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Reducing Landfill Methane Emissions and Expansion of the Hierarchy of Waste Management

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A 2007 study by the Goddard Institute of Space Studies of NASA and the Earth Engineering Center of Columbia University (1) projected the global generation of municipal solid wastes (MSW) in the period 2000-2030, using projections of population growth by the U.N. and per capita energy consumption by the International Energy Agency. On the basis of this and other information, global landfilling was estimated to nearly double between 2000 and 2030. Uncontrolled landfilling is a major anthropogenic source of methane, which is the second most important of the greenhouse gases affecting climate change. The only two options for decreasing the emissions of methane in landfill gas (LFG), corresponding presently to 850 million tons of carbon dioxide, are replacing landfilling by thermal treatment of MSW and, also, increasing LFG capture in the interim period.

The U.S. is the world's largest landfiller with about 23% of the total MSW landfilled. However, it is also leading in the capture of landfill methane, estimated at about 60% of that captured in landfills globally. The world's waste-to-energy (WTE) capacity is about 170 million tons and since 2000 increased at the rate of about 3.5 million tons per year. However, at this rate thermal treatment of MSW cannot catch up with the projected generation of post-recycling MSW. Therefore, it is necessary for governments to encourage WTE growth and also ensure that new and remaining landfills are constructed and operated so as to maximize the capture and utilization of methane in landfill gas. Such measures are already in place in some countries and include energy and carbon credits for LFG and energy recovered from solid wastes. Also, the hierarchy of waste management should be expanded so as to differentiate between modern landfills and the waste dumps that are still used widely in the developing world.

Keywords: *methane, landfill gas, landfilling, global, waste-to-energy, WTE, thermal treatment, municipal solid wastes, MSW, hierarchy, sustainable waste management*

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INTRODUCTION

Sustainable management of municipal solid wastes (MSW) requires that every possible effort be made to separate recyclable or compostable materials from the MSW stream. Experience has shown that these materials should be separated at the source, i.e., at households, businesses and institutions. The cost of separation is then shared by the generators (in terms of time and effort to separate recyclable materials) and by the municipalities (in terms of separate collection vehicles and processing systems).

However, unless the source-separated materials are usable, they will end up in WTEs or landfills. An example of the lack of markets for certain materials is the fact that over 80% of the plastic wastes generated in the USA are landfilled; despite a lot of effort by the petrochemical industry and by many communities to increase recycling of plastics.

There are only two means for dealing with post-recycling MSW: a) thermal treatment facilities where the chemical energy of the solids is recovered in the form of steam or syngas fuel; and b) landfilling where up to one fourth of the chemical energy in the MSW can be recovered in the form of landfill gas (LFG) and methane emissions can be reduced by 50-75%. In 2007, the Earth Engineering Center of Columbia University (EEC) collaborated with the Goddard Institute for Space Studies of NASA (GISS) on a study of global landfilling (1). More recent information on the amount of urban MSW landfilled in developing nations resulted in a revision of the global landfilling to about one billion metric tons annually. This estimate is based on a combination of known tonnages landfilled in the U.S., EU, Japan, and China and interpolation to the rest of the world (Table 1).

Table 1. Estimate of post-recycling MSW landfilled annually

	Population, millions	**Landfilled, million tons**	**Landfilled, tons/capita**
US	304	225	0.7
EU15	380	104	0.3
Japan	127	nil (all is combusted)	nil
Rest of OECD nations	290	116	0.4
China	1322	180	0.14
Rest of the world	4280	385	0.09
Global	6,700	1010	0.15

The EEC-GISS study developed four scenarios of WTE growth ranging from very conservative, where the 2000-2007 growth rate in capacity was assumed to remain constant through to 2030, to assumed WTE growths of 2.5%, 5% and 7.5% per year in the period 2010-2030. The overall conclusion was that although global WTE capacity had increased by about 3.5 million tons per year in the period 2000-2007, to about 170 million tons, this rate of growth will not be enough to curb landfill methane emissions by the year 2030; population growth and economic development will result in a much greater rate of post-recycling MSW generation. The only way to reduce landfill greenhouse gases (GHG) between now and 2030 is by achieving a 7.5% growth in thermal treatment capacity on a global scale, or by increasing the amount of methane captured at landfills (Figures 1,2).

