POTENTIAL FOR GREENHOUSE GAS ABATEMENT FROM WASTE MANAGEMENT AND RESOURCE RECOVERY ACTIVITIES IN AUSTRALIA

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PREPARED BY
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FOR

SITA ENVIRONMENTAL SOLUTIONS

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Front cover photos provided by SITA Environmental Solutions (top to bottom):

SITA liquid waste collection truck

SITA transfer station

SITA Advanced Waste Treatment (SAWT) schematic

Special Note to This Revised Version

An earlier version of this report was released as a draft for comment by SITA Environmental Solutions through the NSW Branch of the Waste Management Association of Australia.

In response to some early feedback, SITA Environmental Solutions asked for a revision of the report to clarify potential areas of ambiguity.

We look forward to comments on this revised version.

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EXECUTIVE SUMMARY

The Intergovernmental Panel on Climate Change (IPCC) has demonstrated that natural levels of greenhouse gases are being increased by human based emissions and that these emissions are changing global climate with potentially disastrous consequences for the planet and humanity. The former chief economist of the World Bank, Sir Nicholas Stern has estimated the societal cost of climate change to be \$110 per tonne of carbon dioxide equivalent (CO_2e). As a result, all countries and sectors must move to operate within a carbon constrained economy, involving deep cuts to greenhouse gas emissions. The waste management and resource recovery sectors are no exception.

Warnken ISE was commissioned by SITA Environmental Solutions to undertake a preliminary examination of the potential contribution that improved resource recovery and waste management practices could make to climate change mitigation efforts in Australia. This report presents the findings on the scale of the carbon abatement potential from related activities that deliver reductions in greenhouse gas emissions. In this sense this paper is a debate starter in a process that will by necessity involve greater detail and analysis. The purpose of this report is to highlight the positive contribution that improved resource recovery and waste management practices can make to reducing Australia's greenhouse gas emissions.

Australia generated approximately 32.5 million tonnes of waste in 2002-03 and had net greenhouse gas emissions of 564.7 mega-tonnes of carbon dioxide equivalent (MtCO_2e) in 2004. Of the total net emissions, solid waste in 2004 represented only 2.7 per cent (15.0 MtCO_2e) of the national total. This was caused by the breakdown of biologically active materials such as paper/cardboard, garden organics, food and other organics, and wood/timber into methane (landfill gas), and does not include any emissions from the transport of waste (these are accounted for under 'Transport' in the national greenhouse accounts).

However, there are a number of strategies that can be implemented by the waste management and resource recovery sectors in Australia to deliver significant levels of greenhouse gas emission reduction (carbon abatement). For example:

a) abatement through improved landfill gas capture and use
b) avoiding future landfill gas emissions by stopping the disposal to landfill of waste materials with degradable organic carbon
c) saving energy by recycling high embodied energy materials
d) using renewable fuels derived from waste
e) converting suitable waste materials to 'biochar' for land application
f) using biodiesel for resource recovery and waste management vehicles.

In order to estimate the potential greenhouse gas abatement accessible through the above measures, a model of waste diversion has been built around an assumption 80 per cent of materials currently disposed of to landfill could be recovered through the development of new and innovative infrastructure including mixed waste sorting for recycling, anaerobic digestion, energy from waste (solid fuel), carbonisation (biochar) and civil works. This would mean the additional recovery of 13,512,000 tonnes of resources and the continued landfill of 3,908,000 tonnes. (Note that the civil works recycling has been assumed to be net carbon neutral in that the energy content of the recycled material is similar to that of the virgin material, and has not been included in this analysis).

On the basis of this preliminary analysis, improved resource recovery practices and waste management could deliver an abatement of 37.8 $\mathbf{MtCO_2e}$, which is a 6.7 per cent reduction on national net greenhouse gas emissions (2004 figures).

A breakdown of the relative contributions from each improvement opportunity is presented in the table below. The theoretical maximum abatement from the waste management and resource recovery sectors is 56.0 $MtCO_2e$, or nearly 10 per cent of total national net emissions.

Category of Improvement	*Potential Abatement (tCO_2e)*	*Theoretical Maximum Abatement (tCO_2e)*
Improved landfill gas flaring and recovery	8,583,000	17,166,000
Avoided emissions from avoided landfilling	13,614,000	17,017,000
Embodied energy savings from recycling	11,053,000	16,200,000
Displacing the use of fossil fuels	2,643,000	3,117,000
Developing new 'carbonising' technologies as a form of carbon capture and storage	1,752,000	2,190,000
Swapping to lower carbon intensity fuels.	173,000	346,000
Totals	**37,818,000**	**56,036,000**

While a full economic cost benefit analysis for each option has not been undertaken in this analysis, it is noted that any carbon abatement that costs less than the Stern Review's estimated societal cost of climate change of $110 per tonne of CO_2e could result in a net improvement to society. A preliminary financial analysis identified that the likely costs of carbon abatement from resource recovery could be delivered at a fraction of this estimated societal cost.

In the case of resource recovery from source separated loads of recyclable materials, carbon abatement benefits are likely to be delivered at low-to-no marginal cost. This is because service fees for waste management provision, in addition to the sale of the recycled commodity are likely to be greater than costs incurred for collection, transport and additional processing.

For mixed waste streams such as MSW and C&I, the additional costs of 'dirty MRFing' and processing are unlikely to be met by current market conditions, highlighting a need for intervention. However, estimates of the marginal cost of carbon abatement over landfill (with externalised carbon emissions), are $35 per tonne of CO_2e for MSW, and $29 per tonne of CO_2e for C&I waste materials, which is a cheaper abatement option that carbon capture and storage and biomass renewable energy. The marginal cost for each option where there is a higher 'willingness to pay' reduces to around $10 and $16 per tonne of CO_2e respectively.

These estimates are lower than the abatement costs for carbon capture and storage and biomass renewable energy, and are comparable to developing forestry sinks. The abatement cost equation highlights the effectiveness of investing into resource recovery infrastructure as a greenhouse gas reduction strategy.

While a full life cycle assessment is beyond the scope of this report, this report identifies a greenhouse gas benefit from the diversion of waste with degradable organic carbon from landfill. However, the question remains as to the scale of this benefit when compared against different alternatives. From a first order analysis on the mass balance of carbon dioxide and methane emissions, alternative technologies generally have lower emissions than landfill options (although the relative difference will naturally vary between different variants of technologies).

The other factor of relevance to options for processing degradable organic carbon is the potential to create carbon offsets or abatement. Without a national trading scheme with rules for the creation of carbon offsets, it is likely that each offset would need to be confirmed through a detailed life cycle assessment, as for example, under the Greenhouse Friendly Programme.

In considering the technology options for processing food waste there are two main positive offsets to consider that could be applicable in an emissions trading scheme: the diversion of waste from landfill (and hence avoided greenhouse gas emissions); and the generation of electricity from landfill gas and biogas, which displaces fossil fuel based electricity. Given the trend of regulation mandating landfills to minimise landfill gas emissions, it is suggested that additionality could be difficult to prove for landfills required by law to minimise landfill gas emissions. As such this has not been included as an offset category. Other offset categories could be included, such as increasing soil carbon through composted products, or avoided use of fossil-fuel based fertilisers, however these are also not considered in this first order example.

From a first order analysis of potential offsets, alternative technologies generally have greater offset potential than landfill options (although the relative difference will naturally vary between different variants of technologies).

There is a need for further analysis on the potential carbon abatement benefits of improved resource recovery and waste management activities, including the economic benefits and costs of each option under life cycle considerations. In addition to further analysis in this area, the following supporting actions are suggested in order to fast track the uptake of abatement potential within the resource recovery and waste management sectors:

a) make landfill owners liable for the fugitive landfill emissions – encourage the internalisation of long term carbon liability into landfill gate prices

b) include the carbon abatement benefits from avoided greenhouse emissions through the diversion of biologically active waste materials into any carbon emissions trading scheme – this would monetise one of the positive benefits of resource recovery, and provide additional support for these technologies and practices

c) recognise the energy savings from recycling as a form of carbon abatement and include as an offset category in the development of any carbon emissions trading schemes – this would encourage the direct recycling of energy intensive materials

d) develop national standards for the use of renewable waste derived fuels – overcome discrepancies across jurisdictions preventing energy from waste and encourage the development of this resource recovery option

e) recognise charring of bio-based materials as an efficient form of carbon capture and storage, and incorporate into any carbon emissions trading schemes – this would monetise one of the advantages of biochar and support the development of this technology

f) develop support for B50 biodiesel distribution – ease of access will facilitate uptake and use.

The solid waste industry currently accounts for 2.7 per cent of net greenhouse gas emissions in Australia. However, this initial analysis has demonstrated that with improved performance in resource recovery, a significant abatement of approximately 38 $MtCO_2e$ could be made, which represents a 6.7 per cent reduction of Australia's net greenhouse gas emissions (2004 figures).

In order to realise the positive carbon abatement potential from resource recovery and waste management, co-operation between government and industry is essential. Government can display leadership by creating the right market interventions and supporting regulation to drive desired changes. Industry can also show leadership through the development of innovative technology for resource recovery and through incorporating carbon issues into business decision making.

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1 INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) has demonstrated that natural levels of greenhouse gases are being increased by human based emissions, including emissions of carbon dioxide (CO_2) from the burning of coal, oil, and natural gas for transport and energy purposes; from additional methane and nitrous oxide produced by farming activities and changes in land use; and by several long-lived industrial gases that do not occur naturally. Computer climate models suggest that the increasing levels of these gases will cause global average temperatures to increase by 1.1 to 6.4°C by the year 2100, which will trigger irreversible and catastrophic changes to our weather and our planet.[1]

The economic implications of climate change were recently examined by the former chief economist of the World Bank, Sir Nicholas Stern. The report of the Stern Review 'The Economics of Climate Change' concluded that 'climate change represents the greatest and widest-ranging market failure ever seen', and estimated the societal cost of climate change to be $110 per tonne of carbon dioxide equivalent (CO_2e). This translates to a global cost of nearly $5 trillion under a business as usual approach to climate change. Unless action is taken, the global consequences will be 'on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century'.[2]

Many international responses are being implemented to reduce greenhouse gas emissions in an attempt to avoid these catastrophic changes. At an Australian level there is a proposed state based National Emissions Trading Scheme (NETS), and a recently announced Federal inquiry into a carbon trading scheme. However, the Stern Review on the economics of climate change has effectively put the global economy on notice and action must follow investigation. All countries and sectors must move to operate within a carbon constrained economy, involving deep cuts to greenhouse gas emissions.

Warnken ISE was commissioned by SITA Environmental Solutions to undertake a preliminary examination of the potential contribution that improved resource recovery and waste management practices could make to climate change mitigation efforts in Australia. Although emissions from solid waste in 2004 represented only 2.7 per cent of the national total (15.0 mega-tonnes out of a reported net emission amount of 564.7 Mt), early indications are that improved practices could make a significant contribution to carbon abatement.

This report presents the preliminary findings on the scale of the carbon abatement potential from the resource recovery and waste management sectors. In this sense this paper is a debate starter in a process that will by necessity involve greater detail and analysis. The purpose of this report is to highlight the positive contribution that improved resource recovery and waste management practices can make to reducing Australia's greenhouse gas emissions.

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[1] *IPCC 2007, 'Climate Change 2007: The Physical Science Basis Summary for Policymakers', Intergovernmental Panel on Climate Change, Geneva, found at http://www.ipcc.ch/SPM2feb07.pdf, February 2007.*

[2] *Stern Review, 2006, 'The Economics of Climate Change', HM Treasury, London, accessed at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm, November 2006. US\$85 = A\$110. 2005 global carbon emissions estimated to be 45 giga-tonnes CO_2e.*

1.1 Overview of Report

The structure of the report is shown overleaf in Figure 1. After this introduction, an overview of waste generation and greenhouse gas emissions in Australia is provided in Section 2. The following sections then examine the potential abatement from improved practices and technologies associated with improved landfill capture and use (Section 3), avoided landfill gas emissions (Section 4), embodied energy savings from recycling (Section 5), displacing the use of fossil fuels (Section 6), developing new 'carbonising' technologies as a form of carbon capture and storage (Section 7), and swapping to lower carbon intensity transport fuels (Section 8).

A discussion is then presented on the cost of carbon abatement through resource recovery and associated implications for waste management and resource recovery technologies. The abatement potential is then summarised in Section 10, in addition to requirements for further action.

