Waste management options to reduce greenhouse gas emissions from paper in Australia

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Abstract

A lifecycle assessment to estimate greenhouse gas emissions in Australia from the paper cycle is summarised. The greenhouse gas emissions from paper in Australia in 1999/2000 were estimated to be 12.1 million tonnes (Mt) of CO2 equivalent. Nearly half of this amount consisted of CH4 emissions from landfilled waste paper. Various waste management options were modelled to investigate the greenhouse impact of a tonne of paper over its whole lifecycle. Options that keep paper out of landfills significantly reduce greenhouse emissions, waste-to-energy recovery being most effective. Recycling is also beneficial, and is of particular interest from a management perspective because it can be controlled by the pulp and paper industry. These findings can be extended to other wood-based and organic wastes.

Keywords: Methane; Carbon dioxide; Recycling; Landfill; Energy recovery; Bioreactor

1. Introduction

Australia’s estimated greenhouse gas emissions (GGEs) in 1998 totalled 460 million tonnes (Mt) of carbon dioxide equivalent (excluding emissions from land use change and forestry). Most was due to fossil fuel use, but 3.4% could be directly attributed to the waste sector—over 90% of which came from emissions related to anaerobic decomposition of organic matter in landfills (AGO, 2000a). Despite recent increases in the paper recovery rate, paper still makes up a significant proportion of Australian municipal waste, comprising some 10% of the municipal waste tonnage going to landfill (EPA, 1999).

A study by Pickin (1996a) located 17 investigations of greenhouse emissions from the paper cycle of varying degrees of complexity. Most were European, undertaken as part of a wider lifecycle environmental assessment or restricted to particular product types. Many of the studies were found to lack comprehensiveness, particularly in the way they considered the greenhouse impacts of methane generated from waste paper in landfills.

This paper reports on an update of Pickin’s (1996a) lifecycle GGE assessment of paper. The aims of the study were to provide a comprehensive investigation of total GGEs from the paper cycle in Australia, from forest through to landfill, and to assess the effectiveness of various waste management options to reduce GGEs from paper.

2. The analysis framework

Spreadsheet models of the paper production and consumption system were constructed and used to undertake two analyses. Analysis 1 examined total GGEs associated with the paper lifecycle in Australia during 1999/2000. Analysis 2 compared the “cradle-to-grave” GGEs from 1t of paper in a range of waste management scenarios. Detailed descriptions of these
analyses are given after consideration of some broad issues in constructing the analysis framework.

2.1. Lifecycle assessment

Environmental assessment of a product over its entire lifecycle can indicate the extent of the manufacturer’s environmental responsibilities beyond the boundaries of its own facilities, and can help to identify appropriate management options. Lifecycle assessment (LCA) is a technique for assessing the environmental aspects and potential impacts associated with a system (product system or service system) by

(i) compiling an inventory of relevant inputs and outputs of the system;
(ii) evaluating the potential environmental impacts associated with those inputs and outputs; and
(iii) interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study (ISO 14040, 1997).

The methodology used in this study has many similarities to the above approach by tracking “cradle-to-grave” impacts of a “functional unit” of a product. Analysis 2 bears a greater similarity since each of the scenarios describes a functional unit. However, this research involves only one type of environmental impact rather than a range of impacts. The analyses were undertaken on a spreadsheet.

2.2. Emission categories

The GGEs from the paper production and consumption system are of two distinct origins: (i) fossil fuel use during harvesting, manufacturing and transport and (ii) uptake and emission of carbon-bearing gases during growth and decay of organic material used in paper production (the organic material cycle). In this study, these two major sources of GGEs were divided into eight major emission categories based on the paper lifecycle, as follows:

1. fossil fuel use in material acquisition and transport;
2. fossil carbon use in pulping and recycling;
3. fossil fuel use in paper making;
4. fossil fuel use in processing and commerce;
5. methane from landfilled waste paper;
6. methane and nitrous oxide from other degradation processes;
7. emissions offset by energy recovery from waste paper; and
8. net carbon dioxide balance in the organic material cycle (after carbon accounted for in categories 5–7 has been deducted).

