Waste management options to control greenhouse gas emissions – Landfill, compost or incineration?

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Executive summary

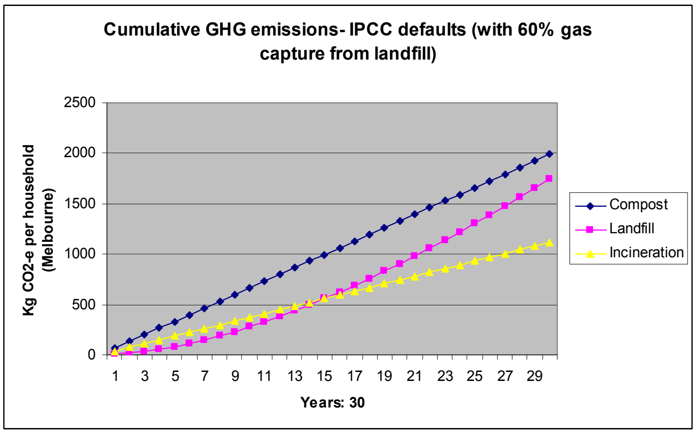
Methane (CH_4) is predicted to cause as much global warming as carbon dioxide (CO_2) over the next 20 years. Traditionally the global warming potential (GWP) of methane has been measured over 100 years. The IPCC's Fourth Assessment Report (IPCC 2007) warns that this under-estimates its immediate impact. Viewed over 20 years it has 72 times the GWP of CO_2.

The current study was prompted by concern about these emissions, and by a recent Government policy study in Melbourne, Australia, which recommended composting of municipal waste. Melbourne has not run out of landfill space, and has best-practice landfills with methane gas extraction. The mass composting of waste would reduce landfill gas, currently used as a fuel.

Aim of the study
This study uses recent information (2006 IPCC Guidelines) with local data to estimate:
- How much greenhouse gas is emitted to the atmosphere from best practice landfill with methane capture pipes? How much can be captured to use as fuel?
- Is aerobic composting or incineration better at controlling emissions than landfill with gas capture ?

Method
A spreadsheet was set up to compare emissions of methane, nitrous oxide and anthropogenic (man-made) carbon dioxide from compost, landfill and incineration, based on IPCC figures. The IPCC model allows for differences in temperature, humidity, dryness and aeration in the landfill, and different types of organic waste. Melbourne (Australia) was used as a case study for the spreadsheet

Results



Greenhouse gas emissions over 30 years: compost, landfill and incineration

Over the next 30 years, incineration produced the least greenhouse gas emissions, followed by landfill with gas extraction. Surprisingly, aerobic composting produced the highest level of emissions. This is based on the assumption that landfill has leachate and gas capture pipes, as is now common in Melbourne, with 60% gas capture. We assumed that 10% of the escaping methane was oxidised as it passed through the soil cover, and some waste would break down aerobically before anaerobic conditions were established. IPCC estimates for CH_4, N_2O and anthropogenic CO_2 emissions from composting and semi-continuous fluidised bed incineration, were compared with the landfill emissions.

Findings

1. Incineration of waste had the least climate impact of the three methods of disposal, followed by landfill with gas capture. This study did not estimate CO_2 savings from waste-to-energy, only the benefits from reducing greenhouse gas emissions, CH_4 and N_2O, from landfill and composting. If energy-from-waste is used to replace coal-fired electricity, results for incineration and landfill gas capture would be even better.

The results supported earlier studies by Pipatti and Savolainen (1996) and the Hyder Study of waste options for Melbourne (2007). Both found that incineration was in fact the best option for reducing greenhouse gases. Anaerobic digestion of wastes for methane would work well if 100% of organic waste could be separated, but this is unlikely to happen in reality. Pipatti and Savolainen found that the second best option was landfill with CH_4 used as fuel. Our study supports this finding.

2. Composting does reduce the amount of waste going to landfill, as an end in itself. In the long run it may reduce GHG emissions. But initially it brings the emissions forward, meaning that climate change is accelerated. In this scenario, it takes more than three decades for greenhouse emissions from landfill to catch up with those from aerobic composting.

It is possible than in 30 years time a solution may be found to methane escaping from landfill, or that energy prices will be so high that landfill is mined as a fuel. So the predicted longer term emissions from landfill may never eventuate. Diverting organic waste to compost now, without capturing emissions from the compost, may be counter-productive, merely hastening the melting of Arctic and Antarctic ice.

Conclusions

An earlier, more detailed study of the options for Melbourne's municipal waste, suggests that the goal of diverting waste from landfill is over-emphasised as Melbourne has adequate landfill space, and more is created by quarrying activities. The huge volume of poor compost produced if all household waste is composted may lead to a collapse in the market for compost.