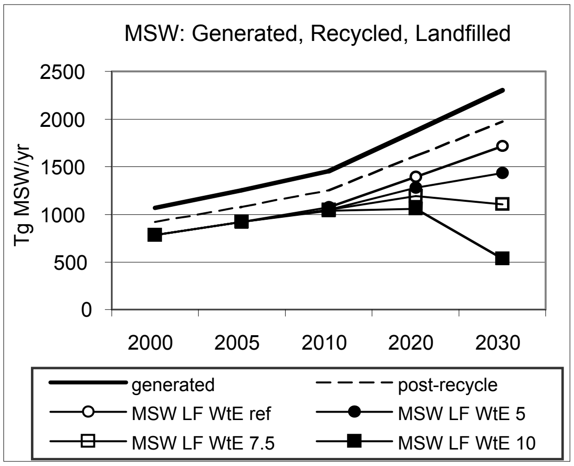

Fig. 1. Generated and post-recycle MSW (constant for all scenarios) and landfilled MSW under four WtE scenarios (1)

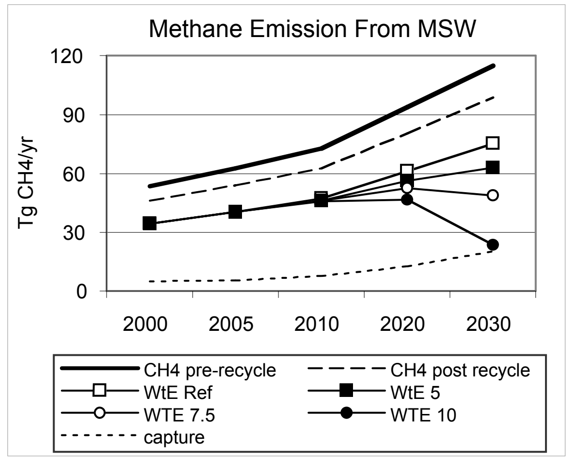

Fig. 2. Impact of WtE growth on net methane emission from MSW. The solid line, potential maximum, is included for reference only (1)

METHANE EMISSIONS FROM U.S. LANDFILLS

U.S. is the world's largest landfiller with 226 million metric ton (249 million short tons, Ref. 2), followed by China with an estimated 180 million metric tons. However, the U.S. landfilling industry and the USEPA Landfill Methane Outreach Project (3) have made a determined effort to collect much of the landfill gas (LFG), which consists of about equal parts of methane and carbon dioxide. The USEPA Greenhouse Gas (GHG) Emissions Report (4) reported that the estimated CH_4 emissions from MSW landfills in 2006 were 11.8 million metric tons (13.05 million short tons) of CH_4. The methane captured by landfills with operational Landfill Gas-to-Energy (LFGE) projects was reported to be 3.11 million metric tons (3.43 million short tons). Methane captured and flared was stated to be 2.85 million metric tons (3.1 million short tons). According to these estimates, the current total capture of LFG in the U.S. was 6.0 million metric tons of CH_4. The Landfill Methane Outreach Program (LMOP, Ref. 5) reported that as of the end of 2007 there were 445 LFG active recovery; there are another 535 candidate large landfills, i.e., containing over one million tons of MSW.

LFG recovery

USEPA, on the basis of experimental work by Barlaz et al (14, 15) has proposed that the total methane generation in landfills is 92 Nm^3 per metric ton of dry MSW. At an assumed 25% moisture, this is equivalent to 69 Nm^3 of CH4 per wet metric ton of MSW. On this basis, the expected total generation of methane, over several years, would be about 0.05 metric tons of methane per metric ton of MSW; this corresponds to a total of 11.3 million metric tons for the 226 million metric tons of MSW that were landfilled in the U.S. in 2004 (2). By coincidence, this number is very close to the estimate of 11.8 million metric tons (13 million short tons) of methane generation per year that was estimated in the USEPA-GHG report (4), using the parameters and assumptions of the LandGEM model of USEPA (16).

An alternative way of estimating the maximum potential generation of methane from one metric ton of MSW is as follows: The carbon content in MSW as received in landfills and WTE facilities is close to 30%C. As reported in another paper at this Symposium by Bahor et al (17), C_{14} measurements on a large number of WTE stack gas samples across the U.S. have shown that two thirds of the carbon in MSW is of biogenic origin. Therefore, the biogenic carbon in one ton of MSW is 1000 kg*30%C*2/3 = 200 kg. Assuming that complete biodegradation, plus some surface oxidation of methane, results in equal parts of methane and carbon dioxide in LFG, the amount of methane generated from complete biodegradation of the biogenic content of MSW would be (200/2)/16*22.4 =140 Nm^3 per metric ton of wet MSW. If only one half of the biogenic carbon is reacted over decades (e.g., cellulose is harder to break down), the expected methane per tone of wet MSW would be 70 Nm^3, which is nearly the same as proposed by USEPA.