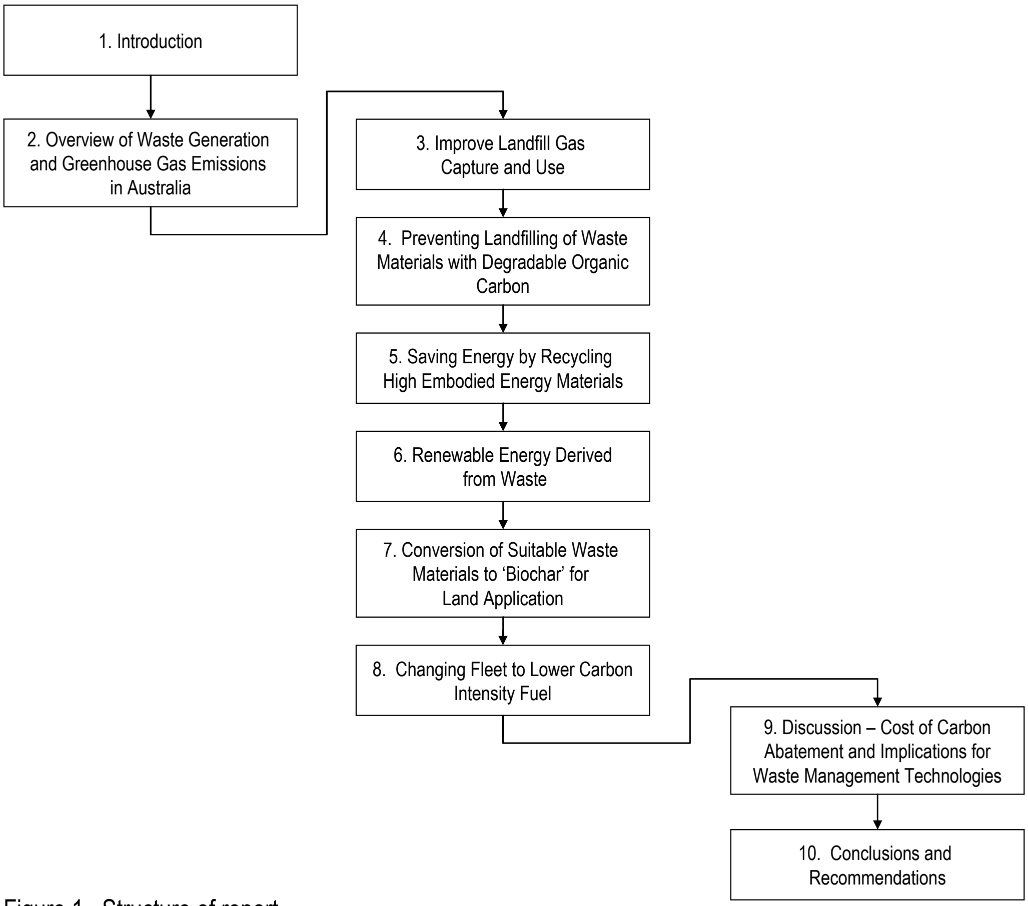

Figure 1 –Structure of report

2 OVERVIEW OF WASTE GENERATION AND GREENHOUSE GAS EMISSIONS IN AUSTRALIA

Australia generated approximately 32.5 million tonnes of waste in 2002-03 and approximately 565 mega-tonnes of carbon dioxide equivalent in greenhouse gases in 2004. Further information on the composition of this waste and greenhouse gas emissions, in addition to potential greenhouse gas abatement avenues for the resource recovery and waste management sectors to consider is presented below.

2.1 Waste Generation

Waste generation comprises the amount of materials that are recycled, and the amount of materials that are wasted to landfill. A breakdown of Australia's waste generation according to material type is presented in Table 1 below.

Table 1 – Summary of waste generation in Australia 2002/2003[3]

Material Type	*Total Tonnes Generated*	*Total Tonnes Recycled*	*Total Tonnes Landfilled*	*% Recycled*
Paper & Cardboard	5,000,000	2,310,000	2,690,000	46%
Glass	870,000	370,000	500,000	43%
Adjusted Non-Ferrous[4]	230,000	100,000	130,000	43%
Ferrous	3,670,000	2,790,000	880,000	76%
Plastic	1,690,000	190,000	1,500,000	11%
Garden Organics	3,800,000	1,550,000	2,250,000	41%
Food and other organics	3,200,000	310,000	2,890,000	10%
Wood/Timber	2,070,000	440,000	1,630,000	21%
Soil/Rubble and Other Clean Excavated Material	3,840,000	1,390,000	2,450,000	36%
Concrete, bricks and asphalt	6,780,000	4,810,000	1,970,000	71%
Other recyclables (inc Textiles)	980,000	700,000	280,000	71%
Other (waste)	250,000	-	250,000	0%
Totals	**32,380,000**	**14,960,000**	**17,420,000**	**46%**

The above materials can also be categorised as to whether they are biologically active or inert. Biologically active materials with degradable organic carbon (DOC) will decompose in landfill and include paper and cardboard, garden organics, food and other organics, and wood/timber (9,460,000 tonnes

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[3] *Derived from Hyder Consulting 2006, ''Waste and Recycling in Australia'', Department of Environment and Heritage, found at http://www.pc.gov.au/inquiry/waste/subs/sub103attachmenta.pdf, November 2006. Note that the Hyder analysis reported that nearly 3 million tonnes of waste disposed of to landfill that was classified as 'other waste' by various jurisdictions. Weighted averages have been used to estimate the composition of other' waste'. This does not alter the accuracy of the impact assessment of materials disposed of to landfill. Especially as the Hyder estimate of 32.38 million tonnes of waste generation contains an underestimate of approximately 5 million tonnes, primarily due to a low Queensland waste generation rate of 1.0 t/c and the use of Perth data for Western Australia (Warnken ISE, 2006, 'State of Waste in Western Australia', Total Environment Centre, accessed at http://www.tec.org.au/dev/index.php?option=com_docman&task=doc_download&gid=18, December 2006.) If anything, the numbers for landfill presented here represent conservative estimates of the greenhouse impacts arising from waste disposed of to landfill.*

[4] *Note that non-ferrous has been estimated on the basis of 0.7% of total waste generation - Nolan ITU, 2004, 'Global Renewables National Benefits of Implementation of UR-3R Process® - A Triple Bottom Line Assessment', Global Renewables Limited, Sydney.*

landfilled in total). Inert and relatively inert materials include glass, metals, plastic, soil/rubble and other clean excavated material, and concrete, bricks and asphalt (7,430,000 tonnes landfilled in total). Some of these materials, although inert, used a high amount of energy in their manufacture (embodied energy).

Waste generation can also be broken down according to the source of the waste in the first instance, for example Municipal Solid Waste (MSW), Commercial and Industrial (C&I) waste, and Construction and Demolition (C&D) waste. Table 2 gives a breakdown of Australian waste generation according to source.

Table 2 – Australian waste generation by source[5]

Source	*Total Tonnes Generated*	*Total Tonnes Recycled*	*% Recycled*	*Total Tonnes Landfill*	*% Landfill*
Municipal Solid Waste (MSW)	8,903,000	2,701,000	30%	6,202,000	70%
Commercial and Industrial Waste (C&I)	9,469,000	4,162,000	44%	5,307,000	56%
Construction and Demolition Waste (C&D)	13,741,000	7,827,000	57%	5,914,000	43%
Unallocated	269,000	269,000	n/a	-	n/a
Totals	**32,382,000**	**14,959,000**	**46%**	**17,423,000**	**54%**

(Note that totals vary slightly from Table 1 due to rounding differences on tonnage allocations to source.)

2.2 Greenhouse Gas Emissions

Greenhouse gases are those gaseous emissions that contribute to global warming. The most abundant greenhouse gas is water vapour. Although the concentration of water vapour in the atmosphere is variable, anthropogenic (human based) activity has little impact on this concentration. There are however six major greenhouse gases released by human activity that actively contribute to global warming:

- carbon dioxide(CO_2): is released during burning of fossil fuels (oil, natural gas and coal), plant material (for example wood) and waste products, however the burning of fossil fuels is the major contributor to global warming
- methane (CH_4): is emitted during production and transport of coal, natural gas and oil,[6] and from the decomposition of biologically active wastes in municipal solid waste landfills. Farm animals (cattle, sheep) also give rise to significant methane emissions
- nitrous oxide (N_2O) is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste
- hydrofluorocarbons (HFCs): used as a substitute for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) primarily in refrigeration and air conditioning applications
- perfluorocarbons (PFCs): emitted during semiconductor manufacture and aluminium smelting
- sulphur hexafluoride (SF_6): used in potentially high temperature applications such as electrical breakers, as well as magnesium casting, sound insulation, and semiconductor etching.

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[5] *Derived from Hyder Consulting 2006, "Waste and Recycling in Australia", Department of Environment and Heritage, found at http://www.pc.gov.au/inquiry/waste/subs/sub103attachmenta.pdf, November 2006.*

[6] *For example, during extraction, processing, storage, transport and distribution of natural gas methane may be lost to atmosphere. During the mining of coal, methane captured in the coal seam can be released.*

Greenhouse gases differ in their ability to retain heat in the atmosphere. The relative radiative forcing impacts of greenhouse gases are measured in terms of their Global Warming Potential GWP). GWP is defined as the cumulative radiative forcing (in terms of both direct and indirect effects)[7] integrated over a period of time from the emission of a unit mass of gas relative to the reference gas, carbon dioxide (CO_2).[8]

HFCs, PFCs and SF_6 are the most heat-absorbent of the greenhouse gases listed above, with GWPs of up to 11,700 for HFC-23 and 23,900 for SF_6, implying that they trap 11,700 and 23,900 times more heat than carbon dioxide. The 100-year global warming potential for methane and nitrous oxide is 21 and 310 respectively. Global warming potential is generally reported in terms of carbon dioxide equivalents (CO_2e). The CO_2e equivalent is calculated by multiplying the tonnes of the gas emitted by the associated 100 year global warming potential, hence one tonne of methane is 21 tCO_2e.[9]

2.3 Australian Greenhouse Gas Emissions

Australia's net emissions of greenhouse gases in 2004 were 564.7 mega-tonnes of carbon dioxide equivalent ($MtCO_2e$).[10] This is broken down by source in Table 3.

Table 3 – Australia's net greenhouse gas emissions

Source	*$MtCO_2e$*
Stationary Energy	279.9
Transport	76.2
Fugitive Emissions	31
Industrial Processes	29.8
Agriculture	93.1
Land Use, Land Use Change and Forestry	35.5
Waste	19.1
Total	**564.7**

A graphical representation of the proportional contribution by each sector to the national greenhouse gas inventory is presented in Figure 2 overleaf.

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[7] *Direct effects are those which occur if the gas is in itself a greenhouse gas. Indirect radiative forcing occurs when chemical reactions involving the original gas produce other greenhouse gases, or when a gas influences other radiatively important processes such as the atmospheric lifetime of another gas.*

[8] *Intergovernmental Panel on Climate Change found at http://www.ipcc.ch/*

[9] *IPCC 2001, 'IPCC Third Assessment Report – Technical Summary of the Working Group I Report', Intergovernmental Panel on Climate Change, Geneva, accessed at http://www.grida.no/climate/ipcc_tar/vol4/english/pdf/wg1ts.pdf, February 2007. Note that the Intergovernmental Panel on Climate Change (IPCC) in their third assessment report has revised the Global Warming Potential (GWP) of methane to 23 times that of carbon dioxide. However the 2004 Australian National Greenhouse Inventory prepared by the Australian Greenhouse Office (AGO, 2006, 'Australian National Greenhouse Inventory 2004', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/inventory/2004/index.html, February 2007) uses the IPCC's previous estimate (Second Assessment Report) of 21 times the 100 year GWP of carbon dioxide in national accounts for the first Kyoto commitment period of 2008-2012. The GWP value of 21 has been adopted here to be consistent with AGO methodology.*

[10] *AGO, 2006, 'Australian National Greenhouse Inventory 2004', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/inventory/2004/index.html, November 2006 – note that this 'net' total includes reduction in greenhouse gas emissions from carbon sinks such as avoided land clearing.*

The emissions from waste comprise 3.4 per cent of net national total greenhouse gas emissions. This is composed of:

- 15.0 $MtCO_2e$ from methane emissions from solid waste landfill on land (2.7% of net national total) – note that this is a net amount that accounts for landfill gas already recovered for flaring or energy, and also this total does not include the transport of waste, which is accounted for under the 'Transport' sector in the national greenhouse gas accounts
- 4.1 $MtCO_2e$ from methane and nitrous oxide emissions from waste water management (0.7% of net national total).