- Well managed landfill with gas capture can reduce methane levels and delay emissions for decades. About 50% of the organic carbon is sequestrated and only about 5% of waste decomposes in landfill annually. Most of the methane can be captured or oxidised at the landfill site.
- There is great potential for energy generation from thermal electricity generation from municipal waste; from landfill gas and in some cases anaerobic digestion of separated waste. Spark ignition motors are currently used to convert methane to electricity, but fuel cells, cogeneration of energy and heat, and direct use of methane are all possible.
- Municipal waste should not be routinely composted before disposal, and certainly not in open air windrows. Landfill with gas capture is a better option for reducing emissions, and producing bio-fuel.
- Home composting bins may produce more greenhouse gas per unit of waste than landfill.
- Compost can play an important role in Australia, especially in organic farming and as tip cover, to oxidise escaping methane, but high quality compost from separated organics is best for both purposes. The priority is to compost rural and animal wastes which currently do not go to best practice landfill and may be releasing large quantities of CH_4 and N_2O.

Background: Melbourne moves to divert organic waste from landfill to compost

In Melbourne, the Metropolitan Waste Management and Resource Recovery Strategy (MWMS 2008) examined several options for solid waste management in 2008 and produced a policy this year.

Melbourne households are already supplied with two bins, one for recyclables (bottles, cans, plastics, paper) and another for residual waste. Suburban households often have a third bin for garden waste. Australia has a policy of minimising waste to landfill. A study of residual waste in 2005-6 found that 41% was food waste, 18% green waste and 6% paper – all organic waste which could be composted.

The MWMS plan considered options for diverting organic waste from landfill, including composting residual waste in large-scale Advanced Waste Treatment composters (AWTs); separating organic waste for aerobic or anaerobic composting, and thermal power from waste.

Hyder Consultants (Hyder 2008) were employed to carry out a study. They found thermal electricity generation performed best in all areas, even reducing air pollution because it would replace highly polluting brown-coal-fired energy, which is the current source of Melbourne's electricity. Burning the waste would also reduce GHG emissions by eliminating methane from landfill. However it rejected the option of incineration because of community concerns and difficulty in siting the incinerators.

Compost: it found anaerobically digested, separated wastes produced the best compost, and produced 80-100kWh of energy for every tonne of waste. But not all organic waste would be removed from landfill; there would still be methane gas escaping. The MWMS study therefore favoured Advanced Waste Treatment, with all residual waste including garbage composted. This produces stabilised landfill and poor quality compost. A submission from Boral, the managers of Melbourne's Western Landfill (Boral submission 2007) and also involved in composting at the Pine-Gro composting plant, suggested the compost from mixed residual waste would be unsalable, and would probably go to landfill. Anaerobic treatment of mixed residual waste is difficult because of contaminants (Fulhage, 1993). The Hyder study found it would produce no net energy and in fact slightly cost in energy.

Measuring methane from landfill, composting and incineration

Our present study aims to objectively compare the options for waste disposal. It uses the United Nations Framework Convention on Climate Change (UNFCCC/CCNUCC) "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site", version 4, 2008 ("the tool") to compare methane generation from landfill versus aerobic composting and GHG emissions from incineration. Equations and background information from the 2006 IPCC "Guidelines for National Greenhouse Gas Emissions", Vol. 5 "Waste", Chapters 2 – 5 and Vol.2, "Energy" were also used.

The following factors are used to calculate methane emissions:
1. Quantity of organic waste deposited in landfill each year, per household.
2. Fraction of degradable organic carbon in the waste (averaged over its various components)
3. Fraction that actually converts to methane. Only about half of this matter ever decomposes, and of this, only half converts to methane.
4. The conversion factor from carbon to methane.
5. The rate of accumulation of waste in the landfill, and the rate of decomposition of waste.
6. Methane captured from landfill for flaring or fuel.
7. "Methane correction factor": Some organic material decomposes aerobically due to oxygen inside the landfill: less if it is wet and anaerobic, more if it is well managed and dry.
8. Some methane oxidises on its way out, if the site has a soil or compost "biocap" cover.

Altogether, only a very small amount of potential methane escapes from best practice landfill, and it is produced very slowly, as the decomposition rate in a dry temperate climate is only about 5% per year. Aerobic composting produces mostly CO_2, but also releases a small amount of methane (the IPCC default estimate is 4 grams of methane per kilogram of organic waste).

Incineration produces mostly CO_2. Open burning of waste does produces CH_4 but continuous fluidised bed incineration produces none at all. In this study it is assumed that semi-continuous fluidised bed incineration is used – this produces CH_4 and N_2O which have been taken into account in calculating emissions.