METHANE EMISSIONS FROM GLOBAL LANDFILLING

In 2008, Bogner et al of IPCC reported (6) that the utilization of landfill CH_4 is globally implemented at more than 1150 plants worldwide. The emission reductions due to LFG utilized to produce energy were estimated to be "less than 105 Mt CO_2-eq year", i.e., corresponding to about 5 million metric tons of methane. These authors also stated that "This number should be considered a minimum, because there are also many sites that recover and flare landfill gas without energy recovery". If we assume that the ratio of utilized/flared LFG at global landfills is the same as in the U.S. (i.e., 3.11/2.85), the global LFG capture (utilized plus flared methane) is calculated to be > 201 Mt CO_2-eq year, that is >9.6 million metric tons of methane. Table 2 and Figure 3 summarize the above estimates. It can be seen that the U.S. is doing a much better job in capturing and using LFG methane than the rest of the landfilling nations.

Table 2. Comparison of U.S. and global generation and utilization of LFG (million metric tons)

	LFG methane generation	LFG methane utilization	LFG methane flaring	LFG fugitive methane	CO_2 equivalent Mt
U.S.A. landfills	11.8	3.11	2.85	5.84	123
Global landfills	50	5	4.6	40.4	848
U.S. as % of global	23.6%	62.2%	62.0%	14.5%	14.5%

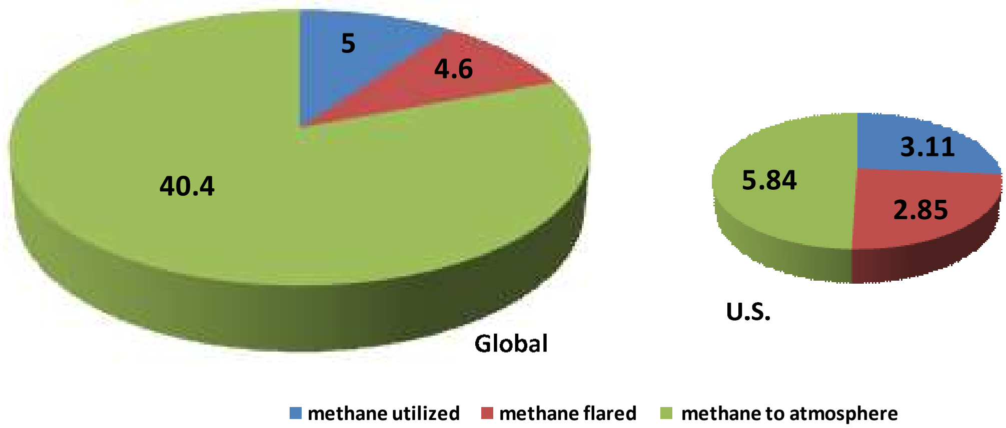

Figure 3. Global and U.S. generation and capture of landfill methane (all numbers are in million metric tons per year)

THERMAL TREATMENT OF POST-RECYCLING MSW

The only proven alternative to the landfilling of post-recycling MSW is controlled combustion or gasification to recover electricity, heat, syngas and metals. Worldwide, there are over 600 thermal treatment plants, most of them in E.U., Japan, and the U.S. The most efficient waste-to-energy (WTE) facilities are in Europe and, on the average, recover 500 kWh of electricity plus an additional 500 kWh of thermal energy for district heating, per ton of MSW processed.

Most thermal treatment plants built in the last two decades have been based on the combustion of as-received municipal solid wastes (MSW) on a moving grate; this stoker-type technology is also called “mass burn”. A survey of three dominant technologies (Martin, Von Roll, Keppel-Seghers, Ref. 7) showed consistent growth of about three million tons per year. However, novel technologies, such as direct smelting (JFE, Nippon Steel), fluid bed (Ebara), and circulating fluid bed (Zhejiang University) have accounted for an additional estimated growth of another million tonnes per year.

