourth Assessment Report*, Waste Chapter 10, p. 600 (2008).
[17] Office of Air Quality Planning and Standards and Office of Air and Radiation, *Emission Factor Documentation for AP-42, Section 2.4, Municipal Solid Waste Landfills* (Revised 1997).
[18] "Critique of SCS Engineers' Report Prepared for California's Landfill Companies on Gas Collection Performance," by Peter Anderson, Center for a Competitive Waste Industry, Sept. 5, 2008.
[19] SCS Engineers, *Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills*, for the Solid Waste Industry for Climate Solutions (June 2008), p. 16-17 (http://www.scsengineers.com/Papers/ FINAL_SWICS_GHG_White_Paper_07-11-08.pdf).
[20] California Integrated Waste Management Board, Overview of Climate Change and Analysis of Potential Measures to Implement Greenhouse Gas Emission Reduction Strategies, May 8, 2007.
[21] "Initial Statement of Reasons for the Proposed Regulation to Reduce Methane Emissions from Municipal Solid Waste Landfills," (May 2009) p. IV-5 and Appendix D (http://www.arb.ca.gov/regact/2009/landfills09/isor.pdf).
[22] Oonk and Boom, 1995, *Landfill gas formation, recovery and emissions*, Chapter 7, TNO-report 95-130.

shown in the two right columns found that, averaged over the life of the landfill, flaring gas extraction systems designed for minimizing emissions could realize collection efficiencies only up to 50%, while energy recovery systems averaged only 20% efficiency. However, the numerical factor is the same, 1.6 times more methane is likely escaping when a landfill is used for energy recovery.

We note that a recent report[23] by Patrick Sullivan, senior vice president of SCS Engineers, consultants for the solid waste industry, states, "Opponents of landfills claim development of LFGTE projects will increase methane emissions at landfills [in comparison with flaring]. . . This is simply not true." Some of the points he makes are quoted in italics below:

1. *"The landfill is required by federal regulations to achieve the same surface emission limits and LFG system operational requirements in either case."* Our response is the landfill operator must demonstrate there is no increase in fugitive emissions from practices that aid LFGTE, such as reducing the vacuum pump pull, as mentioned above.
2. *"Landfill opponents suggest that LFG engines, which represent the largest majority of LFGTE devices, do not destroy methane as well as flares. Indeed, the capacity of flares to destroy methane is greater than most LFGTE equipment, but the true difference between the two devices is very small with flares and other control devices achieving more than 99% control and lean-burn LFG engines achieving more than 98% control of methane (Solid Waste Industry for Climate Solutions [SWICS], 2007)."* He is referencing his own company report, but the report actually states that methane destruction efficiency of flares is 99.96% compared to internal combustion engines 98.34%. As shown later, this **1.6% difference is very significant**, even using the outdated GHG multipler of 21 (and much worse using the 20-year multiplier 105).[24] This means that it is impossible to use engines and have less net impact than flaring, but turbines with high destruction efficiency are fine. Also acceptable are systems that inject the methane directly into natural gas pipelines for normal uses.
3. *"There are some landfills, which are not required by regulation to collect and control LFG, that are developed for LFGTE."* Our response is this is a valid point. Voluntary LFGTE projects undertaken before the NSPS standards require temporary capping and collection could significantly reduce GHG emissions compared to cases where operators wait as long as possible (up to 5 years is allowed for active cells) to cap and install collection systems. A consultant report found a very large collection of methane before the five year limit produced substantial carbon reduction credits.[25] However we feel the EPA needs to drastically tighten the NSPS standards, especially in light of the studies reported above that the largest emissions from wet organics occur within the first three years.

Figure 5. Methane Capture Efficiency in Energy Recovery Systems is much less than in Flaring sites, which increases <u>Escaping</u> Methane by 1.6 Times



[23] Patrick Sullivan, SCS Engineers, The Importance of Landfill Gas Capture and Utilization in the U.S., April 2010, p. 28-30. (http://www.scsengineers.com/Papers/Sullivan_Importance_of_LFG_Capture_and_Utilization_in_the_US.pdf)

[24] It is very unfortunate that EPA 40 CFR Part 98 allows the use of a default 99% destruction efficiency for methane for all types of LFG combustion devices, including engines, ignoring this large GHG impact.