Results

1. GHG from landfill versus aerobic composting

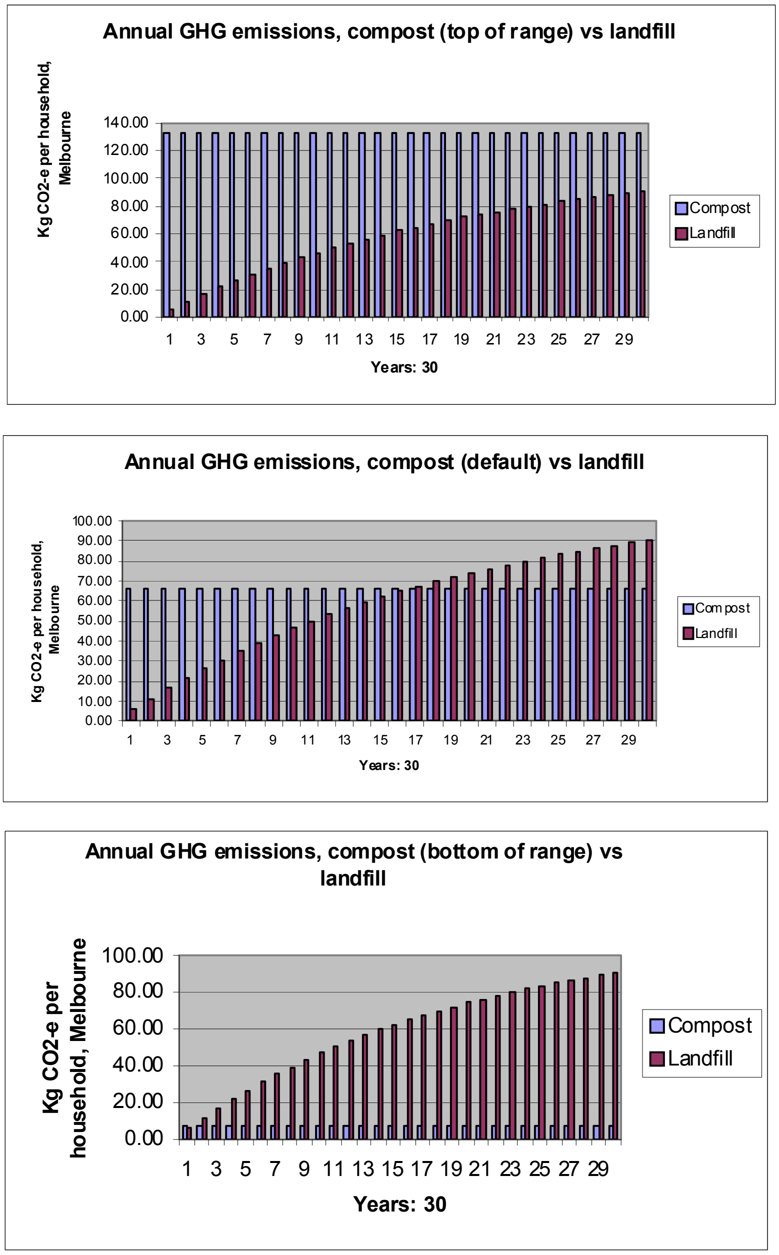


Fig. 1: Greenhouse gas emissions over 30 years: landfill compared to a range of values for composting.

The top chart shows maximum expected GHG emissions for managed composting. These are likely to be found in a warm climate, where compost is kept wet. The second chart shows the IPCC default value for compost. The third shows minimum values, probably inapplicable to Australia. Much of the IPCC's referenced data is from Scandinavia and Finland where it is very much colder than Australia and so little methane is produced.

Methane and N_2O emissions from poorly managed composting may be even higher than those shown in the top graph. Bert Metz (2007 IPCC) points out "CH_4 and N_2O can both be formed during composting by poor management and the initiation of semi-aerobic (N_2O) or aerobic (CH_4) conditions; recent studies also indicate production of CH_4 and N_2O in well-managed systems (Hobson et al 2005)."
A small but disturbing study from the Griffith University, Queensland, Australia (the Insinkerator study, 1994) compared household composting systems with sink disposal units and landfill. Very high levels of methane were found in unmanaged household compost bins.

Assumptions on methane correction factor in landfill
The above graphs assume a methane correction factor (MCF) of 0.6 for landfill, i.e. it is 60% anaerobic. The IPCC recommends this value if it is not known how the waste is managed. If waste is unmanaged in a shallow tip, the MCF value is 0.4, as much of the waste will degrade aerobically. If the waste is buried deep or the water table is a high, e.g. if it is dumped in a swampy area, a value of 0.8 is used. If it just compacted or levelled and covered, the MCF is 1.

In the 1996 IPCC Guidelines, all managed waste was assumed to be 100% anaerobic (an MCF of 1). This was a heroic assumption. It requires only very low levels of oxygen in the waste to produce some aerobic decomposition, especially before anaerobic conditions are established in the waste (see Metz, IPCC 2007). A recent Swedish study (Smars, Sven and Beck-Friis 2002) found some aerobic decomposition in waste was still occurring at 1% oxygen levels.