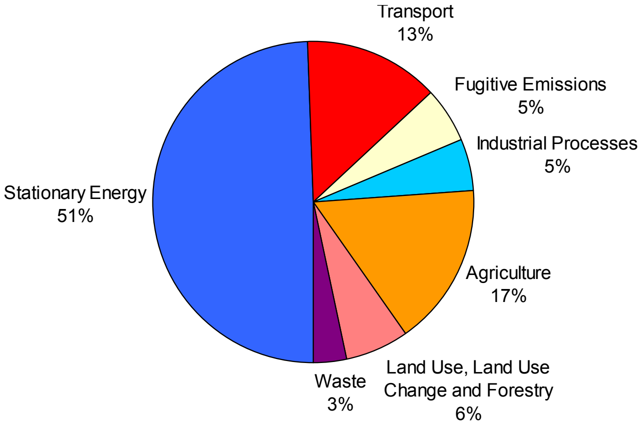

Figure 2 – Proportional contributions by sector to Australian net greenhouse gas emissions[11]

(Note that emissions from the collection of recycling and transport of waste are accounted for under transport.)

2.4 Potential Avenues for Greenhouse Gas Reduction

There are a number of potential greenhouse gas reduction options that could implemented within the Australian resource recovery and waste management sectors. For example:

a) abatement through improved landfill gas capture and use

b) avoiding future landfill gas emissions by stopping the disposal to landfill of waste materials with degradable organic carbon

c) saving energy by recycling high embodied energy materials

d) using renewable fuels derived from waste

e) converting suitable waste materials to 'biochar' for land application

f) using biodiesel for resource recovery and waste management vehicles.

In order to estimate the potential greenhouse gas abatement accessible through the above measures, a number of assumptions have been made regarding the amount of waste diverted and the efficiency of each option in reducing emissions.

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[11] *AGO, 2006, 'Australian National Greenhouse Inventory 2004', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/inventory/2004/index.html, November 2006.*

The model for waste diversion and resource recovery assumes that 80 per cent of materials currently disposed of to landfill could be recovered through the development of new and innovative infrastructure including mixed waste sorting for recycling, anaerobic digestion, energy from waste (solid fuel), carbonisation (biochar) and civil works. This would mean the additional recovery of 13,512,000 tonnes of physical waste recovery and the continued landfill of 3,908,000 tonnes of waste. While it is acknowledged that there may questions around the immediate practicability of such additional resource recovery, this level of performance is technically possible with currently available technology. Furthermore, given that this is a preliminary analysis, the intention is to scope out the potential greenhouse gas abatement. Additional work is required on the costs and benefits of each option, and associated risks.

The material flows under the diversion model for this analysis are presented in Figure 3 overleaf. While 3,908,000 tonnes continues to be wasted in landfill, there are five resource recovery options which together account for 13,512,000 physical tonnes of waste recovery, including:

- recycling of high embodied energy materials – 3,084,000 tonnes including 1,076,000 tonnes of paper and cardboard, 300,000 tonnes of glass, 104,000 tonnes of non-ferrous metal, 704,000 tonnes of ferrous metal and 900,000 tonnes of plastic
- anaerobic digestion of 2,312,000 tonnes of food and other organics
- solid fuel from waste derived materials – 1,490,000 tonnes including 538,000 tonnes of paper and cardboard, 652,000 of wood/timber and 300,000 tonnes of plastic (although the plastic energy content is not counted as renewable as it is derived from fossil based hydrocarbons)
- manufacture of biochar – 2,990,000 tonnes including 538,000 tonnes of paper and cardboard, 1,800,000 tonnes of garden organics and 652,000 tonnes of wood/timber
- use in civil works – 3,636,000 tonnes including 100,000 tonnes of glass, 196,000 tonnes of soil/rubble and other clean excavated material, and 1,576,000 tonnes of concrete bricks and asphalt. (Note that the civil works recycling has been assumed to be net carbon neutral in that the embodied energy of the recycled material is similar to that of the virgin material, and as such has not been included in this analysis).

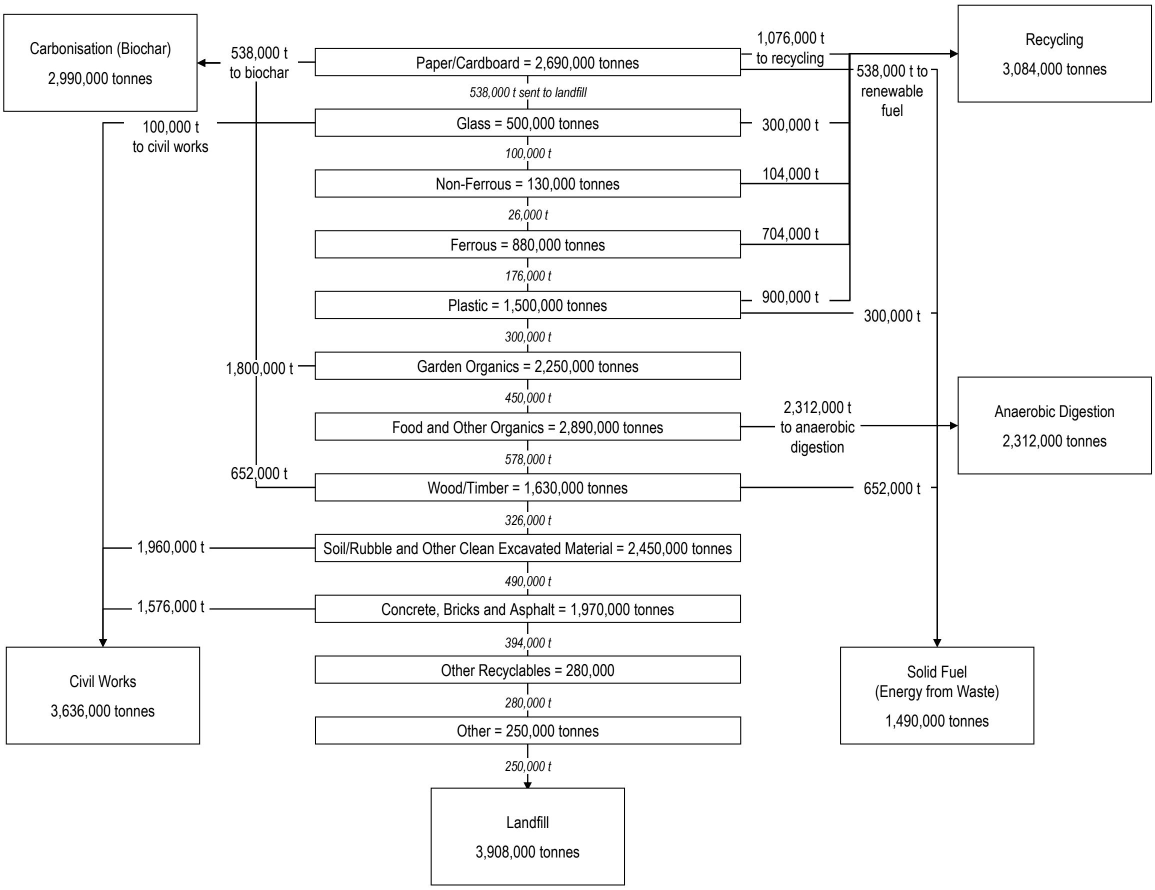

Figure 3 – Model of materials flows for increased resource recovery

The following Sections 3-8 present the potential greenhouse gas reduction that can be delivered through improved resource recovery and waste management practices.

3 IMPROVING LANDFILL GAS CAPTURE AND USE

Improving landfill gas management systems has the potential to avoid greenhouse gas emissions by either flaring landfill gas (methane is converted to carbon dioxide, lessening the greenhouse impact), or using the landfill gas to generate electricity.

An estimated 8.583 million tonnes of CO_2e impact could be prevented through better capture of landfill gas and increased generation of electricity. 7.5 million tonnes CO_2e of this total would be saved through better capture of landfill gas (half of current emissions). The remaining 1.083 million tonnes CO_2e abatement would be created through the offset of fossil fuel emissions by using half of the gas captured to generate 1,000,000 MWh of electricity.

3.1 Landfill Gas and Waste Disposal

Once biologically active waste materials with degradable organic carbon (for example food and garden organics) are disposed of to landfill, they start to degrade and form landfill gas. The process of biological degradation involves micro-organism activity in the absence of air (anaerobic)[12] to form primarily methane (CH_4) and carbon dioxide (CO_2) gases, known as landfill gas. Landfill gas composition varies from site to site, however an indicative composition is given in Table 4 below.

Table 4 – Indicative composition of landfill gas[13]

Constituent	*Percentage (Volume)*	*Assumed Composition for this Analysis (%)*	*Equivalent Mass %*[14]
Methane (CH_4)	45 to 58	50.0%	29.0%
Carbon dioxide (CO_2)	35 to 45	38.0%	60.6%
Nitrogen (N_2)	<1 to 20	6.0%	6.1%
Oxygen (O_2)	<1 to 5	1.5%	1.7%
Hydrogen (H_2)	<1 to 5	1.5%	0.1%
Water vapour (H_2O)	1 to 5	2.0%	1.3%
Trace constituents	<1 to 3	1.0%	1.2%

Note that the trace constituents include gases such as hydrogen sulphide (H_2S) and non-methane organic compounds (NMOCs).

The major greenhouse impact of landfill gas is methane which has a global warming potential (GWP) 21 times that of carbon dioxide. This means that every tonne of methane released into the atmosphere is equivalent to the release of 21 tonnes of carbon dioxide (1 t CH_4 = 21 tCO_2e).[15]

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[12] *Note that for a short period after placement and coverings the landfill will be aerobic, giving rise to primarily CO_2. For the bulk of the landfill's life, however, degradation will be under anaerobic conditions, during which it has its most significant greenhouse impact.*

[13] *Qian, X., Koerner, R.M. and Gray, D.H., 2002, 'Geotechnical Aspects of Landfill Design and Construction', Prentice Hall, New Jersey.*

[14] *Assumes ideal gas behaviour*

[15] *Note that the Intergovernmental Panel on Climate Change (IPCC) in their third assessment report has revised the Global Warming Potential (GWP) of methane to 23 times that of carbon dioxide. However the 2004 Australian national greenhouse inventory used the IPCC's previous estimate of 21 times the GWP of carbon dioxide in their national accounts, so this figure has been used for consistency.*

Converting the volumetric composition of landfill gas in Table 4 into a mass based composition gives an average estimate of landfill gas comprising 29 per cent methane and 60.6 per cent carbon dioxide, with the rest a mixture of non-greenhouse gases. Every tonne of landfill gas released to the atmosphere is considered to have a greenhouse impact of 6.1 tCO_2e.[16] The national greenhouse gas emissions from solid waste disposal to landfill (15.0 $MtCO_2e$) arise from the release of 2,459,000 tonnes of landfill gas, which is equivalent to approximately two billion normal cubic metres.[17]

It should be noted that the annual release of landfill gas represents a cumulative build-up from the past 50 years of waste disposal to landfill. This is because decomposition of waste continues over time, and can take up to 50 years before stabilisation (no more biological activity) has occurred.[18] This also highlights the need to act now in order to reduce future emissions from the waste sector. One potential action is the improved capture of landfill gas for flaring or to generate electricity.

3.2 Carbon Abatement Benefit from Landfill Gas Capture

Most large landfills now in operation have some form of landfill gas capture. Once captured the landfill gas can be flared or processed for electricity generation. Flaring (burning) the landfill gas converts the methane into carbon dioxide (CO_2) and water vapour (H_2O), effectively neutralising its greenhouse potential.[19] The landfill gas can also be processed to make it more suitable as a fuel, and then used to generate electricity, usually in a reciprocating gas engine.

There are many small to medium landfills spread throughout rural and regional Australia which could capture landfill gas for flaring or recovery, in addition to improving the performance of landfill gas capture on sites with existing systems.

Assuming that 25 per cent of the Australian total landfill gas emissions of 15.0 $MtCO_2e$ (that is, the fugitive emissions that are currently not being captured) could be flared through greater coverage and improvement of landfill gas technology, and 25 per cent could be captured for electricity generation, then 7.5 million tonnes CO_2e could be prevented from being released. However, the use of landfill gas for electricity generation would also displace fossil fuel electricity, which should also be counted as a carbon offset.