[25] McCommas Bluff LFGTE Project, Voluntary Carbon Standard Assessment, Jan. 2010, by Blue Source LLC

Combining the Two Effects Produces Much More Net GHG Emissions for Energy Recovery

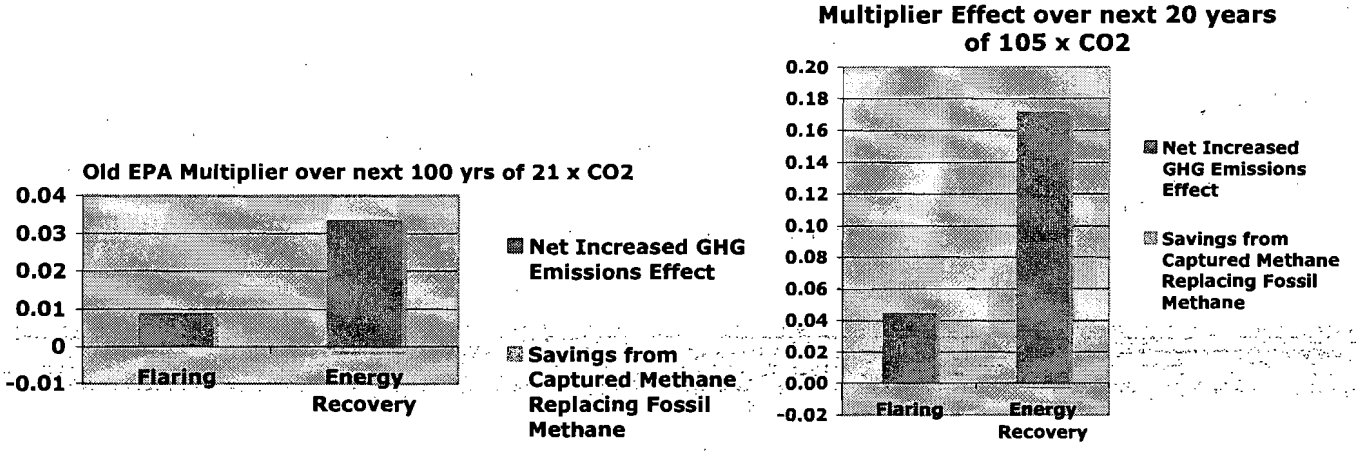
In addition to the increase in fugitive emissions, there is the effect reported above that **wet** landfills produce 2.3 – 4.7 times more methane than dry ones. If we combine these two observed effects, the net result would be **3.8 - 7.8 times more net GHG emissions for energy recovery compared to flaring** (a result that applies irrespective of the value of the GHG multiplier for methane).

The charts in Figure 6 on the next page indicate the actual global warming savings using the captured methane from energy recovery to replace the burning of fossil methane are very small (0.0007 tons of carbon dioxide equivalent per typical ton of municipal solid waste (MSW)), much less than the overall impacts of the escaping methane. The left chart shows a net increase of GHG emissions of 0.034 CO2 equivalent tons/ MSW ton using the old (1995) multiplier of 21 (which is still used by the US EPA for "consistency").

The right chart shows a net increase of GHG emissions of 0.172 CO_2 equivalent tons/MSW ton using the latest (2009) multiplier of 105 over the next critical 20 years. Below the large right red bars for energy recovery in both figures, there is a very tiny blue line (that looks almost like a shadow) that represents the amount of benefit from offsetting the use of fossil fuels, which in each case is only 0.0007 tons of carbon dioxide equivalent per typical ton of MSW.

Note that the charts essentially apply to landfills with active gas collection systems, and do not include the methane lost before the landfill is capped, or after the permanent landfill cap is no longer maintained and starts to leak, adding moisture from precipitation.