In the 2006 IPCC guidelines a new category of semi-anaerobic landfill has been introduced with an MCF of 0.5. This type of landfill has leachate drainage, gas capture, ventilation and permeable cover. In Melbourne, landfill sites typically have leachate drainage and gas capture. It is uncertain whether the tip cover is permeable. (It is not intended to be, yet it is estimated that 40% of the methane escapes through it.) The subsoil is extemely dry, relative to Europe and Scandinavia. This would tend to allow oxygen to penetrate.

Further studies are required to establish how much decomposition occurs before landfill conditions become anaerobic, how much oxygen is found in landfill gas and what the real MCF is in Melbourne. The Australian Government Department of Climate change still classifies all landfill in Australia as 100% anaerobic on the grounds that it is "managed". This follows the classification in the now superseded 1996 IPCC Guidelines. More up-to-date estimates are needed.

Why do the results show higher emissions for compost relative to landfill and incineration than are generally assumed?

Much of the widespread understanding of GHG emissions from landfill, compost and incineration is based on early modelling in the 1996 IPCC Guidelines. Since then it has been discovered that:
- composting does release CH4 and N2O. A range of estimates has been provided.
- landfill is not always 100% anaerobic but can be semi-anaerobic, with an MCF of 0.5.
- much organic material in waste does not degrade under anaerobic conditions. The 2006 IPCC advises that only 50% at most will decompose in landfill. Of this, only about 5% of decomposable organic waste decomposes each year.
- a "First Order Decay model" has been introduced to account for the slow decay of waste in landfill: Earlier models erroneously assumed that decomposition all occurred in the first year.

Assumptions on carbon storage, gas capture and gas oxidation in tip cover

The 2006 IPCC Guidelines' assumption of 50% carbon storage in landfill is conservative. The IPCC also conservatively assumes that only 10% of methane is oxidised in soil or compost cover of landfill: the USEPA (2002) puts it at 70-85%. Finally our study assumes 60% of landfill gas is captured but Metz (IPCC 2007) states that gas capture may be 90% or more.
There are still many unknowns but assumptions in this study are probably conservative.

2. Results on Incineration versus the other two options

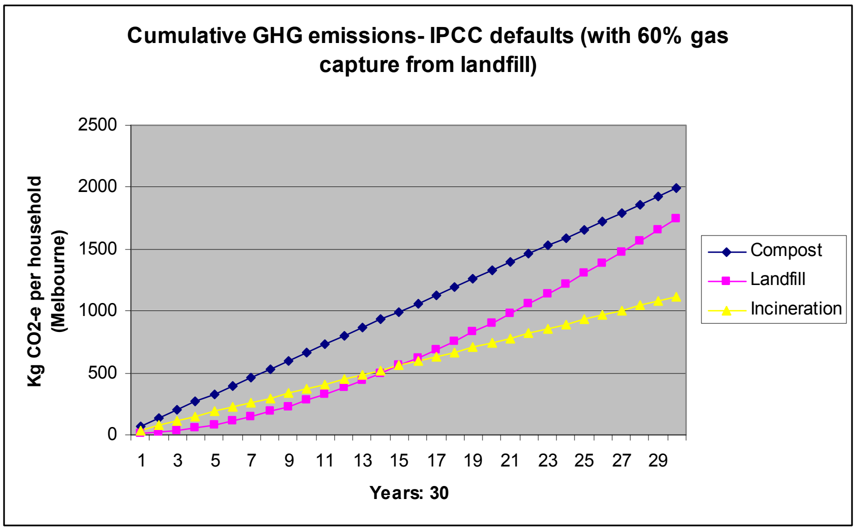


Fig 2: Cumulative Greenhouse gas emissions over 30 years: compost, landfill and incineration.

Incineration produces the least GHG. According to the Hyder report 2007 it would also produce less of other kinds of air pollution and more green energy than other options.