The analyses aimed to assess the relative importance of GGEs in these key categories.

2.3. Boundaries

For the purpose of analysis, the system must be bounded but in reality it is connected to and embedded in the general economy and environment. The system boundaries and rationale for choosing them are summarised in Table 1. Some are logically implicit but, inevitably, there is a degree of arbitrariness about others.

In Analysis 1, a national focus was required so GGEs from paper imports and exports that arose outside Australia were ignored. Both analyses excluded construction emissions, which are difficult to estimate and are of lesser relevance to the research aims. Most analysts, for example, Bousted (1992) and BNMA (1995) maintain that construction emissions are generally small compared with the emissions related to production, and it has consequently become standard procedure to ignore them. Only the main greenhouse gases (carbon dioxide, methane, and nitrous oxide) are included in the analyses. Unlike carbon dioxide, the latter gases are not taken up by plants so these emissions represent net exports from the paper system (SCCCS, 1995; Crutzen et al., 1979).

2.4. Time considerations

Calculation of the emissions from paper in Australia during 1999/2000 required data on material flows in that year for each of the system elements, most of which were estimated from paper production statistics. However, this is not an accurate method for estimating emissions from decaying organic material, since degradation processes are drawn out over years or decades and therefore the waste generated during 1999/2000 is not the material actually decaying in that year. Consequently, the emissions from the decay of harvest residues and of landfilled waste paper were estimated on the basis of historical production data and an assumed exponential decay rate (described later).

A second time consideration relates to the warming effect of the emitted greenhouse gases. Each gas has a different warming intensity and a different expected atmospheric residence time, so comparisons can only be made with reference to a given time span. The unit “Global Warming Potential” (GWP) is used for this purpose, and is defined as the degree of greenhouse warming caused by a mass of gas relative to carbon dioxide, from the start of the assessment period to some selected planning horizon. Choice of time frame depends on the planning horizon considered appropriate in the particular analysis to be undertaken. The National Greenhouse Gas Inventory (NGGI) and most other
studies use a 100 yr planning horizon (AGO, 2000a). This is because a 100 yr assessment period is reasonably long term but is still short enough to account for the strong short-term effect of methane. This study similarly uses a 100 yr planning horizon.

2.5. Collecting information and data

A wide range of data and information were required. This included general information on the greenhouse effect, forestry and paper manufacturing and decay processes, as well as data on mass flows of materials, the energy content of materials, emission intensities of fossil fuels, power generation methodologies in different areas, vehicle fuel consumption, and transport distances. Most information required for the study was obtained from published literature, particularly industry statistics, government reports, and technical journals. Additional information, written and verbal, came from consultations with academics and industry representatives. Data from the NGGI (AGO, 2000a–c; NGGIC, 1998; NGGIC, 1994) were used where possible so that the results of this research would be comparable with the national figures. Other main sources of data used in the analyses are summarised by subject theme in Table 2.

2.6. Limitations

With the exception of data obtained from the NGGI (AGO, 2000a–c) where some of the uncertainty and levels of confidence were provided, the degree of uncertainty in the data and assumptions in most cases is unquantified and probably unquantifiable. Hence data, calculations, and results are expressed as point estimates with no confidence levels. The results should therefore be seen as indicative only.