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[16] *From a mass balance perspective, 290 kg of methane is equivalent to 6.1 tCO_2e because methane has a global warming potential 21 times greater than carbon dioxide, and 606 kg of carbon dioxide equals 0.6 tCO_2e. 6.1 + 0.6 = 6.7 tCO_2e. However, the AGO does not account for the carbon dioxide component of landfill gas as this is considered to be part of the natural carbon cycle, and does not arise from human activity. Thus from a carbon accounting perspective, each tonne of landfill gas has a greenhouse impact of 6.1 tCO_2e.*

[17] *One mole of an ideal gas at standard temperature and pressure (STP) occupies 22.4 litres. Standard temperature: 0°C = 273.15 K; Standard pressure = 1 atmosphere = 760 mmHg = 101.3 kPa ; (- http://hyperphysics.phy-astr.gsu.edu/hbase/kinetic/idegas.html). Calculating the density of landfill gas given the molecular weight of elements according to the composition in Table 4, gives 1.233 kg per normal cubic metre (nm^3). This means that one tonne of landfill gas has a volume of 811 m^3 at standard temperature and pressure.*

[18] *AGO, 2006, 'Australian National Greenhouse Inventory 2004', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/inventory/2004/index.html, November 2006.*

[19] *The carbon dioxide released is considered to be in line with the normal process of biological decay as part of the natural carbon cycle, and thus is greenhouse gas neutral, because the carbon released had been recently removed from the atmosphere through the actions of photosynthesis and sunlight manufacturing cellulose and hemicellulose, and is assumed to be regrown (hence a neutral balance).*

3.3 Using Landfill Gas to Generate Electricity

The calorific value of methane is 37.5 mega joules per normal cubic metre (MJ/Nm^3).[20] Given that landfill gas is approximately 50 per cent methane by volume, a calorific value of 18.75 MJ/Nm^3 has been assumed. An indicative mid point for the electricity efficiency of a reciprocating engine generator of 38.5 per cent has also been assumed, based on original equipment manufacturer specifications.[21] One quarter of two billion normal cubic metres of landfill gas escaping as emissions is equal to 500 million normal cubic metres available for electricity generation. Using a calorific value of 18.75 MJ/Nm^3 and an electrical efficiency of 38.5 per cent gives a potential electricity generation of approximately 1,000,000 megawatt hours (MWh) which offsets the emission of 1,083,000 tonnes CO_2e from fossil fuel electricity.[22]

The different types of landfill in operation present a number of challenges to reducing greenhouse gas emissions, as do the number of non-operational and rural/regional sites. Most metropolitan landfill sites have existing landfill gas capture systems, with efficiencies of landfill gas capture that range from 40 to 70 per cent.[23] In terms of existing fugitive emissions efforts could be made to improve capture efficiencies and increase the number of landfills that are capturing landfill gas.

3.4 Summary - Abatement from Improved Landfill Gas Capture and Use

The total abatement from a 25 per cent flaring and 25 per cent recovery and use for electricity generation scenario is 8,583,000 tonnes of CO_2e (7.5 $MtCO_2e$ from prevented emissions plus 1.083 $MtCO_2e$ from the offset of coal fired electricity).

[If 100 per cent landfill gas capture was possible, and half of this used to generate electricity (the other half flared), the total diversion would be 17.166 million tonnes of CO_2e (15 $MtCO_2e$ from prevented emissions plus 2.166 $MtCO_2e$ from the offset of coal fired electricity)].

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[20] *One mega joule is one million joules. For comparison the calorific value (heat energy content) of natural gas is closer to 37.5 MJ/nm^3 as it is composed primarily of methane SEPA 2004, 'Guidance on gas treatment technologies for landfill gas engines, Environment Agency, Bristol, accessed at http://www.sepa.org.uk/pdf/guidance/landfill_directive/gas_treatment_tech.pdf, November 2006.*

[21] *SEPA 2004, 'Guidance on gas treatment technologies for landfill gas engines, Environment Agency, Bristol, accessed at http://www.sepa.org.uk/pdf/guidance/landfill_directive/gas_treatment_tech.pdf, November 2006.*

[22] *500 million Nm^3 * 18.75 = 9,375,000,000 MJ (nearest 1,000,000 MJ), multiply by 0.385 to adjust for electrical efficiency and divide by 3600 to convert into MWh gives 1,000,000 MWh (nearest 10,000 MWh). The full fuel cycle emissions for coal fired electricity from the 2006 AGO workbook and averaged across NSW, Vic, Qld, WA and SA for 2003 is 1,083 $kgCO_2e$ per MWh. Multiplying 1,000,000 by 1.083 gives 1,083,000 tonnes of CO_2e abated (nearest 1,000 tonnes).*

[23] *AGO 2005, 'Methane to Markets – Landfill Gas Technical Subcommittee Country Profile – Australia', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/international/partnerships/pubs/landfillgas-australia.pdf, December 2006.*

4 PREVENTING LANDFILLING OF WASTE MATERIALS WITH DEGRADABLE ORGANIC CARBON

Waste materials such as Paper and Cardboard, Garden Organics, Food and other organics, and Wood/Timber contain degradable organic carbon that decomposes to form methane in landfills. Preventing the disposal of these 'biologically active' waste materials to landfill prevents the release of greenhouse gases into the atmosphere. **Under the resource recovery model developed for this analysis (see Section 2.4), and using Australian Greenhouse Office default emission factors, it is estimated that preventing the landfilling of waste materials with degradable organic carbon would avoid the release of 13.614 million tonnes of CO_2e.**

4.1 Technologies Available to Prevent the Disposal of Waste with Degradable Organic Carbon

There are a number of technologies that can recover resource value from waste materials with degradable organic carbon, thus preventing their eventual anaerobic decomposition in landfill and generation of landfill gas. Some of these technologies include:

- composting – open window composting is the most common form of composting and is used primarily for garden organics. Leaves, branches and grass clippings are shredded and formed into long windrows. Bacteria and other organisms in the window will initiate the decomposition process if there is sufficient moisture, oxygen and the right carbon to nitrogen balance. Because composting is an aerobic process, methane is not generated and a carbon neutral balance maintained
- anaerobic digestion – is the controlled in-vessel breakdown of organic matter by microbial activity in the absence of oxygen. The organic matter normally has high concentrations of moisture or nitrogen and may comprise food waste, grease trap waste, animal waste or sewerage sludge. The bio-gas that is produced is similar in composition to landfill gas, however, because the process is completely contained, all of the gas can be captured for beneficial use such as process heat or electricity generation
- alternative waste technology – a combination of mechanical, biological and in some cases thermal processes to recover resource value from mixed municipal waste. For example the SITA Advanced Waste Treatment system (SAWT) uses a combination of mechanical separation stages with composting in ventilated enclosed static piles to produce a range of recyclate and compost products
- biochar production –char is manufactured using a form of pyrolysis. Pyrolysis is a similar process to gasification, with the difference being that 'woody' materials are heated in the absence of oxygen, and produce a 'syn-gas' (as in the case of gasification), a liquid 'pyrolytic oil' and char. The char is essentially a more stable form of carbon than was originally in the biomass
- energy from waste – recovery of energy from waste materials by preparing selected waste derived materials, such as paper, wood, garden organics and some plastics, for processing into a fuel – 'process engineered fuels'. These fuels can then be used to replace fossil fuels in coal fired power stations, cement kilns and standalone power stations.

In addition to the end products that are produced by these technologies, they have the added benefit of preventing the generation of landfill gas with its associated greenhouse gas impacts, and preventing the ongoing accumulation of a potential carbon liability. The amount of greenhouse gas prevented through diverting 'biologically active' materials from landfill is examined in the following section.

4.2 Australian Greenhouse Office Default Emission Factors

The Australian Greenhouse Office AGO) has calculated the greenhouse gas abatement benefit from diverting biologically active waste from landfill. The calculations are based on the amount of degradable organic carbon (DOC) in each waste materials; the fraction of degradable organic carbon that decomposes to form landfill gas (DOC_f); the fraction of methane in landfill gas (F_1); the methane to carbon ratio (16/12); and the amount of methane that is oxidised by the landfill cap (OX – see also Section 9.2 for a more in depth discussion of these calculations). The AGO CO_2e emission factors for waste materials are presented in Table 5 below

The analysis used here assumes that the greenhouse emissions generated as defined by the AGO factors workbook, would be avoided if this material was diverted from landfill (here set as business-as-usual). The actual amount of net reduction would need to cover additional factors such as the actual recovery option and any additional emissions from plant and equipment, residual landfilling and other such issues, which would need a full life cycle assessment to define. However, these estimates here are presented to scale the potential avoided emissions from landfilling of degradable organic carbon.

For example the diversion of one tonne of garden and park material from landfill could prevent the release of 1.1 tonnes of CO_2e in landfill gas. Default emission factors have also been estimated for Municipal Solid Waste (MSW), Commercial and Industrial (C&I) waste, and Construction and Demolition (C&D) waste. These are presented in Appendix 1.

Table 5 – Diversion of biologically active waste materials from landfill and avoided greenhouse gas emissions

Biologically Active Material Type	*Tonnes Diverted*[24]	*Emissions Factor (tCO_2e)*[25]	*Potential Tonnes CO_2e Avoided*
Paper & Cardboard	2,152,000	2.50	5,380,000
Garden Organics	1,800,000	1.10	1,980,000
Food and other organics	2,312,000	0.90	2,081,000
Wood/Timber	1,304,000	3.2[26]	4,173,000
Totals	**7,570,000**		**13,614,000**

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[24] Tonnes of diversion based on the recovery model presented earlier in Section 2.4.

[25] 'AGO, 2006, ' AGO Factors and Methods Workbook - For use in Australian greenhouse emissions reporting', Australian Greenhouse Office, Canberra, found at http://www.greenhouse.gov.au/workbook/pubs/workbook2006.pdf, January 2007.

[26] The AGO considers that the disposal of wood/timber to landfill will result in greenhouse gas emissions. A study by Gardner et al on the decomposition of wood products in landfill identified slower decomposition rates than previous estimates had suggested. The conclusion was that 95% of the carbon in wood remained after 30 years in landfill (see FWPRDC, undated, 'Forests, Wood and Australia's Carbon Balance', Forest and Wood Products Research and Development Corporation, Melbourne, accessed at http://www.fwprdc.org.au/content/pdfs/new%20pdfs/Forests,Wood&CarbonBalance.pdf, December 2006). However, care should be exercised before concluding that landfill somehow acts as a carbon sink. For example, it is not clear whether the 5% carbon loss reports as methane to the atmosphere, in which case 5% could neutralise any sequestration 'benefit'; slower rates of decomposition point to longer requirements for post closure maintenance and monitoring, and could increase landfill gas generation over periods when recovery is not commercially viable; ongoing subsidence could compromise capping systems (especially over 60+ years post closure); and also it is unknown whether decomposition rates accelerate post 30 years, at say years 60 – 90.

4.3 Summary - Avoided Greenhouse Gas Emissions from Landfill Diversion

Applying the AGO emission factors to the tonnes of biologically active waste materials diverted from landfill under the model of resource recovery developed for this analysis gives an avoided greenhouse emission amount of 13.614 million tonnes of CO_2e.

[If all wastes with degradable organic carbon that are currently disposed of to landfill was diverted to resource recovery,[27] the release of 17 million tonnes of CO_2e in landfill gas would potentially be avoided.]

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[27] *Table 1 identifies the disposal to landfill of 2,690,000 tonnes of Paper and Cardboard, 2,250,000 tonnes of Garden Organics, 2,890,000 tonnes of Food and other organics, and 1,630,000 tonnes of Wood/Timber.*

5 SAVING ENERGY BY RECYCLING HIGH EMBODIED ENERGY MATERIALS

Embodied energy is a measure of the amount of energy used to transform raw materials into a final product or material. The recycling of materials with high embodied energy reduces the amount of energy used to manufacture commodities, thus preventing the release of greenhouse gases associated with energy use. **Under the resource recovery model developed for this analysis (see Section 2.4), the release of 11.053 million tonnes of CO_2e could be prevented from the direct recycling of 'dry recyclables' (paper/cardboard, non-ferrous, ferrous and plastic) currently disposed of to landfill.**

5.1 Embodied Energy of Materials Disposed of to Landfill

In the manufacture of aluminium, energy is used to mine bauxite, refine alumina, smelt into aluminium and then extrude, roll or cast into products. This energy used to transform the raw material into a saleable commodity is known as embodied energy. It is generally realised that recycling delivers a net energy saving as there is less embodied energy in recycled material than comparable virgin products, however the link between this energy savings and a reduction in greenhouse gas emissions is often overlooked.