It should be noted that some of these new processes are called “gasification” but in fact they consist of partial oxidation and gasification followed by combustion of the volatiles produced and recovery of the heat in the form of steam, same as in the conventional waste-to-energy processes. An exception to this is the Thermoselect process in Japan that produces a syngas fuel to power as gas turbine or engine (7). Another exception, currently under development, are processes that use electricity in the form of a plasma jet to produce a syngas, such as the Plasco Energy (8) and the Europlasma (9) processes.

In the last fifteen years, the emissions of the traditional WTE facilities have been reduced to very low levels. Table 1 shows that the average emissions of the 10 plants nominated for the 2006 Industry Award of the Waste-to-Energy Research and Technology Council headquartered at Columbia University (10), including four U.S. facilities emissions, were significantly lower than the EU and the US standards. Some opponents of waste-to-energy cite dioxin emissions as the main reason for their opposition. It is therefore interesting to note that the dioxin concentration of

0.02 ng/Nm^3 of stack gas, shown in Table 1 corresponds to an emission rate of 0.2 grams of TEQ dioxins per million tons of MSW combusted in such WTE plants. The total annual emissions for the 87 WTE facilities in the U.S. are less than 10 grams TEQ dioxins. For comparison, USEPA has estimated that the dioxins emitted from the annual "backyard barrel burning" in this country in 2004 were 628 grams TEQ (11).

Table 2. Atmospheric emissions of nominees to the WTERT 2006 Award

Emission	**Average of 10 finalists (mg/Nm^3)**	**EU standard (mg/Nm^3)**	**USEPA standard (mg/Nm^3)**
Particulate matter (PM)	3.1	10	11
Sulphur dioxide (SO_2)	2.96	50	63
Nitrogen oxides (NOx)	112	200	264
Hydrogen chloride (HCl)	8.5	10	29
Carbon monoxide (CO)	24	50	45
Mercury (Hg)	0.01	0.05	0.06
Total organic carbon (TOC)	1.02	10	n/a
Dioxins (TEQ), ng/m^3	*0.02*	*0.10*	*0.14*

NEED FOR GOVERNMENT SUPPORT OF WTE

Despite several advantages of WTE over landfilling (energy and metal recovery, GHG reduction, and, most importantly from the viewpoint of sustainable development, land conservation), its wider application in the U.S. has been impeded a) by some environmental groups (18) that believe that all MSW can be recycled or composted and therefore there is no need for either WTE facilities or for landfills , and b) by short term economics that do not take into account the GHG reduction and fuel and land conservation advantages of this renewable source of energy. As in the case of other infrastructure,e.g., supply of potable water and wastewater treatment, waste management should be not only a local but also a state and federal responsibility, as is the case in Japan and E.U. For example, it is interesting to note that in recent years, China provides a renewable energy credit of $30 per MWh of electricity produced by WTE facilities. This and other government incentives have led to building in China of nearly 50 WTE facilities in the last ten years.

HIERARCHY OF WASTE MANAGEMENT

In the EPA hierarchy of waste management (Figure 4; Ref.12), waste reduction is the first priority followed by recycling , composting, combustion with energy recovery, and then landfilling. On the average, U.S. citizens generate twice as much MSW (1.2 metric tons per capita) as Japanese and Europeans so there is a lot of room for waste reduction in this country. However, the goal of "zero waste" advocated by people who oppose **both** WTE and landfilling is unattainable. This has been demonstrated by the most environmentally advanced nations; for example, in Japan where every possible effort has been made to increase recycling and yet they still have to treat thermally about 0.35 metric tons per capita. Also, opposing both WTE and modern landfilling, on the grounds that solid waste should either be prevented or recycled, is as unrealistic as opposing new hospitals because they will encourage people to get sick.

Figure 4. The USEPA hierarchy of waste management (12)

It should be noted that composting - both aerobic and anaerobic- is practical only for source separated organics. Otherwise, experience has shown, that most of the compost product is not marketable as a soil conditioner and in many cases end up in landfills.

CONCLUSIONS

At the present rate of growth , WTE cannot cope with the constantly increasing generation of MSW. Government support for new WTEs in the U.S., China and other major landfilling nations is needed to increase the current rate of growth of WTE. Eventually, only inorganic, non-recyclable materials will be landfilled in most regions, as already is the case in Japan, Switzerland, Denmark, and some other nations. However, until there is sufficient global WTE capacity, there is much to be done with existing and new landfills. In particular, it is necessary for developing nations like China and India to follow the leading example of U.S. in constructing sanitary landfills that prevent liquid effluents from contaminating ground and surface waters and also reduce methane and other gaseous emissions to the atmosphere.