2.7. Fate of carbon in waste paper degradation

Decay of paper in municipal landfills generally follows a predictable sequence in which a brief aerobic stage producing CO2 is succeeded by anaerobic processes producing mainly CH4 and CO2 as end products. The rate of progression is highly variable and is critically

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Table 1
Boundaries of the system analysed

<table>
<thead>
<tr>
<th>System component</th>
<th>Selected boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse gases</td>
<td>Included: The main greenhouse gases: carbon dioxide, methane and nitrous oxide</td>
</tr>
<tr>
<td></td>
<td>Excluded: Various minor greenhouse gases</td>
</tr>
<tr>
<td>Product types</td>
<td>Excluded: Imported finished paper products not classified as paper in import data (e.g. books, product packaging). These are not detectable in industry statistics, but are thought to be a relatively small component of total consumption (Stafford, pers. comm.)</td>
</tr>
<tr>
<td></td>
<td>Included: All types of paper and paperboard</td>
</tr>
<tr>
<td>Infrastructure construction</td>
<td>Excluded: Emissions from constructing industry-owned infrastructure (e.g. pulp mills, vehicles, offices) and other utilised infrastructure (e.g. roads, power stations)</td>
</tr>
<tr>
<td>Hydroelectric power</td>
<td>Excluded: Emissions from decaying vegetation and soils in flooded areas (Rosa and Schaeffer, 1994)</td>
</tr>
<tr>
<td>Fossil fuel energy</td>
<td>Included: Production emissions, encompassing the energy industry’s own emissions from mining, refining, transport, storage and marketing, and the fugitive emissions from these processes</td>
</tr>
<tr>
<td></td>
<td>Excluded: Emissions from geological exploration</td>
</tr>
<tr>
<td>Material acquisition and transport</td>
<td>Excluded: Emissions from harvesting and delivery to sawmill of material which becomes sawmill residue and is subsequently used in pulp manufacture; Emissions from transport for support functions (e.g. mill staff travelling to work); Return journeys of trucks used for transporting material (except logging trucks, for which there is no possibility of a return load of other products); and Emissions and uptake associated with growing, harvesting and transporting export woodchips</td>
</tr>
<tr>
<td>Paper processing</td>
<td>Excluded: Emissions associated with coatings and additives applied during converting, printing and publishing</td>
</tr>
<tr>
<td>Paper use by consumers</td>
<td>Excluded: All emissions from paper use by consumers (e.g. the operations of Australia post)</td>
</tr>
</tbody>
</table>
dependent on the amount of moisture. Most organic carbon leaving a landfill does so as CO₂ or CH₄, a minor proportion leaches out in solution and the rest becomes incorporated in humic materials and microorganism cells in the landfill (Belevi and Baccini, 1989; Christensen and Kjeldsen, 1989).

Paper displays “a high degree of biodegradability in a microbially active environment” and significant deterioration can occur in a matter of weeks (RTI, 1990). The major constituents, cellulose and hemicellulose, are readily broken down when conditions are suitable (Barlaz et al., 1989). Deterioration is generally slower in paper that is derived from mechanical pulp (RTI, 1990; IIED, 1995), which contains a high proportion of lignin, a “natural plastic” which is “slowly metabolised by microorganisms in air” but is “biologically inert in the absence of molecular oxygen” (Zeikus, 1980). However, in experiments using laboratory-scale landfills, Barlaz et al. (1997) found that “the degree of lignification of particular [waste] component was not a good predictor of the extent of [its] biodegradation”.

The “typical” decay time of paper in landfills estimated in various studies is shown in Table 3.

This study follows the methodology proposed in IPCC (2000), which suggests it is reasonable to assume that 77% of the degradable organic carbon (DOC) in landfilled organic material will be gasified if lignin carbon is not counted as DOC. The DOC component was estimated by subtracting the lignin carbon content from the average carbon content of paper as set out in Barlaz et al. (1997).

For Analysis 1, degradation of waste paper (excluding the lignin fraction) was assumed to follow a simplified exponential decay curve with a half-life of 5 yr. Although some paper may survive more than 20 yr, particularly if it is lignin-rich, the proportion was assumed to be negligible.

In accordance with NGGIC (1998), anaerobic degradation of paper was assumed to produce CH₄ to CO₂ in the proportion 1:1.


Analysis 1 examined the total GGEs associated with the paper lifecycle in Australia during 1999/2000. Table 4 lists all the emission categories and sub-categories.