Embodied energy is usually reported in standardised units of megajoule per kilogram (MJ/kg) or gigajoules per tonne (GJ/tonne). It is important to use gross energy figures. For example the amount of electricity (as measured in kilowatt hours or megawatt hours) used must be converted into the amount of energy that was used to generate the electricity in the first instance.[28]

A distinction also needs to be made on whether a product or a material is being analysed. For example, the manufacture of complex electronics involves many component materials, in addition to a large amount of energy use in the product assembly. In this analysis only the embodied energy of component materials in the waste stream has been assessed, and not the embodied energy of a product at final assembly, nor of any energy used for transport during distribution.[29]

The embodied energy of the major material groups disposed of to landfill is presented in Table 6 overleaf. The greenhouse intensity per gigajoule (GJ) of embodied energy is 0.098 tCO_2e/GJ.[30] The total embodied energy contained in landfilled materials is estimated to be 415,485,000 GJ. This is equivalent to the energy content of 15.4 million tonnes of washed black coal, which in turn is approximately equal to the release of 40 million tonnes of CO_2e.[31] If this coal was used to generate electricity it would make 40,400 gigawatt hours, which is 20.5 per cent of the electricity generated in Australia by fossil fuels.[32]

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[28] *In other words, given that the conversion of coal into electricity is to the order of 35% efficient, the original energy value of the coal should be used rather than the electricity itself.*

[29] *This is because the energy used to manufacture and assemble a product is unable to be 'recovered', whereas the energy difference in the materials of manufacture (the plastic, glass and metal) can be 'recovered' in the form an energy saving arising through recycling.*

[30] *CSIRO (undated), 'Embodied Energy', CSIRO Manufacturing and Materials Technology, Sydney, accessed at http://www.cmit.csiro.au/brochures/tech/embodied, November 2006.*

[31] *Energy content (calorific value) of washed black coal at 27 GJ/tn from 'AGO, 2006, ' AGO Factors and Methods Workbook - For use in Australian greenhouse emissions reporting', Australian Greenhouse Office, Canberra, found at http://www.greenhouse.gov.au/workbook/pubs/workbook2006.pdf, January 2007.*

[32] *This equation assumes an electrical efficiency of 35%. Total fossil fuel electricity generation in 2003/2004 was 197,000 GWh. Source: ESAA, 2005, 'Further growth in Australia's electricity consumption', Electricity Suppliers Association of Australia, Melbourne, found at http://www.esaa.com.au/media_releases/2005_media_releases/further_growth_in_australia's_electricity_consumption.html, November 2006.*

Table 6 – Embodied energy values of materials disposed of to landfill

Material Type	*Total Tonnes Landfilled*	*Embodied Energy (GJ/tn)*[33]	*tonnes CO_2e in Embodied Energy*	*Total Embodied Energy (GJ)*	*Total tonnes CO_2e in Landfill*
Paper & Cardboard	2,690,000	42.3	4.1	113,787,000	11,151,000
Glass	500,000	22.5	2.2	11,250,000	1,103,000
Non-Ferrous (aluminium)	130,000	206.0	20.2	26,780,000	2,624,000
Ferrous	880,000	34.7	3.4	30,536,000	2,993,000
Plastic	1,500,000	78.2	7.7	117,300,000	11,495,000
Garden Organics	2,250,000	0.5	0.0	1,125,000	110,000
Food and other organics	2,890,000	29.3	2.9	84,677,000	8,298,000
Wood/Timber	1,630,000	13.0	1.3	21,190,000	2,077,000
Soil/Rubble and Other Clean Excavated Material	2,450,000	2.0	0.2	4,900,000	480,000
Concrete, bricks and asphalt	1,970,000	2.0	0.2	3,940,000	386,000
Other recyclables (inc Textiles)	280,000	-	0.0	-	-
Other (waste)	250,000	-	0.0	-	-
Total	**17,420,000**			**415,485,000**	**40,717,000**

In order to estimate the carbon abatement potential from recycling, it is necessary to estimate the *net energy savings* from recycling (embodied energy in virgin material minus embodied energy in recycled material).

5.2 Net Energy Savings from Recycling High Embodied Energy Materials

Embodied energy 'abatement' is created when recycling uses less energy to reprocess commodity materials than is used to manufacture from virgin feedstock. In this analysis only the direct recycling benefit from high energy materials has been considered, for example paper/cardboard, non-ferrous, ferrous and plastic. Lower embodied energy materials such as concrete and wood/timber are assumed to have a relatively neutral energy balance between virgin and recycled products, and as such have been excluded from this study.

Once the net savings in energy have been calculated, the potential greenhouse abatement can be estimated, as shown in Table 7 overleaf. For example, the recycling of non-ferrous metals like aluminium uses 14.1 GJ of energy per tonne of production. This compares to the 206 GJ that are used to make one tonne of 'virgin' aluminium. The 191.9 GJ of energy saved through recycling translates to a savings of 18.8 tCO_2e in greenhouse gas emissions for each tonne of aluminium that is recycled.

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[33] *Derived from Grant, T., James, K., Lundie, S., and Sonneveld, K., 2001, 'Stage 2 of the National Project on Life Cycle Assessment of Waste Management Systems for Domestic Paper and Packaging', RMIT, Melbourne, accessed at http://www.cfd.rmit.edu.au/content/download/123/836/file/Pkg&PapWaste2_Main_Report.pdf, December 2006, and GHD and Warnken ISE, 2006, Draft Stage 2 Report: Review and Assessment of the Performance of Extended Producer Responsibility and Product Stewardship Schemes', Waste Management Association of Australia, Sydney, found at http://www.wmaa.asn.au/uploads/documents/stage2.pdf, November 2006.*

Table 7 – Net embodied energy advantage of recycling and associated carbon abatement

Material Type	*Tonnes Recovered*	*Recycled Embodied Energy (GJ/tn)*[34]	*Energy Savings (GJ/tn)*	*tonnes CO_2e-abated per tonne of recycling*	*Net abatement tCO_2e- from recycling*[35]
Paper & Cardboard	1,076,000	28.2	14.1	1.38	1,487,000
Glass	300,000	9.7	12.8	1.25	375,000
Non-Ferrous (aluminium)	104,000	14.1	191.9	18.81	1,956,000
Ferrous	704,000	7.3	27.4	2.69	1,890,000
Plastic	900,000	17.6	60.6	5.94	5,345,000
Total	**3,084,000**				**11,053,000**

5.3 Summary - Greenhouse Gas Savings from the Recycling of High Embodied Energy Materials

The resource recovery model developed for this analysis estimates that 3,084,000 tonnes of 'dry recyclables' could be diverted from landfilled and recycled. **This recycling action could save over 112,000,000 GJ of energy, and prevent the release of 11.053 million tonnes of CO_2e (see Table 7 above).** If the energy savings were used to generate electricity it would make 10,965 gigawatt hours, which is 5.6 per cent of the electricity generated in Australia by fossil fuels.[36]

[If 100 per cent recovery was possible for glass, metal, and plastic and 50 per cent recycling for paper and cardboard[37] *the potential carbon abatement benefit would be 16.2 million tonnes of CO_2e.]*

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[34] *Derived from Grant, T., James, K., Lundie, S., and Sonneveld, K., 2001, 'Stage 2 of the National Project on Life Cycle Assessment of Waste Management Systems for Domestic Paper and Packaging', RMIT, Melbourne, accessed at http://www.cfd.rmit.edu.au/content/download/123/836/file/Pkg&PapWaste2_Main_Report.pdf, December 2006..*

[35] *Net position to nearest 1,000 tonnes CO_2e calculated using previous table of embodied energy calculations. Some discrepancies may exist due to rounding of per tonne CO_2e abatement.*

[36] *References as for Section 5.1.*

[37] *The remaining 50 per cent of paper and cardboard under a 100 per cent recovery scenario is split between bio-char and energy from waste and so not included here to avoid double counting of the potential benefit.*

6 RENEWABLE ENERGY DERIVED FROM WASTE

There are a number of opportunities to recover renewable energy from waste materials. All of the bio-based materials are considered renewable, including Paper and Cardboard, Garden Organics, Food and other organics, and Wood/Timber. These materials can be used to create a solid waste derived fuel to replace coal in power stations and cement kilns. Food and some other organics can be anaerobically digested to make 'biogas', which can be used to replace coal fired electricity. **Under the resource recovery model developed for this analysis (see Section 2.4), using renewable fuels derived from bio-based waste materials could offset the emission of 2.643 tonnes of CO_2e through the displacement of fossil fuels (1.783 million tonnes CO_2e from the use of renewable solid fuels and 0.86 million tonnes CO_2e from anaerobic digestion).** Note that this benefit is over and above the benefit from avoiding the generation of landfill gas in the first place.

6.1 Technologies for Recovering Renewable Energy from Waste

The main carbon abatement benefit from waste derived renewable energy is the replacement of fossil fuel energy. For example, the combustion of one tonne of washed black coal with an energy content (calorific value) of 27 gigajoules (GJ) for electricity generation creates approximately 2.44 tCO_2e, while the combustion of brown coal with a calorific value of 10 GJ creates 0.93 tCO_2e.[38] There are a number of opportunities to recover renewable energy from waste materials, and thus displace the use of fossil fuels and avoid their associated greenhouse gas emissions. These include:

- use as a coal replacement in a cement kiln – the manufacture of cement is very energy intensive, involving high temperatures. The high temperature also creates ideal combustion conditions for the use of alternative fuels such as processed engineered fuel and wood derived fuel. There is also no residual ash, as all ash content from the fuel is incorporated into the final cement product
- use as a coal replacement in a power station – alternative bio-based fuels such as wood derived fuel can be successfully co-fired with coal into a power station to create the steam that turns electricity generating turbines. There are some technical difficulties to overcome as most coal fired power stations were designed to burn pulverised coal, however addressing some of the materials handling and ash management issues can avoid the need for new renewable energy infrastructure development
- use in a stand alone purpose built biomass power station – smaller power stations (for example 30 mega-watts electric (MWe) generating capacity as opposed to coal fired stations in the order of 1-2,000 MWe) have been purpose built to handle a range of bio-based fuels. Smaller facilities can also contribute to a distributed electricity supply, which can reduce electricity losses in transmission

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[38] *Direct point source emissions from combustion from - 'AGO, 2006, ' AGO Factors and Methods Workbook - For use in Australian greenhouse emissions reporting', Australian Greenhouse Office, Canberra, found at http://www.greenhouse.gov.au/workbook/pubs/workbook2006.pdf, January 2007.*

- biogas production – the anaerobic digestion of food waste creates a biogas that is produced is similar in composition to landfill gas, and can be used for process heat or electricity generation (for example, in a reciprocating engine)
- creation of liquid fuels – biodiesel and bio-ethanol can be made from select components within the waste stream, such as animal fats and wood. There are a range of technical issues to overcome, primarily related to contamination from other waste materials.

In Australia renewable energy is generated through the use of solid waste derived fuels (primarily wood/timber) in power stations and cement kilns, and through the anaerobic digestion of food and other organics. These options have been included as part of the resource recovery model developed in Section 2.4 and their contribution to greenhouse gas abatement is explored in the following sections.

6.2 Renewable Energy from Solid Waste Derived Fuels

Typical solid waste derived fuels include paper/cardboard, plastics and wood/timber materials. These materials are used to replace coal in cement kilns and power stations. However, the energy content of plastic is not counted as a renewable fuel for the purposes of carbon accounting.[39] In order to calculate the amount of coal use that could potential be displaced by renewable solid waste derived fuels, a ratio of 64:34 between black coal and brown coal use has been assumed.[40] Table 8 below identifies the potential energy for coal replacement arising from the use of solid waste derived fuels (tonnes recovered are based on the resource recovery model from Section 2.4).