It is evident, from the environmental and resource conservation points of view, that all landfills are not the same. Modern landfilling requires a serious investment and effort to collect landfill gas and use it to generate energy, thus reducing GHG impacts and use of fossil fuels. Therefore, it is necessary that the hierarchy of waste management adopted by environmental agencies here and abroad be expanded so as to recognize this fact. Landfills that collect LFG and use it to generate electricity should be placed above those that collect LFG and flare it; and both of these types should be above the traditional landfills that, regrettably, are still used in many parts of the world. As a step in this direction, it is proposed to expand the hierarchy of waste management so as to clearly differentiate between better and worse types of landfills. The suggested expanded hierarchy of waste management is illustrated in Figure 5.

It should be noted that, incredibly, there is one more type of landfills that lies below the lowest level of Figure 5: Landfills that are intentionally set on fire so as to create more space; one can imagine the environmental damage ensuing when a landfill is on fire: In 2006, an unintentional fire at the Tagarides landfill near Salonica, Greece, resulted in estimated emissions of 10 grams TEQ of dioxins per day, which corresponds to about 30% of the total dioxin emissions emitted by all U.S. diesel trucks in the course of a year.

Figure 5. Expanded hierarchy of waste management differentiating between types of landfills

REFERENCES

1. Matthews, E. and N.J. Themelis, "Potential for reducing global methane emissions from landfills". Proceedings Sardinia 2007, 11th International Waste Management and Landfill Symposium, Cagliari, Italy, 1–5 October 2007, pp. 2000-2030, 2007.
2. Simmons, P., N. Goldstein, S.M. Kaufman, N.J. Themelis, and J. Thompson, Jr., "The State of Garbage in America", BioCycle (Journal of Composting & Organic Recycling), pp. 26-42, April 2006; www.jgpress.com/archives/_free/000089.html
3. USEPA Landfill Methane Outreach Program; www.epa.gov/lmop/
4. USEPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006", Waste, www.epa.gov/climatechange/emissions/downloads/08_Waste.pdf

5. USEPA-LMOP, "Energy Projects and Candidate Landfills" , www.epa.gov/lmop/proj/index.htm
6. Bogner et al, "Mitigation of global greenhouse gas emissions from waste: conclusions and strategies from the Intergovernmental Panel on Climate Change", 4th Assessment, *Waste Management and Research* 2008; 26; 11; http://wmr.sagepub.com/cgi/reprint/26/1/11
7. Themelis, N.J. , "Global Growth of Traditional and Novel Thermal Treatment Technologies", Waste Management World, Review Issue 2007-2008, p. 37-47, July-August 2007.
8. Waste-to-Energy Research and Technology Council; www.wtert.org
9. Plasco Energy, www.plascoenergygroup.com
10. Europlasma, www.europlasma.com/gasification-units_39.html
11. P. Deriziotis, "Substance and Perceptions of Dioxin Emissions", www.columbia.edu/cu/wtert/sofos/Deriziotis_thesis_final.pdf
12. USEPA, "Frequently Asked Questions", www.epa.gov/garbage/faq.ht
13. Themelis, N.J. P. Ulloa, "Methane generation in landfills", Journal of Renewable Energy, 32, 2007, p. 1243-1257; www.aseanenvironment.info/Abstract/41014160.pdf, 2006.
14. Barlaz, M., Ham, R., and D. Schafer (1989). "Mass-Balance Analysis of Anaerobically Decomposed Refuse." Journal of Environmental Engineering, 115(6): 1088-1102.
15. Eleazer, W., Odle, W., Wang, Y. and M. Barlaz, (1997), "Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills," Environmental Science and Technology, 31(3): 911 – 197.
16. USEPA LandGEM model, www.epa.gov/ttn/catc/dir1/landgem-v302-guide.pdf .
17. Brian Bahor, Keith Weitz, and Andrew Szurgot, " Carbon Balance to Estimate Greenhouse Gas Emissions and Mitigation from Municipal Solid Waste Management", this Symposium.
18. Pitt, B. D. Ciplet, K.M. Bailey, and E. Lombardi, "Stop Trashing the Climate" (Institute for Local Self-Reliance; Global Anti-Incinerator Alliance/Global Alliance for Incinerator Alternatives; Eco-Cycle). www.stoptrashingtheclimate.org.