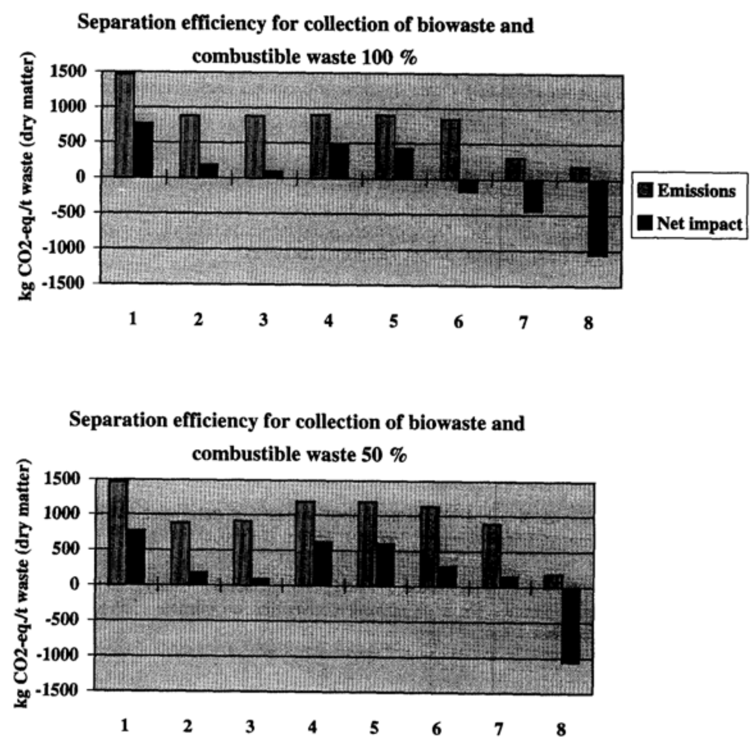
Note that the IPCC considers only CO2 from burning fossil-fuel based wastes to be anthropogenic (man-made). CO_2 produced from burning organic waste is not counted. It would occur anyway in nature, whether the waste material oxidised slowly in decomposition or quickly in burning. CO_2 emissions from composting and landfill are also not counted. As the global warming potential of methane and nitrous oxide is much greater than that of CO_2, including non-anthropogenic CO_2 would make little difference to the results.

Findings

1. For about the first 30 years, under the assumptions used in our study, aerobic composting releases greenhouse gas (GHG) more quickly than landfill, meaning that climate change is accelerated. Possibly in 30 years, energy prices will be so high that landfill is mined as a fuel, or better methods of containing CH4 in landfill will be developed. So the predicted longer term emissions from landfill may never eventuate. Diverting organic waste to compost now may be counter-productive, merely hastening global warming.

2. Incineration produces the least man-made GHG emissions of all methods of waste disposal. The Hyder study of Melbourne's waste (2007) found the same thing. In some Scandinavian countries, thermal waste-to-energy has been part of national energy since the 1970s global energy crisis (Bateman 2006). A study by Dr Riitta Pipatti, leading author of the 2006 IPCC Guidelines Vol. 5, "Waste", and I. Savolainen (1996) found that mass incineration was the best option and that composting released more emissions than landfill with gas capture: compare options 3 and 4 in the following diagram from the Pipatti study:

PIPATTI and SAVOLAINEN: ROLE OF ENERGY PRODUCTION 1109



Waste treatment chain
1 Landfills
2 Landfills + gas recovery + flaring
3 Landfills + gas recovery + energy production
4 Composting of biowaste + landfills
5 Anaerobic treatment of biowaste + landfills
6 Burning of combustible waste + landfills
7 Anerobic treatment of biowaste + burning of combustible waste + landfills
8 Mass incineration

Figure 2. Greenhouse impact due to alternative municipal waste treatment chains per tonne dry matter of average municipal waste.

Recommendations

- Provide public education to calm the public's fears about incineration, and explain that CO_2 and some CH_4 are released when waste decomposes in landfill or compost. This is not widely understood. Many people believe composting produces no GHG of any kind, and that the carbon all stays in the compost.
- Further research should be done on:
  -Municipal waste as an alternative fuel for electricity generation, instead of the present fuel, coal.
  -Emission levels of methane from municipal and household compost in warm conditions. There is little data on emissions from household composting systems, but what exists, suggests unmanaged bins may produce high levels of methane.
  -the possibility of reducing CH4 emissions from landfill with compost bio-caps
- Where possible methane emissions from aerobic composting should be captured and oxidised. The emphasis in composting should be on rural and agricultural wastes, especially animal manure.

References

IPCC 2007: Fourth Assessment Report, chapter 2 pp 206, 212 Diagram 22.25 and text.

MWMS 2008: “Draft Metropolitan Waste and Recovery Strategic Plan” released on 2 April 2008 at www.sustainability.vic.gov.au , now accepted with some changes. Most information is in the “Schedule”.

2006 IPCC Guidelines for National Greenhouse Gas Emissions Vol. 5 “Waste”, Chapter 2-5 and Vol. 2, “Energy”, section 2.3 Table 2.4.

Also the UNFCCC/CCNUCC “Tool to determine methane emissions avoided from disposal of waste at a solid waster disposal site” (version 4, 2008).