Table 8 – Potential energy for coal diversion from solid waste derived renewable fuels

Solid Waste Derived Fuel	*Total Tonnes Recovered*	*Calorific Value (GJ/tn)*[41]	*Total GJ Energy Recovery*	*Tonnes CO2e abated*
Paper & Cardboard	538,000	17	9,146,000	833,000
Plastic	[300,000]	34.5	[10,350,000]	-
Wood/Timber	652,000	16	10,432,000	950,000
Total Renewable Energy (ex plastic)	**1,190,000**		**19,578,000**	**1,783,000**

The total renewable energy of 19,578,000 GJ could be used to replace 464,000 tonnes of washed black coal and 705,000 tonnes of brown coal. Together this represents an abatement of 1,783,000 tCO_2e using emission coefficients from the AGO workbook.[42]

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[39] *The plastic energy content has not been counted towards the total coal replacement. It has also not been added as a 'negative' emission as it would be substituting the use of coal, which is already being accounted for in the national greenhouse gas accounts. .*

[40] *Based on existing coal use in Australian energy generation. For example in 2003/2004 Australia burned 51 million tonnes of black coal and 76 million tonnes of brown coal : ESAA, 2005, 'Further growth in Australia's electricity consumption', Electricity Suppliers Association of Australia, Melbourne, found at http://www.esaa.com.au/media_releases/2005_media_releases/further_growth_in_australia's_electricity_consumption.html, November 2006. Here AGO 2006 Workbook calorific values of 27 GJ/tn and 10 GJ/tn have been used to convert the ratio from tonnes into energy content.*

[41] *Derived from GHD and Warnken ISE, 2006, Draft Stage 2 Report: Review and Assessment of the Performance of Extended Producer Responsibility and Product Stewardship Schemes', Waste Management Association of Australia, Sydney, found at http://www.wmaa.asn.au/uploads/documents/stage2.pdf, November 2006.*

[42] *'AGO, 2006, ' AGO Factors and Methods Workbook - For use in Australian greenhouse emissions reporting', Australian Greenhouse Office, Canberra, found at http://www.greenhouse.gov.au/workbook/pubs/workbook2006.pdf, January 2007.*

6.3 Renewable Energy from Anaerobic Digestion Biogas

The use of anaerobic digestion to process 2.312 million tonnes of food waste to produce biogas for electricity generation also provides an abatement benefit. Using the methodology outlined in Section 9.2, the digestion of 2.312 million tonnes of food waste would generate approximately 217, 500 tonnes of methane. The energy content of this methane is approximately 11,419,000 GJ, of which 35 per cent is used to run the process of anaerobic digestion.

Using a mid-point manufacturers electrical efficiency rating of 38.5 per cent (as for the landfill gas electricity generator) means that this amount of biogas could be used to generate 794,000 MWh of renewable electricity which avoids the emission of 860,000 tCO_2e.[43]

6.4 Summary - Potential Abatement from Using Renewable Waste Derived Fuels

Combining the carbon abatement from the renewable solid waste derived fuels and anaerobic digestion electricity generation gives an estimated abatement of 2,643,000 tCO_2e (1,783,000 tCO_2e from the use of solid fuels and 860,000 tCO_2e from anaerobic digestion). Note that this benefit is over and above the benefit from avoiding the generation of landfill gas in the first place.

[If 25 per cent of paper/cardboard, and 50 per cent of wood timber; in addition to 100 per cent of food waste, were sent for solid fuel and anaerobic digestion respectively,[44] *a combined total of 3.117 million tonnes CO_2e would be abated.]*

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[43] *Electricity calculation is (1-0.35) * 11,419,000GJ = 7,423,000 GJ for electricity generation. Multiply by electrical efficiency of 38.5% = 2,857,713 GJ of electricity = 2,857,713,000 MJ. Divide by 3,600 to convert MJ into MWh = 793,800 MWh (nearest 100 MWh). The full fuel cycle emissions for coal fired electricity from the 2006 AGO workbook and averaged across NSW, Vic, Qld, WA and SA for 2003 is 1083 $kgCO_2e$ per MWh. Multiplying 793,800 by 1.083 gives 860,000 tonnes of CO_2e abated (nearest 1000 tonnes).*

[44] *This is based on the material flows in the resource recovery model from Section 2.4.*

7 CONVERSION OF SUITABLE WASTE MATERIALS TO ‘BIOCHAR’ FOR LAND APPLICATION

The manufacture of biochar from material sources such as garden organics and wood/timber converts the degradable organic carbon content into a form that is stable over long term horizons. This creates a ‘carbon pump’ effect where carbon is removed, captured and stored. **Under the resource recovery model developed for this analysis (see Section 2.4), 1.752 million tonnes of CO_2e would be removed from the atmosphere and ‘stored’ through the land application of biochar.**

7.1 Biochar for Land Application

The manufacture of biochar from material sources such as garden organics and wood/timber converts the degradable organic carbon content within these materials into a form that is stable over long term horizons. As was identified in Section 4.1, char manufacture involves a pyrolysis process where biomass materials are heated in the absence of oxygen. The longevity of biochar has been established by studies into the practices of Amazonian Indians and the ‘slash and char’ that formed part of their agricultural practices. The resulting so called ‘Terra Preta’ soils (black earth) are still identifiable some two thousand years later, with much a much higher carbon content than surrounding plots of land (in some cases up to 18 times the carbon content as in surrounding soil).[45] This effectively means that the manufacture of biochar for use as a soil improver (either alone or in conjunction with other forms of fertiliser) is a form of carbon capture and storage, with additional upside benefits such as improved water and nutrient retention when used as part of a soil treatment regime.

7.2 Manufacture of Biochar and Carbon Abatement Benefit

Char can be manufactured such that 50 per cent of the bio-based carbon in the input material is converted into a stable form and retained over a long time horizon (in the order of thousands of years). This is net of the energy used to operate the charring process. Given that most woody materials have a carbon to dry weight ratio of 50 per cent,[46] and that ‘green’ wood often has a moisture content of 50 per cent, eight tonnes of garden organics would make biochar that contained one tonne of carbon. (The actual amount of char is likely to be in the order of 1.5 – 2 tonnes, with a carbon content of between 50% and 66.7%).

Other bio-based materials such as paper/cardboard and wood/timber would have greater yields of carbon because of their lower average moisture contents of 15 per cent.

Solid carbon is converted into tonnes of carbon dioxide equivalent by multiplying by 44/12.[47] This means that eight tonnes of garden organics converted into biochar would remove 3.7 tonnes of CO_2e from the atmosphere and into long term storage through the application of the biochar to land.

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[45] *Lehmann, J. (undated),’ Terra Preta: Soil Improvement and Carbon Sequestration’, Cornell University Soil Biochemistry Programme, Ithaca, found at http://www.css.cornell.edu/faculty/lehmann/terra_preta/Flyer%20terra%20preta%20landuse%20strategy.pdf, November 2006.*

[46] *See for example, UK Forestry Research, (undated), ‘Carbon Accounting’, found at http://www.forestresearch.gov.uk/website/forestresearch.nsf/ByUnique/INFD-633DJ4, November 2006.*

[47] *The molecular weight of carbon is 12, while the molecular weight of carbon dioxide is 44.*

7.3 Summary - Abatement Benefit from Converting Suitable Wastes to Biochar for Land Application

Using the model of waste diversion developed for this analysis, it has been assumed that 538,000 tonnes of paper/cardboard, 1,800,000 tonnes of garden organics and 652,000 tonnes of wood/timber is diverted into biochar production. Accounting for differing moisture contents, this amount of 'woody' waste is equivalent to 1,911,500 tonnes of bone dry wood with a carbon content of 50 per cent. **Converting this biomass into biochar would produce biochar with a carbon content of 477,875 tonnes. Adjusting solid tonnes of carbon (tC) into tCO_2e gives a carbon abatement of 1,752,000 tCO_2e (nearest thousand tonnes).**

[If 25 per cent of paper/cardboard, 100 per cent of garden organics and 50 per cent of wood/timber were recovered for biochar manufacture, the potential carbon abatement would be 2.190 million tonnes of CO_2e*.]*[48]

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[48] *This is based on the material flows in the resource recovery model from Section 2.4.*

8 CHANGING FLEET TO LOWER CARBON INTENSITY FUEL

Approximately 234 million kilometres are travelled each year in the collection, recycling and disposal of wastes generated in Australia. Biodiesel is a renewable fuel that has lower greenhouse gas emissions than diesel. **If the entire waste and resource recovery transportation fleet was to use a blended fuel of 50 per cent biodiesel (B50), the emission of 172,446 tonnes of CO_2e would be avoided because of the lower carbon intensity of B50.**

8.1 Greenhouse Gas Emissions from Waste and Resource Recovery Transportation

The summary of Australian waste generation in presented in Section 2 identified that approximately 32,380,000 tonnes of waste was generated in Australia for the 2002/2003 financial year. These materials required collection and transportation, either from 240 litre mobile garbage bins for Municipal Solid Waste (MSW), or from larger front lift and rear hook lift bins from the Commercial and Industrial (C&I), and Construction and Demolition (C&D) sectors.

The following rates of travel for waste collection in Table 9 (rounded to nearest 1,000 tonnes, kilometres and kilolitres respectively) have been developed using data supplied by participants in the waste industry. As recyclables are lighter that waste disposed of to landfill in MSW and C&I waste, the estimated kilometres per tonne have been doubled. C&D waste contains a lot of hard core materials like concrete, bricks and rubble. As such the estimate for recycling and collection for landfill remains the same.

Table 9 – Kilometres travelled and associated greenhouse gas emissions to collect, recycle and dispose of waste generated in Australia

Waste Source	*Tonnes*[49]	*Kilometres Per Tonne*	*Total Kilometres*	*Total Kilolitres Diesel*	*Emissions (tCO_2e)*
MSW Landfill	6,202,000	5	31,010,000	17,000	46,000
MSW Recycling	2,701,000	10	27,010,000	15,000	41,000
C&I Landfill	5,307,000	5	26,535,000	14,000	38,000
C&I Recycling	4,162,000	10	41,620,000	23,000	62,000
C&D Landfill	5,914,000	5	29,570,000	16,000	43,000
C&D Recycling	7,827,000	5	78,270,000	43,000	116,000
Totals	**32,113,000**		**234,015,000**	**128,000**	**346,000**

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[49] *Hyder Consulting 2006, "Waste and Recycling in Australia", Department of Environment and Heritage, found at http://www.pc.gov.au/inquiry/waste/subs/sub103attachmenta.pdf, November 2006 – Note that the total generation does not match the material specific analysis because of 269,000 tonnes of waste which were unallocated, in addition to other rounding differences.*

Estimates presented here are indicative only, and are intended to scale the amount of transport involved in the collection, recycling and disposal of waste generated in Australia. In total it is estimated that the waste and resource recovery industry travels an estimated 234 million kilometres to manage Australia's waste generation.

The Australian Greenhouse Offices (AGO) estimates that heavy trucks have an average fuel usage of 0.546 litres per kilometre (or 1.832 km/l) and that each kilolitre of diesel used emits 2.7 tonnes of CO_2e at the point of combustion.[50]

The waste management and resource recovery industry will use 128,000 kilolitres of diesel to travel 234 million kilometres and, in so doing, release 346,000 tonnes of CO_2e (assuming all of the fleet uses diesel). The greenhouse gas intensity of transport in the resource recovery and waste management sectors can be reduced by using a blended biodiesel fuel.

8.2 Summary - Use of Biodiesel Blend to Lower Transport Emissions

Biodiesel is a diesel fuel substitute that is made from renewable sources such as canola, tallow and waste oil. Because biodiesel is a renewable fuel, it has lower greenhouse gas emissions than diesel. For example, AGO estimates that the point source emissions from combustion of biodiesel are 0.0 tonnes of CO_2e per kilolitre.[51]

It has been assumed that the entire waste and resource recovery industry swaps to a blended fuel of 50 per cent biodiesel and 50 per cent diesel (B50). **A B50 blend would release are 1.35 tonnes of CO_2e per kilolitre used. The use of a B50 blend would thus abate 173,000 tonnes of CO_2e because of its lower carbon intensity.**

[If the entire waste management and resource recovery fleet was to use B100 (100% biodiesel) a potential savings of 344,891 tonnes of CO_2e could be achieved.]

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[50] 'AGO, 2006, ' AGO Factors and Methods Workbook - For use in Australian greenhouse emissions reporting', Australian Greenhouse Office, Canberra, found at http://www.greenhouse.gov.au/workbook/pubs/workbook2006.pdf, January 2007 – Note that this is not the full fuel cycle estimate of 3.0 tCO_2e.

[51] Ibid. Note that this is not the full fuel cycle emission estimates, which are 2.1 tCO_2e for BD100 (canola), 1.9 tCO_2e for BD100 (tallow) and 0.3 tCO_2e for BD100 (waste oil). However these emissions are accounted for under different sectors and so are not counted in transport so as to avoid double counting. Also note that other authors have lower full fuel cycle emissions. For example Judd, B., 2003, 'Feasibility of Producing Diesel Fuels from Biomass in New Zealand', Energy Efficiency and Conservation Authority, accessed at www.eeca.govt.nz/eeca-library/renewable-energy/biofuels/report/feasibility-of-producing-diesel-fuels-from-biomass-in-nz-03.pdf, December 2006 – estimates 1.75 tCO_2e for BD100 (canola), and 0.23 tCO_2e for BD100 (tallow).