Table 2
Types and sources of data used in the analyses

<table>
<thead>
<tr>
<th>Subject theme</th>
<th>Sources of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse gas emissions—general</td>
<td>Wilkenfeld et al. (1990), IPCC (1996)</td>
</tr>
</tbody>
</table>

Table 3
Estimate typical decay times for landfilled paper

<table>
<thead>
<tr>
<th>Source</th>
<th>Assumed decay time of paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bingemer and Crutzen (1987)</td>
<td>5–20 yr</td>
</tr>
<tr>
<td>Barson and Gifford (1989: p. 438)</td>
<td>Exponential decay function with a half-life of 1 yr</td>
</tr>
<tr>
<td>Grierson et al. (1991: p. 24)</td>
<td>1–5 yr</td>
</tr>
<tr>
<td>NGGIC (1994)</td>
<td>1 yr</td>
</tr>
<tr>
<td>NGGIC (1998)</td>
<td>25 yr (all waste types)</td>
</tr>
</tbody>
</table>

from the average carbon content of paper as set out in Barlaz et al. (1997).

Analysis 1 examined the total GGEs associated with the paper lifecycle in Australia during 1999/2000.
<table>
<thead>
<tr>
<th>Emission categories</th>
<th>Sub-categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1.1 Fossil fuel use in material acquisition and transport</td>
<td>A1.1.1 Felling and splitting of logged timber</td>
</tr>
<tr>
<td></td>
<td>A1.1.2 Plantation management</td>
</tr>
<tr>
<td></td>
<td>A1.1.3 Native forest management</td>
</tr>
<tr>
<td></td>
<td>A1.1.4 Transport of logs from forest or plantation to pulp mill</td>
</tr>
<tr>
<td></td>
<td>A1.1.5 Transport of sawmill residue to pulp mill</td>
</tr>
<tr>
<td></td>
<td>A1.1.6 Transport from pulp mill to paper mill</td>
</tr>
<tr>
<td></td>
<td>A1.1.7 Transport of sludge and solid waste from pulp/paper mill to disposal site</td>
</tr>
<tr>
<td></td>
<td>A1.1.8 Quarrying of fillers</td>
</tr>
<tr>
<td></td>
<td>A1.1.9 Transport of fillers from mine to pulp/paper mill</td>
</tr>
<tr>
<td></td>
<td>A1.1.10 Transport of paper from mill through merchant, converter, printer, wholesaler and retailer to consumer (including pre-consumer waste to recycling mill)</td>
</tr>
<tr>
<td></td>
<td>A1.1.11 Shipping of pulp and paper imports</td>
</tr>
<tr>
<td></td>
<td>A1.1.12 Transport of imported pulp to paper mill</td>
</tr>
<tr>
<td></td>
<td>A1.1.13 Transport of imported paper from port through merchant, converter, printer, wholesaler and retailer to consumer (including pre-consumer waste to recycling mill)</td>
</tr>
<tr>
<td></td>
<td>A1.1.14 Garbage collection</td>
</tr>
<tr>
<td></td>
<td>A1.1.15 Recycling collection</td>
</tr>
<tr>
<td></td>
<td>A1.1.16 Shipping of imported waste paper</td>
</tr>
<tr>
<td></td>
<td>A1.1.17 Transport of domestic waste paper from recycling warehouse to paper mill or port, and of imported waste paper from port to paper mill</td>
</tr>
<tr>
<td>A1.2 Fossil carbon use in pulping and recycling</td>
<td>A1.2.1 Fossil fuel used in pulping and recycling</td>
</tr>
<tr>
<td></td>
<td>A1.2.2 Pulping chemicals manufacture</td>
</tr>
<tr>
<td>A1.3 Fossil fuel use in paper making</td>
<td>A1.3.1 Fossil fuel use in paper making</td>
</tr>
<tr>
<td>A1.4 Fossil fuel use in processing and commerce</td>
<td>A1.4.1 Fossil fuel use in paper processing</td>
</tr>
<tr>
<td></td>
<td>A1.4.2 Fossil fuel use in commercial activities</td>
</tr>
<tr>
<td>A1.5 Methane from landfilled waste paper</td>
<td>A1.5.1 Methane from landfilled waste paper</td>
</tr>
<tr>
<td>A1.6 Methane and nitrous oxide from other degradation processes</td>
<td>A1.6.1 Methane emissions from disposal of paper in sewage</td>
</tr>
<tr>
<td></td>
<td>A1.6.2 Methane and nitrous oxide emissions from waste paper incineration</td>
</tr>
<tr>
<td></td>
<td>A1.6.3 Methane emissions from treatment of manufacturing effluent</td>
</tr>
<tr>
<td></td>
<td>A1.6.4 Methane emissions from disposal of manufacturing sludge and solid waste</td>
</tr>
<tr>
<td></td>
<td>A1.6.5 Methane and nitrous oxide emissions from forest fires</td>
</tr>
<tr>
<td>A1.7 Offset by energy recovery from waste paper</td>
<td>A1.7.1 Emissions offset by landfill gas recovery</td>
</tr>
<tr>
<td>A1.8 Net carbon dioxide balance in the organic material cycle</td>
<td>A1.8.1 Carbon dioxide uptake by material grown for domestic paper production</td>
</tr>
<tr>
<td></td>
<td>A1.8.2 Carbon dioxide emissions from paper</td>
</tr>
</tbody>
</table>
covered in Analysis 1. Each of the sub-categories represents a discrete calculation of GGEs based on specified assumptions and the best available data. The results of these calculations were summed to provide an estimate of emissions in each of the major categories and an overall total. In all, the Analysis 1 involved 40 specified assumptions, 300 items of data and over 360 calculation steps.