Figure 6. Energy recovery procedures increase global warming impact by at least 3.8 times using either multiplier of 21 or 105, even considering the savings from "energy recovery." The GHG emissions from escaping methane are expressed in $CO_{2\ equivalent}$ Tons/MSW Ton



Methane Destruction Inefficiency of Internal Combustion Engines Increases GHG Impact

Finally, we consider the latest data from the waste industry of average methane destruction efficiency of flares (99.96%) compared to internal combustion engines (98.34%) and turbines (99.97%).[26] Their analysis indicates turbine destruction efficiency is essentially equivalent to a flare, but an internal combustion engine adds significant GHG impact from its 1.6% lower destruction efficiency. Thus using an engine increases the GHG impact from energy recovery by 0.0006 CO_2 equivalent tons/ MSW ton, using the old multiplier of 21, or 0.0028 CO_2 equivalent tons/ MSW ton, using the latest 20-year multiplier of 105. The net outcome is the methane destruction inefficiency of an internal combustion

[26] SCS Engineers, *Current MSW Industry Position and State-of-the-Practice on Methane Destruction Efficiency in Flares, Turbines and Engines*, prepared for the Solid Waste Industry for Climate Solutions (July 2007), p. 2.

engine essentially **negates its global warming savings** from replacing fossil methane at the old multiplier, and dramatically increases GHG impacts using the multiplier of 105, but turbines are okay. Also acceptable are systems that inject the methane directly into natural gas pipelines for normal uses.

Policy Recommendations

In summary, to reduce global warming requires the following steps to be implemented immediately:

1. Use current scientific data to calculate the GHG **impacts of methane** emissions from landfills.
2. **Divert all organics** from landfills (including green waste used as alternate daily cover) to reduce uncollected emissions.[27]
3. **Compost or digest all organics in sealed processors** that capture all methane.
4. **Keep out liquids** from landfills (including not recirculating leachate).
5. **Cap landfills and install gas collection systems as soon as possible** (long before the 5-year limit).
6. **Stop new landfill gas to energy projects and don't give "renewable energy" credits to landfill gas** unless capture rates over the entire landfill and destruction efficiencies are scientifically demonstrated and continually monitored to ensure they are equal to or exceed those of a flare, or the projects are installed earlier than the NSPS requirements.[28]

The above analysis is consistent with Sierra Club National Policy,[29] which (quoted here *in toto*):

- Opposes establishment of new LFGTE facilities, and conversion of existing facilities to LFGTE technology, except at facilities which have completed the process of separating all organic materials from the waste stream going to the landfill, permanently covered the cells being used to generate energy, and adopted best management practices to minimize methane generation.
- Opposes subsidies for LFGTE facilities, including but not limited to eligibility for production tax credits, carbon trading credit, and credit toward meeting renewable portfolio standards.
- Supports the adoption of regulations to minimize methane emissions from landfills.
- Supports the adoption of regulations to require diversion of organic materials from the waste stream for landfills.

[27] We note that organics can be processed by aerobic composting or by anaerobic competitively-priced sealed digesters that can capture all the methane for energy purposes and produce high quality compost, with only small amounts of inert waste remaining for a landfill.

[28] The potential difficulty and expense of these measurements have been detailed by Peter Anderson in "Critique of SCS Engineers' Report Prepared for California's Landfill Companies on Gas Collection Performance," Sept. 5, 2008, p. 12 (available from the author at anderson@recycleworlds.net.) However, a new spectroscopy method, developed by Picarro in cooperation with Waste Management and US EPA, claims to efficiently accomplish this monitoring (http://www.picarro.com/assets/docs/Quantfying_Methane_Fluxes_Simply_and_Accurately_-_Trace_Dilution_Method.pdf).

[29] Sierra Club Policy, Landfill Gas to Energy, 2009 (http://sierraclub.org/policy/conservation/landfill-gas.pdf)