9 DISCUSSION – COST OF CARBON ABATEMENT AND IMPLICATIONS FOR WASTE MANAGEMENT TECHNOLOGIES

The waste industry currently accounts for 2.7 per cent of net greenhouse gas emissions in Australia. However, this initial analysis has demonstrated that with improved performance in resource recovery, a significant potential abatement of up to nearly 38 $MtCO_2e$ could be made, which represents a 6.7 per cent reduction of Australia's net greenhouse gas emissions (2004 figures).

In order to gain further insight into the carbon abatement potential from resource recovery and improved waste management the cost of carbon abatement (from an investment perspective) and carbon implications of waste management technologies need to be considered.

9.1 Where to Invest – Maximising Carbon Abatement

An economic assessment is required to determine the cost-benefit implications of implementing each of the options presented this study. A significant element of such an analysis will be the relative value of abated emissions within a carbon trading market either at a national or international level. However, any CBA must also be balanced against the societal costs of greenhouse emissions, such as the Stern Review's estimated societal cost of climate change of $110 per tonne of CO_2e.[52] For example, on the basis of this estimate, any carbon abatement that costs less than the societal cost of climate change of $110 per tonne of CO_2e would result in a net improvement to society.

In order to determine the value of investing in landfill diversion, gas capture or additional recycling capacity for carbon abatement, it is necessary to consider the costs of other abatement alternatives. The Stern Review identified generic costs for greenhouse gas abatement, including:[53]

- carbon capture and storage - a developing technology that is used in conjunction with coal fired power stations to convert exhaust gases into a liquid or solid form of CO_2 and then store in depleted oil or gas wells, or abandoned coal mines with appropriate geology. Estimates on the likely cost of this abatement range from $27 - $63 (US$19-49) per tonne of CO_2 (a midpoint of $45 per tCO_2e is used for this analysis)
- planting new forests (afforestation and reforestation) - converts atmospheric CO_2 into 'wood', which is approximately 50 per cent carbon. Provided the forest is managed over a long period, the tree carbon becomes a carbon sink. Likely costs range from $6.50 - $19 (US$5-15) per tonne of CO_2 (a midpoint of $13 per tCO_2e is used for this analysis)
- biomass - the use of woody crops for power generation for electricity, process heat and transport fuels. By offsetting the use of fossil fuels, biomass has the potential to abate carbon emissions at an estimated cost of $32 ($US25) per tonne of CO_2.

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[52] *US$85 - Stern Review, 2006, 'The Economics of Climate Change', HM Treasury, London, accessed at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm, November 2006.*

[53] *ibid*

Three examples are presented here to as a preliminary investigation into the cost effectiveness of greenhouse gas abatement through improved resource recovery practices:

- recovery of one tonne of Municipal Solid Waste (MSW)
- recovery of one tonne of Commercial and Industrial (C&I) waste
- recovery of one tonne of source separated C&I plastic.

9.1.1 Cost of Carbon Abatement from One Tonne of MSW Recovery

The material composition of one tonne of MSW is presented in Table 10 below. In order to process this 'bundle' of materials, there are a number of costs for sorting, processing and transport, in addition to sales of both service fees (for waste management) and sale of commodity. Estimates used in this first order analysis are also presented in Table 10. It has been assumed that all materials pass firstly through a 'dirty MRF' (materials recycling facility) to be sorted into their primary material groupings. A transport component has been included to cover the situation where bulk materials are transported to a processing plant for further beneficiation. The additional processing covers the costs of transforming the material into a form where it can be sold as a commodity or used directly in the process of manufacture. In the case of inert materials, however, disposal to landfill has been assumed. All product sales have been set at a wholesale level. No product sale has been estimated for food, garden organics and wood/timber, or for materials disposed of to landfill.

Table 10 – Material composition of one tonne MSW and cost of recovery

Material Type	*Kilograms in One Tonne*	*Cost of MRFing*	*Transport*	*Additional Processing*	*Wholesale Product Sale*	*Net Cost*
Paper & Cardboard	224	$ (20.19)	$ (3.37)	$ (11.22)	$ 15.70	$ (19.07)
Glass	58	$ (5.26)	$ (0.88)	$ (5.85)	$ 4.21	$ (7.77)
Non-Ferrous (aluminium)	10	$ (0.89)	$ (0.15)	$ (0.99)	$ 11.85	$ 9.83
Ferrous	42	$ (3.80)	$ (0.63)	$ (4.23)	$ 3.38	$ (5.28)
Plastic	60	$ (5.37)	$ (0.90)	$ (17.91)	$ 14.92	$ (9.25)
Garden Organics	181	$ (16.29)	$ (2.71)	$ (14.48)	$ -	$ (33.48)
Food and other organics	339	$ (30.49)	$ (5.08)	$ (27.10)	$ -	$ (62.67)
Wood/Timber	32	$ (2.92)	$ (0.49)	$ (2.60)	$ -	$ (6.00)
Soil/Rubble and Other Clean Excavated Material	27	$ (2.45)	$ (0.41)	$ (2.72)	$ -	$ (5.58)
Concrete, bricks and asphalt	20	$ (1.78)	$ (0.30)	$ (1.98)	$ -	$ (4.06)
Other recyclables (inc Textiles)	4	$ (0.32)	$ (0.05)	$ (0.36)	$ -	$ (0.73)
Other (waste)	3	$ (0.23)	$ (0.04)	$ (0.26)	$ -	$ (0.52)
Total	**1000**	**$ 90.00)**	**$ (15.00)**	**$ (89.67)**	**$ 50.07**	**$(144.61)**

Table 10 above estimates the cost of operating a dirty MRF to recover resources from MSW as $144.61 per tonne. However this does not include the gatefee that can be charged as a waste management service fee. Assuming a charge of $60 per tonne (comparable to a national indicative cost of putrescible landfill), reduces the net cost down to $84.61. The potential greenhouse gas abatement from this resource recovery, based on the methodology developed in this study, is presented in Table 11 below.

Table 11 – Greenhouse gas abatement and indicative cost from one tonne of MSW resource recovery

Greenhouse Gas Abatement Category	*Abatement (tCO_2e)*
Avoided Landfill Gas Emissions (waste stream)	1.14
Paper and Cardboard Embodied Energy Savings	0.31
Glass Embodied Energy Savings	0.07
Aluminium Embodied Energy Savings	0.19
Steel Embodied Energy Savings	0.11
Plastic Embodied Energy Savings	0.35
Anaerobic digestion of food	0.1
Biochar manufacture from Garden Organics	0.14
Biochar manufacture from Wood Timber	0.03
Total Greenhouse Gas Abatement	**2.44**
Cost to deliver this abatement	$ 84.61
Cost per tonne GHG abatement	**$ 34.67**

The estimated cost of greenhouse gas abatement is thus estimated to be $35 per tonne of CO_2e. This cost is cheaper than carbon capture and storage, relatively equal to biomass power generation, but is nearly three times as expensive as a forestry carbon sink. However, it should be noted that a key determinant here is the gatefee for service. With a $120 service fee (an estimated market gatefee for an alternative waste technology) the greenhouse gas abatement cost per tonne would also be reduced to around $10 per tonne of CO_2e, making it cost competitive with a forestry carbon sink abatement option.

9.1.2 Cost of Carbon Abatement from One Tonne of C&I Recovery

The material composition of one tonne of C&I waste is presented in Table 12 overleaf. As with MSW, there are a number of costs for sorting, processing and transport, in addition to sales of both service fees (for waste management) and sale of commodity. Estimates used in this first order analysis are also presented in Table 12 and are based on the same assumptions as for the MSW analysis in Table 10.

Table 12 – Material composition of one tonne C&I and cost of recovery

Material Type	*Kilograms in One Tonne*	*Cost of MRFing*	*Transport*	*Additional Processing*	*Wholesale Product Sale*	*Net Cost*
Paper & Cardboard	213	$ (19.21)	$ (3.20)	$ (10.67)	$ 14.94	$ (18.14)
Glass	28	$ (2.49)	$ (0.41)	$ (2.76)	$ 1.99	$ (3.67)
Non-Ferrous (aluminium)	10	$ (0.87)	$ (0.15)	$ (0.97)	$ 11.62	$ 9.63
Ferrous	57	$ (5.09)	$ (0.85)	$ (5.65)	$ 4.52	$ (7.07)
Plastic	122	$ (11.02)	$ (1.84)	$ (36.74)	$ 30.62	$ (18.98)
Garden Organics	99	$ (8.91)	$ (1.49)	$ (7.92)	$ -	$ (18.32)
Food and other organics	152	$ (13.65)	$ (2.27)	$ (12.13)	$ -	$ (28.06)
Wood/Timber	153	$ (13.81)	$ (2.30)	$ (12.28)	$ -	$ (28.39)
Soil/Rubble and Other Clean Excavated Material	68	$ (6.15)	$ (1.02)	$ (6.83)	$ -	$ (14.00)
Concrete, bricks and asphalt	69	$ (6.20)	$ (1.03)	$ (6.89)	$ -	$ (14.13)
Other recyclables (inc Textiles)	23	$ (2.04)	$ (0.34)	$ (2.26)	$ -	$ (4.64)
Other (waste)	6	$ (0.56)	$ (0.09)	$ (0.63)	$ -	$ (1.29)
Total	**1000**	**$ (90.00)**	**$ (15.00)**	**$(105.74)**	**$ 63.68**	**$(147.05)**

Table 12 above estimates the cost of operating a C&I MRF to recover resources from C&I waste materials is $147.05 per tonne. However this does not include the gatefee that can be charged as a waste management service fee. Assuming a charge of $45 per tonne (comparable to an indicative cost per tonne of C&I landfill), reduces the cost down to $102.05. The potential greenhouse gas abatement from this resource recovery, based on the methodology developed in this study, is presented in Table 13 below.

Table 13 – Greenhouse gas abatement and indicative cost from one tonne of C&I resource recovery

Greenhouse Gas Abatement Category	*Abatement (tCO_2e)*
Avoided Landfill Gas Emissions (waste stream)	1.9
Paper and Cardboard Embodied Energy Savings	0.29
Glass Embodied Energy Savings	0.03
Aluminium Embodied Energy Savings	0.18
Steel Embodied Energy Savings	0.15
Plastic Embodied Energy Savings	0.73
Anaerobic digestion of food	0.05
Biochar manufacture from Garden Organics	0.08
Biochar manufacture from Wood Timber	0.12
Total Greenhouse Gas Abatement	**3.53**
Cost to deliver this abatement	$102.05
Cost per tonne GHG abatement	**$28.91**

The estimated cost of greenhouse gas abatement is thus estimated to be $29 per tonne of CO_2e. This cost is cheaper than carbon capture and storage, and biomass power generation., but is over twice as expensive as a forestry carbon sink. However, it should be noted that a key determinant here is the gatefee for service. With a $90 service fee the greenhouse gas abatement cost per tonne would be reduced to around $16 per tonne of CO_2e, bringing it into the cost range of abatement through forestry carbon sinks.

9.1.3 Cost of Carbon Abatement from One Tonne of Recycled C&I Plastic

The recycling of commercial plastic currently occurs on the basis that the saleable commodity value of the recyclate, plus any gatefee for receiving the material, is more than the costs involved with processing the recycled plastic into a form where it can be used in other applications. It is assumed that there is additional processing capacity within the system that could also recycle plastic at a negative cost (that is as a profitable business activity).

According to Table 8, each additional tonne of plastic recycled into the same or similare plastic stream from waste that would have otherwise been disposed of to landfill is estimated to abate 6.8 tonnes of CO_2e. Taking the mid-points of the cost ranges for abatement options from Stern Review means the marginal cost of one tonne of plastic recycling would have to be less than the comparative per tonne abatement cost of $306.00 (carbon capture and storage), $88.40 (carbon forestry sink) or $217.60 (biomass power generation) in order to be a ‘cheaper’ abatement option.

Given that plastic recycling is currently economic, and that a number of non-financial barriers to increased recycling such as access to materials, siting of recovery facilities, and the value of recycling could be overcome through strong policy interventions, the marginal cost for increased plastic recycling is likely to be small, and could even be covered by increased commodity sale prices caused by higher increases in the cost of virgin plastic feedstock due to fluctuations in the cost of oil.