Assessing the GGEs from the organic material cycle required construction of a carbon balance for the paper lifecycle in which decay emissions were weighed against CO$_2$ uptake by the plants used in the production system. Data are scant and some broad assumptions were necessary, they included:

- Soil carbon was in equilibrium throughout the production system.
- Five per cent of consumed paper entered net storage (based on discussions with industry sources).
- Energy recovered from waste paper was exported from the system, offsetting some GGEs from the use of conventional fuels.

2.9. Analysis 2: emissions from a tonne of paper in a range of scenarios

This analysis modelled GGEs from the lifecycle of a tonne of paper under a range of conditions in order to compare the effects of different waste management options. Three options were simulated:

(a) paper recycling;
(b) waste-to-energy; and
(c) various adjuncts (landfill gas recovery, composting and waste-to-energy) to paper recycling.

Landfill gas is commonly collected at modern well-engineered sites in Australia. Combustion of methane to carbon dioxide yields an energy harvest which can be used for producing electricity or process heat. Because of the expense of piping, “electricity production [is] the most favoured of landfill gas to energy projects” (Thorneloe et al., 1995). NGGI figures suggest that in 1998, 13% of methane generated at landfill sites in Australia was recovered, mainly for electricity generation (AGO, 2000a). Incineration of municipal waste, with or without energy recovery, is a common alternative to landfill disposal overseas, including the US, Europe, and Japan. In Australia, several dedicated waste-to-energy facilities using a range of technologies are planned or in the early stages of their operations.

Use of landfill gas and incineration of waste paper for energy recovery represent exports of energy from the paper system which effectively offset emissions from the use of conventional fuels. In this study, it was assumed that any energy recovered from waste paper is converted to electricity at an efficiency rate equal to the average for electricity generation in Australia. Calculation of the offset emissions was likewise based on the national average emission factors.

Analysis 2 mainly employed the data, assumptions and emission calculations from Analysis 1, to which a further 16 items of data and 12 assumptions were added. For each scenario, mass flows of material through the various production and consumption processes were calculated. The emission intensities of each process were derived and applied to the mass flow data to yield an estimate of the GGEs in each of the eight categories for each scenario. This involved more than 50 calculation steps for each scenario.