R. Pipatti and I. Savolainen 1996, “Role of Energy Production in the Control of Greenhouse Gas from Waste Management,”

Hyder Consulting (2007): “Modelling and analysis of options for the Metropolitan Waste and Resource Recovery Strategic Plan,” 2007. Lifecycle calculations by Tim Grant are in the “Appendix: LCA of Waste Management Options”, RMIT Centre for Design, Dec 2007, on www.mwmg.vic.gov.au

Boral 2007: Comments from Boral in response to reference 3 above, from Boral Melbourne, www.boral.com.au, or at: www.sustainability.vic.gov.au/resources/documents/boral.pdf

Fulhage, Charles et al, 1993. “Generating Methane” University of Missouri Extension,

Insinkerator Study 1994: Professor Philip Jones et al: “Economic and environmental impacts of disposal of kitchen organic wastes using traditional landfill - Food waste disposer - Home composting”, Waste Management Research Unit, School of Engineering, Griffith University, Queensland.

Bateman, Sam, Hanson Landfill Services: “Response to the Productivity Commission Inquiry Draft Report on Waste Management” Feb 2006.

Guzzone. Brian and Mark Schlagenhauf “ Garbage in, energy out - landfill gas opportunities for CHP projects” in Cogeneration & On-Site Power Production website //www.cospp.com. September 2007

“Cover Up with Compost” U.S. EPA fact sheet, Washington 2002
The fact sheet concerns a study of biocaps on landfill.: “Austrian researchers Humer and Lechner found that their [compost cover] system results in complete decomposition of the methane released from a 10-year-old landfill site more than 65 feet deep... a matured compost characterized by a high humic content, low ammonium and salt concentrations, and adequate pore volume yielded the best results. Their emission reductions exceed that of a landfill gas recovery system, generally thought to collect about 70 to 85 percent of the total landfill gas generated."

Metz, Bert: IPCC Climate Change 2007: “Mitigation of Climate Change”
Intergoverrmental Panel on Climate Change, Working Group 3, Chapter 10 Waste Management.

Smars, S: “Influence of different temperature and aeration regulation strategies on respiration in composting”, Doctoral Thesis, Swedish University of Agricultural Sciences, Uppsala 2002, with B. Beck-Friis.

Assumptions Used in the Spreadsheets

It is assumed that 60% of the methane landfill gas is captured. This is based on the estimate for Victoria given in the Hyder study and personal communication with Mr Clete Elms of Boral for Western Landfill. As Western Landfill (and Victoria in general) has low rainfall, a low water table and gas and leachate collection, the MCF was assumed to be 0.6 (the default option for “unknown”). The oxidation factor for methane escaping through the biocap.from landfill is assumed to be 10%.

A Victorian Department of Sustainability study of residual waste for northern municipalities of Melbourne 2005/6, shows 41% of waste is food organics, 18% garden organics, 6% paper and cardboard and a small quantity of nappies. This breakdown of waste was used in the study. Household waste is assumed to be 75% organic. Average amount of waste to landfill for a suburban household was assumed to be 500 kg. p.a.

The 2006 IPCC Guidelines were used for the following:

IPCC Fractions of degradable organic carbon (DOCj) by weight the waste type j (wet weight)

Wood, wood products	43%	
Pulp, paper & cardboard (other than sludge)	40%	
Food, food waste, beverages, tobacco ,,	15%	
Textiles	24%	
Garden, yard and park waste	20%	(Inert waste 0)

<u>IPCC Default k values - boreal and temperate (for a low rainfall area)</u>
multiplied by percentage of organic component of waste to give average decay rate (as a fraction):

Paper, cardboard	0.04	x	8%	0.0032
Green waste	0.05	x	25%	0.0125
Food waste	0.06	x	60%	0.0360
			Total	0.052 per annum weighted average.

Source: 2006 IPCC Vol. 5 "Waste", Tables 2.4 and 2.5, and Chapter 3. The original formula from The UNFCCC "Tool for calculating the amount of methane avoided from solid waste disposal, Version 4, 2008" is used as a basis for the equations:

$$BE_{CH4,SWDS,y} = \varphi \cdot (1-f) \cdot GWP_{CH4} \cdot (1-OX) \cdot \frac{16}{12} \cdot F \cdot DOC_f \cdot MCF \cdot \sum_{x=1}^{y} \sum_{j} W_{j,x} \cdot DOC_j \cdot e^{-k_j \cdot (y-x)} \cdot \left(1-e^{-k_j}\right) \quad (1)$$

What the terms mean:

BE Baseline emissions

Φ This is an uncertainty factor to make the equation more conservative when claiming carbon credits for avoiding emissions. It is omitted from the spreadsheet.

(1-f) Fraction of methane flared or captured. If 60% or 0.6 of the methane is captured, 1-f is 0.4.

GWP This is the global warming multiplier to convert methane to CO_2; a 21 GWP has been used in the graphs but the higher figure of 72 (over 20 years) is shown in the tables as well.