3. Results


The GGEs generated by paper in Australia during 1999/2000 were calculated at about 12.1 Mt of CO$_2$ equivalent. CH$_4$ represented 57% of the total net emissions and the rest was almost all CO$_2$. The GGEs in each of the eight emission categories are shown in Fig. 1.

The GGEs from fossil carbon were dominated by the manufacturing phase, with pulping, recycling, and paper making amounting to 41% of the total CO$_2$ equivalent. The combined effect of processing, commerce, material acquisition, and transport was a further 25%. The largest category was CH$_4$ emissions from landfilled paper, which gave rise to nearly 50% of the net emissions. The net carbon dioxide balance in the organic material cycle reduced gross GGEs by 17%.

3.2. Analysis 2: emissions from a tonne of paper in a range of scenarios

Fig. 2 demonstrates the effect of waste management option (a)—recycling paper at different rates. GGEs fall from 6.5 t of CO$_2$ equivalent per tonne of paper with no recycling to 4.4 t with 60% recycling. Fig. 3 gives GGEs in the eight emission categories used above. This shows that higher recycling rates cause changes in five of the categories but by far the most significant effect is a large decrease in CH$_4$ emissions from landfills due to a lower input of paper.

In waste management option (b), the waste is used as a fuel for producing electricity instead of being recycled, based on the same recovery rates as modelled in (a). The fall in GGEs with energy recovery, shown in Fig. 4, is sharper than with recycling, indicating that this approach is more effective for GGE abatement. The major difference is a large gain from using the recovered energy to offset GGEs from fossil fuel usage, as shown in Fig. 5.
Option (c) explores post-consumer management further, comparing the effect of three waste treatments as adjuncts to a 50% recycling rate. From left to right, Fig. 6 shows the effect of:

- 50% recycling and no additional waste treatment;
- 50% recycling and recovery of 30% of CH\textsubscript{4} emitted from landfilled paper for generating electricity;
- 50% recycling and 25% composting of waste paper; and
- 50% recycling and 25% waste-to-energy recovery for electricity production.

Again, waste-to-energy recovery produces the biggest reductions, but landfill gas recovery and composting are also beneficial.

3.3. The effect of planning horizon in GGE assessment

As mentioned previously, comparison of the warming effect of different greenhouse gases employs the unit GWP and a time frame must be specified because each gas has a different atmospheric residency period.

CH\textsubscript{4} has a strong greenhouse warming effect but a relatively short atmospheric residence period, consequently its GWP falls sharply from 56 over 20 yr to only 6.5 over 500 yr (IPCC, 1996). Most GGE assessments (including this work) use an intermediate 100 yr planning horizon over which CH\textsubscript{4} has a GWP of 21.

Fig. 7 illustrates the effect of altering the planning horizon in assessing the GGEs from a typical tonne of paper using an example of 50% recycling and no additional waste treatment. The 4.8 t of GGEs in a 100 yr planning horizon, shown in the first column, becomes 8.6 t over 20 yr and 3.2 t over 500 yr. This does not imply that the actual warming effect decreases with assessment time but, rather, the mass of CO\textsubscript{2} required to produce a warming effect equivalent to that of the gases actually emitted declines with time, following the GWP of CH\textsubscript{4}. The consequence of this variability is that CH\textsubscript{4} from landfills dominates GGEs over the short term and fossil carbon use in manufacturing processes dominates over the long term.

4. Discussion

Limitations in the data mean that the results are indicative only. The most critical uncertainty relates to
the fate of organics in landfills. The input data were derived from rather scant landfill literature that is disputed by some. The landfill archaeologists Rathje and Murphy (1992), for example, denied that rapid biodegradation in landfills is the norm, and pulp and paper industry researchers Gilbreath (1991) and Stott (1991) concluded that paper in many landfills emits little or no greenhouse gas.

These findings allude to the “dry tomb” management approach that aims to seal landfills from water ingress to minimise biodegradation. This approach is increasingly regarded as flawed since containment is bound to eventually fail, permitting more rapid biodegradation (Ham et al., 1993; Lee and Jones-Lee, 1993; Muntoni et al., 1995). However, the dry tomb approach will delay biodegradation and the emission of greenhouse gases. In contrast, the “bioreactor” landfill design—which aims to speed up decay processes to achieve rapid stabilization (Yuen, 1999)—will accelerate GGE production and concentrate the greenhouse impact nearer to the present.

The results of the analyses demonstrate the significance of landfills as sources of GGEs from paper and the importance of post-consumer waste management in controlling these emissions. The pulp and paper industry’s main GGE abatement efforts have focused on production processes (Jones, 1995) but improvements in recycling rates in recent years have probably provided greater benefits, mainly through directing waste paper away from landfills.

Table 5 summaries some of the waste management options for reducing GGEs from paper. It lists their potential effectiveness, the time frame over which they deliver benefits (dependent on whether they affect CH₄ or CO₂ emissions) and the relevant management organisations.

The most promising option is energy recovery from waste paper as a substitute for fossil fuels. Both CO₂ and CH₄ emissions are reduced, providing both long- and short-term benefits. Incineration of municipal waste with energy recovery is practiced widely overseas but little in Australia, partly because of community fears that incinerator emissions may pose a health risk (Winder, 1993). This appears to be changing due to technological improvement and greenhouse policy initiatives promoting “renewable energy”.

Fig. 3. Lifecycle GGEs at different recycling rates by emission category.

Fig. 4. Total lifecycle GGEs at different rates of direct conversion of waste paper to energy.
Recycling is also beneficial, providing mostly short-term gains from displacement of CH$_4$ emissions. It is particularly important as the only current large-scale alternative to landfilling.

Landfill gas energy recovery is now occurring at a number of Australian landfills but the recovery rate is small in relation to the quantity of gas emitted (EPA, 2001). The process is cheaper and less politically controversial than incineration but has less potential greenhouse benefit.

Where recycling is uneconomic, composting is perhaps the cheapest post-consumer management alternative to landfills. Its greenhouse benefit derives from limiting CH$_4$ production and retaining carbon as organic matter.

The greenhouse benefits of waste reduction were not assessed in this study.

5. Conclusion

This study provides guidance to the pulp and paper industry and to government in relation to greenhouse gas abatement strategies. The principle of Extended Producer Responsibility would advocate a pulp and paper industry role in appropriate management of waste paper.

The findings can be extended to other wood-based products and, to a lesser extent, other organic wastes,
which collectively form almost half of Australia’s municipal waste stream (EcoRecycle, 2000). A strong general argument can be made in favour of composting, landfill gas recovery and, especially, waste-to-energy based on the reduced GGEs afforded.

Acknowledgements

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References


Table 5
Waste management options for greenhouse gas emission abatement in the paper lifecycle

<table>
<thead>
<tr>
<th>Waste management option</th>
<th>Potential for reducing GGEs</th>
<th>Time frame over which benefit occursa</th>
<th>Management organisation(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase recycling</td>
<td>High</td>
<td>Short term</td>
<td>Gov’t, pulp and paper industry</td>
</tr>
<tr>
<td>2. Incinerate waste paper with energy recovery</td>
<td>Very high</td>
<td>Short- and long-term</td>
<td>Gov’t, energy industry</td>
</tr>
<tr>
<td>3. Recover more landfill gas</td>
<td>High</td>
<td>Short- and long-term</td>
<td>Gov’t, energy industry</td>
</tr>
<tr>
<td>4. Compost waste paper</td>
<td>High</td>
<td>Short term</td>
<td>Gov’t, particularly local</td>
</tr>
</tbody>
</table>

a Short term = years or decades; long term = centuries


SCCCS (Steering Committee of the Climate Change Study), 1995. Climate Change Science: Current Understanding and Uncertainties. Australian Academy of Technological Sciences and Engineering, Melbourne.