OX Oxidation factor: the amount of methane oxidised in the bio-cap. The 2006 IPCC default value is 0.1 or 10%. If there is soil bio-cover, (1 - OX) = 0.9.

16:12 This ratio converts the molecular weight of carbon to that of methane.

F Fraction of methane in landfill gas- usually 50% or 0.5 as a fraction.

Doc_f Fraction of degradable organic carbon that can decompose in landfill – again 0.5. (2006 IPCC)

MCF Methane correction factor – this indicates that some organic waste decomposes aerobically. For a shallow unmanaged landfill it is 0.4. A managed site with permeable cover, leachate drainage, gas ventilation etc in a temperate/boreal climate is 0.5. (Source, "Tool" cited above.)

$\sum_{x=1}^{y}$ is the sum of the amounts of waste deposited since first year of the project (x = 1), shown as a table.

∑Wj,x is the sum of the types of waste deposited in the SWDS. For Western Landfill

Docj Fraction of degradable organic carbon by weight in the waste type. Food is 15% DOC by wet weight, green waste is 20% and paper 40%.

Kj is the decay rate for waste type j. (See table above.)

e is Euler's number, a constant used for calculating exponential decay or accumulation. The two expressions involving "e" show time taken for methane levels to accumulate, and for the waste to decompose away.

y is the year for which emissions are calculated, for instance year 10 of waste disposal. Note the results will be different for every year. The years are set out sequentially in Spreadsheet 2:

The Spreadsheet:

Methane emissions: Landfill, composting and incineration

For a typical Melbourne SWDS, per household, p.a.

Landfill ***Variables related to waste***

Source 1	Waste to landfill per household	500 kg		MCF = 0.6	MCF=!	
	$W_{j,x}$	organic waste: assume 75% of waste	kg	375.00		
	DOCj	Fraction of degradable organic carbon (wet weight)		0.20		
	DOCf	Fraction of DOC that degrades in anaerobic site		0.50		
	MCF	methane correction factor- if unknown		0.60		1
	Semi-aerobic managed is 0.5. Completely anaerobic = 1					
	DDOCm	mass of decomposable org. carbon that degrades			22.5	37.50

Variables related to time and decay rate

Ratio CH4:C = 16:12			1.333
kj = decay rate for waste type j		0.053	
e^{-kj}	rate of accumulation of waste	0.9484	
$(1 - e^{-kj})$	decomposition rate of accumulated waste		0.0516

Variables related to SWDS

F- assumes 60% of gas is captured		0.6	(1-f)	0.40
(1-OX)	Default (assumes soil or compost cover)			0.90

Results

Methane captured in year 20		Kg methane	5.88
Methane emissions		Kg methane	3.53
GWP	21	Kg CO2-e	**74**
GWP	72	Kg CO2-e	**254**

2. Compare aerobic composting

Source 2

CH4 emissions = $\sum(M_i \cdot EF_i) \cdot 10^{-3} - R$ *R = 0*

Mi	mass of organic waste treated, kg	375.00	IPCC min:	IPCC default:	IPCC max:
Efi	emission factor for composting	As follows:	0.03	4	8
Convert from grams to kgs		0.001			
			Range from boreal to warm		
Methane emissions		Kg methane	0.01	1.50	3.00
GWP	21	Kg CO2-e	**0.24**	**31.50**	**63.00**
GWP	72	Kg CO2-e	**0.81**	**108.00**	**216.00**
Nitrous oxide emissions	(calculate as for CH4)		0.06	0.30	0.60
		Kg N2O	0.02	0.11	0.23
GWP	310		**6.98**	**34.88**	**69.75**
Total greenhouse emissions	methane GWP = 21		0.24	31.50	63.00
	Nitrous oxide, GWP=310		6.98	34.88	69.75
	TOTAL	Kg CO2-e	**7.21**	**66.38**	**132.75**

Sources:

1 UNFCCC 2008, "Tool to determine methane emissions avoided from disposal of waste at a SWDS"
2 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 5, Chs 4, table 4.1
3 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 5, Ch. 5 Equation 5.2 & Ch 3.
4 As above, Vol 2 Ch. 2: Stationary Combustion, table 2.2

3. Compare incineration

Sources 3, 4.

Equation 5.2 CO2 emissions based on the solid waste composition

Waste incinerated per household		kg	500.00
CO2 emissions	27.50		
CO2-e (methane)	1.97		
CO2-e (nitous oxide))	7.75		
Greenhouse emissions Kg Co2	**37.22**		

Note biogenic emissions of CO2 (from incineration, landfill and composting) are not reportable.
To find the total for incineration (for information only) omit the FCF factor. For landfill it will equal methane generated.

The following diagrams do not take into account the GHG emissions that would be saved by using landfill solids or landfill gas as an alternative fuel, so avoiding the use of brown coal in Victoria.

Total GHG emissions from electricity in Victoria are 1.31 tonnes CO2-e per MWh
(based on brown coal use for electricity generation)
Total GHG emissions from natural gas used directly for heat are 0.0572 Tonnes CO2-e per GJ.
Sources: National Greehouse Accounts (NGA) Factors Nov 2008

Greenhouse gas emissions for gas to electricity are estimated at:
0.4 tonnes per MWh for combined cycle gas plants
0.6 tonnes per MWh for other oil and gas to electricity technologies.
Source: "Greenhouse Gas Issues with Australia's Electricity Industry
Cumpston, R. and Burge, A. The Institute of Actuaries of Australia 2003.

Total methane emissions over a 30 year period

Assumes MCF = 0.6 (default option where management is not known)

	Cumulative org. carbon in landfill at end of yr kg p.a.	Methane generated landfill kg p.a.	Methane emissions landfill kg p.a.	Cumulative methane from landfill kg	Cumulative GHG compost (inc. N2O) Kg CO2-e	Cumulative CO2-e GWP = 21 Landfill kg CO2-e	Cumulative Co2 emissions Incineration Kg CO2
	A	B	C	D	E	F	G
Year	DDOCma	Generated	Emitted	Landfill	Compost	Landfill	Incineration
Yr 1	22.50	0.77	0.28	0.28	66	5.85	**37.22**
Yr 2	43.84	1.51	0.54	0.82	133	17.25	74.44
Yr 3	64.08	2.20	0.79	1.61	199	33.91	111.66
Yr 4	83.27	2.86	1.03	2.65	266	55.56	148.88
Yr 5	101.47	3.49	1.26	3.90	332	81.94	186.10
Yr 6	118.73	4.08	1.47	5.37	398	112.81	223.32
Yr 7	135.10	4.65	1.67	7.04	465	147.94	260.54
Yr 8	150.63	5.18	1.86	8.91	531	187.10	297.76
Yr 9	165.36	5.69	2.05	10.96	597	230.09	334.98
Yr 10	179.32	6.17	2.22	13.18	664	276.72	372.20
Yr 11	192.57	6.62	2.38	15.56	730	326.78	409.42
Yr 12	205.13	7.05	2.54	18.10	797	380.12	446.64
Yr 13	217.04	7.46	2.69	20.79	863	436.55	483.86
Yr 14	228.34	7.85	2.83	23.61	929	495.91	521.08
Yr 15	239.05	8.22	2.96	26.57	996	558.07	558.30
Yr 16	249.21	8.57	3.09	29.66	1062	622.86	595.52
Yr 17	258.85	8.90	3.20	32.86	1128	690.16	632.74
Yr 18	267.99	9.22	3.32	36.18	1195	759.84	669.96
Yr 19	276.66	9.51	3.43	39.61	1261	831.77	707.18
Yr 20	284.88	9.80	3.53	43.14	1328	905.84	744.40
Yr 21	292.67	10.07	3.62	46.76	1394	981.93	781.62
Yr 22	300.07	10.32	3.72	50.47	1460	1059.95	818.84
Yr 23	307.08	10.56	3.80	54.28	1527	1139.79	856.06
Yr 24	313.73	10.79	3.88	58.16	1593	1221.36	893.28
Yr 25	320.04	11.01	3.96	62.12	1659	1304.57	930.50
Yr 26	326.02	11.21	4.04	66.16	1726	1389.33	967.72
Yr 27	331.69	11.41	4.11	70.27	1792	1475.57	1004.94
Yr 28	337.07	11.59	4.17	74.44	1859	1563.21	1042.16
Yr 29	342.17	11.77	4.24	78.68	1925	1652.18	1079.38
Yr 30	347.01	11.93	4.30	82.97	1991	1742.40	1116.60

When SWDS is full, wastes decline (half life about 13-14 years)

Column A DDOCma = organic waste x 0.2 x 0.5 x MCF (0.5) + 0.948 x previous year's accumulated DDOCm
column B methane generated = DDOCma X 0.5 x 0.333 x).052
Column C methane emitted = methane generated x 0.4 x 0.8
Column D Column C (annual methane emissions) cumulative over 30 years
Column E Cumulative CO2-e, aerobic compost. Includes CH4 & N2O. Note N2O from land
Column F Cumulative CO2-e from landfill, derived from CH4.
Column G Cumulative CO2 emissions from non-biogenic sources, from incineration of mun

Biogenic CO2 emissions are excluded from all calculations, as these are not included under IPCC requirements.

Graph 1. assumes 60% of methane is captured. Landfill has some of the characterisitics of semi-anaerobic and some aerobic characterisitics. MCF of 0.6 has been used, with the default option for GHG emissions from compost. Incineration is assumed to be by semicontinuous fluidised bed incineration.