The potential carbon abatement from plastic recycling could thus be delivered at a low-to-no cost per tonne of CO_2e. Or in other words, each dollar invested in plastic recycling would deliver carbon abatement benefits at a low marginal cost, at least an order of magnitude below afforestation/reforestation, and two orders of magnitude below carbon capture and storage and biomass power generation. Similar arguments can be made for source separated paper and cardboard, glass, timber, and garden organics, in terms of CO_2e abatement and a low-to-no additional cost structure.

9.1.4 Summary of Carbon Abatement Costs from Resource Recovery

In the case of resource recovery from source separated loads of recyclable materials, carbon abatement benefits could potentially be delivered at low-to-no marginal cost. This is because service fees for waste management provision, in addition to the sale of the recycled commodity could be greater than costs incurred for collection, transport and additional processing.

For mixed waste streams such as MSW and C&I, the additional costs of ‘dirty MRFing’ and processing are unlikely to be met by current market conditions, highlighting the need for intervention by government in order to access the potneial greenhouse gas abatement. However, estimates of the marginal cost of carbon abatement (with current service fee estimates) are $35 per tonne of CO_2e for MSW, and $29 per tonne of CO_2e for C&I waste materials, which is a cheaper abatement option that carbon capture and storage and biomass renewable energy. The 'marginal' cost for each option where an increased service fee is received reduces to around $10 and $16 per tonne of CO_2e respectively.

These estimates are lower than the abatement costs for carbon capture and storage and biomass renewable energy, and are comparable to developing forestry sinks. The estimated abatement cost equation highlights the effectiveness of investing into resource recovery infrastructure as a greenhouse gas reduction strategy.

9.2 Carbon Implications of Waste Management Technologies

Based on the methodology developed in this report, the diversion of waste with degradable organic carbon from landfill demonstrates a greenhouse gas benefit. However, the question remains as to the scale of this benefit when compared against different alternatives. A full life cycle analysis of the specific options would be required to provided a definitive determination on the relative abatement or emission of each option and would also depend on a number of local features, including technical details such as onsite power usage. Such a life cycle assessment is beyond the scope of this discussion paper. However, the following example is presented to illustrate the issues involved.

In order to investigate the carbon implications of a range of technologies, options to process 1,000 tonnes of food waste are considered. (Note that the implications for other waste streams, for example a mixed organic residue from Municipal Solid Waste are likely to have similar outcomes, the difference being the starting amount of degradable organic carbon).

The greenhouse gas potential of a waste material relates to the amount of degradable organic carbon (DOC) present, the dissimilation factor of this carbon (DOC_f) and whether this carbon decomposes into methane or carbon dioxide. Food waste is composed of 15 per cent DOC. This means that 1,000 tonnes of food waste contains 150 tonnes DOC. However, not all of this is available to form methane or carbon dioxide. The default dissimilation factor for landfill is 0.5 (DOC_f), meaning that half of DOC dissimilates or decomposes into the atmosphere. In the case of 1,000 tonnes of food waste, this translates to 75 tonnes of carbon.[54]

9.2.1 Aerobic Composting (also Alternative Waste Technology – Mechanical Biological Treatment with Aerobic Composting)

If 1,000 tonnes of food waste was to completely decompose with no anaerobic activity (such as in a best practice composting system incorporated as part of an alternative waste technology facility with composting as the mechanical biological treatment), the amount of DOC dissimilated would convert to carbon dioxide. Assuming the same dissimilation factor as landfill (in order to balance with the AGO workbook), 75 tonnes of carbon in the food waste would breakdown to form 275 tonnes of carbon dioxide (CO_2).[55]

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[54] *'AGO, 2006, ' AGO Factors and Methods Workbook - For use in Australian greenhouse emissions reporting', Australian Greenhouse Office, Canberra, found at http://www.greenhouse.gov.au/workbook/pubs/workbook2006.pdf, January 2007.*

[55] *The molecular weight of carbon is 12 and the molecular weight of CO2 is 44, so multiply C content by 44/12*

This production of carbon dioxide is considered to be part of the natural carbon cycle and as such is considered to be greenhouse neutral. In other words, aerobic composting of waste materials represents the release of carbon recently removed from the atmosphere, which means no net change in greenhouse gas atmospheric concentration.

9.2.2 Landfill with no Gas Capture

If all of the landfill gas emitted by landfills was carbon dioxide, landfills could be considered greenhouse gas neutral (ignoring other resource recovery issues such as the potential for recycling of materials with high embodied energy). However, landfills are generally anaerobic, and the decomposition of degradable organic carbon in these conditions generates methane, a greenhouse gas with 21 times the warming potential of carbon dioxide. The below equation is used by AGO to estimate the release of greenhouse gas emissions from landfill in the form of methane (over and above any carbon dioxide content in landfill gas):[56]

$$\text{GHG emissions } (tCO_2e) = [((Q*DOC*DOC_f*F_1*16/12-R)*(1-OX))*21]$$

where:

Q = tonnes of waste

DOC = degradable organic carbon

DOC_f = fraction of degradable organic carbon dissimilated, default for landfill = 0.5

F_1 = fraction of methane in landfill gas, default for landfill gas = 0.5

16/12 = methane to carbon ratio

R = recovered landfill gas for flaring or electricity generation (measured in tCH_4)

OX = oxidation factor, amount of methane that gets oxidised through landfill capping systems (default for best practice = 0.1, for no landfill cap = 0)

21 = global warming potential of methane

Thus if the food waste was sent to landfill with no gas recovery, but with a best practice capping system, an estimated 945 tonnes of CO_2e would be released.[57] However, in order to compare this on a gross emission level with the CO_2 emissions from compost, the amount of CO_2 in landfill gas (137.5t), and the CO_2 from oxidation in the landfill cap (13.75t) also needs to be included.[58] Thus total gross emissions from landfill is 1,096.3 tCO_2e.

9.2.3 Landfill with Gas Capture

The effect of gas capture and flaring or recovery for energy is to convert the methane back to carbon dioxide and restore the carbon 'balance' for the decomposed material that produced the methane. AGO estimates best capture rates of 70 per cent for landfill gas.[59] Using this estimate means thar for this example, 30 per cent of landfill gas would escape to the atmosphere.

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[56] *'AGO, 2006, ' AGO Factors and Methods Workbook - For use in Australian greenhouse emissions reporting', Australian Greenhouse Office, Canberra, found at http://www.greenhouse.gov.au/workbook/pubs/workbook2006.pdf, January 2007.*

[57] *GHG emissions (tCO2e) = [((1,000*0.15*0.5*0.5*16/12-0)*(1-0.1))*21] = 50*0.9*21=945. (Note that this is higher than using the default factor for food waste of 0.9 tCO_2e per tonne of food waste (900 tCO_2e) because the default factor is rounded to one decimal point).*

[58] *Half of the dissimilated carbon is transformed into CO_2 (1000*0.15*0.5*0.5*44/12)=137.5 tCO_2. 5 tonnes of methane (10% of generation) is assumed to be oxidised into CO_2. Converting this amount of carbon = 5/16*12 3.75 tC = 3.75*44/12 = 13.75 t CO_2.*

[59] *AGO 2005, 'Methane to Markets – Landfill Gas Technical Subcommittee Country Profile – Australia', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/international/partnerships/pubs/landfillgas-australia.pdf, December 2006.*

(Note that different landfills have different gas capture rates which also differ over time in their operation cycle). In the scenario where 70 per cent of landfill gas is captured, there would be a release of 283.5 tCO_2e using the AGO equation, with an additional 35 tonnes of methane captured for energy generation.

In order to compare this on a 'gross' basis with the compost emissions, the CO_2 from combustion of methane also needs to be added (96.25t) in addition to the CO_2 component of landfill gas (137.5 t), and the oxidised element of methane in the landfill cap (4.1t), giving an estimated greenhouse gas emission of 521.4 tCO_2e.[60]

9.2.4 Alternative Waste Technology – Mechanical Biological Treatment with Anaerobic Digestion

Another option is to anaerobically digest the food waste to generate biogas. The anaerobic digester is an efficient form of converting degradable organic carbon into biogas, for example the dissimilation factor for digestion is 0.784, as opposed to 0.5 for landfill.[61] Biogas can also have a higher concentration of methane, (60% as opposed to 50%), giving it a higher energy content.[62] Using the greenhouse gas equation from above, the anaerobic digestion of 1,000 tonnes of food waste would produce 94.1 tonnes of methane for energy generation. When combusted and assuming that there are no fugitive emissions from the facility, this methane would release 258.8 tonnes of carbon dioxide. In order to compare this option against the composting option, the carbon dioxide component of the biogas also needs to be added (172.5t), giving a total greenhouse gas emission of 431.3 tCO_2e. [63]

9.2.5 Alternative Waste Technology – Mechanical Biological Treatment with both Aerobic Composting and Anaerobic Digestion

An alternative waste technology (AWT) could provide a combination of composting and anaerobic digestion. Here a 50/50 combination has been assumed. This means the greenhouse gas emissions from processing 1,000 tonnes of food waste through an AWT facility would be 353.2 tCO_2e.[64]

9.2.6 Comparison of Performance on Gross Emissions

The comparison of gross greenhouse gas emissions from the processing of 1,000 tonnes of food waste is presented in Table 14 overleaf. On the basis of this first principles 'mass balance' analysis, composting is the best option (275.0 tCO_2e), with landfill without gas capture the worst (1,096.3 tCO_2e). Both an AWT combination of anaerobic digestion and composting (353.2 tCO_2e) and straight anaerobic digestion (431.3 tCO_2e) are better than landfill with 70 per cent landfill gas recovery (521.4 tCO_2e), which was the second worst option.

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[60] *GHG emissions (tCO2e) = [((1,000*0.15*0.5*0.5*16/12-35)*(1-0.1))*21] = 15*0.9*21=283.5. 35 CH_4 convert to tC = 35/16*12 = 26.25 tC. Convert to CO_2 = 26.25*44/12= 96.25 t CO_2. Half of dissimilated DOC forms CO_2, = (1,000*0.15*0.5*0.5*44/12) = 137.5 t CO_2. 15 t CH_4 escapes from landfill (50t – 35t), of which 10% is oxidised = 1.5 t CH_4. 1.5/16*12 = 1.125 tC = 4.1tCO_2.*

[61] *AGO 1997, 'Methane Capture and Use - Waste Management Workbook, A Quick Reference Guide', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/challenge/publications/methanequickref.html, January 2007. Assumes an operating temperature of 36 ºC.*

[62] *Residua, (undated), 'Anaerobic Digestion', Warmer Bulletin, North Yorkshire, found at http://www.waste.nl/redir/content/download/472/3779/file/WB89-InfoSheet(Anaerobic%20Digestion).pdf, November 2006.*

[63] *Methane generation = (1,000*0.15*0.784*0.6*16/12) = 94.1 tCH_4 convert to tC = 94.1/16*12 = 70.58 tC. Convert to CO_2 = 70.58*44/12= 258.8 t CO_2. Biogas is 40% CO_2, (40% of DOC goes to carbon dioxide) = (1,000*0.15*0.784*0.4*44/12) = 172.5 t CO_2.*

[64] *50% of 275 tCO_2e + 50% of 431.3 tCO_2e*

Table 14 – Gross greenhouse gas emissions for technology options processing 1,000 tonnes of food waste

	Aerobic Compost (including AWT MBT)	*AWT MBT Combination of Compost and AD*	*AWT Anaerobic Digestion (AD)*	*Landfill with 70% Gas Capture*	*Landfill with BP Cap and No Gas Capture*
Gross greenhouse gas emissions (tCO_2e)	**275.0**	**353.2**	**431.3**	**521.4**	**1,096.3**

The above analysis presents an estimate of emissions based on the fate of the carbon in the food waste. However, the above table does not separate 'biogenic' carbon dioxide from methane emissions. This would be a factor in determining a relative net greenhouse balance between options. The other factor of relevance to each option is the potential to create carbon offsets or abatement. The potential for offset creation is presented in the following section.

9.2.7 Inclusion of Offsets - Potential for Greenhouse Abatement

There has been much recent discussion about the establishment of a national emissions trading scheme. For example, the states based National Emissions Trading Scheme, and at a Federal level, the Task Group on Emissions Trading. The general approach to establishing the relative positions of each technology choice can be presented as the following equation:

> Greenhouse gas emissions of a given option (excluding bio-based emissions of carbon dioxide), less allowable offsets, equals 'tradable' greenhouse gas position (either as an emitter of GHG, neutral, or an abater of GHG).

The key to any emissions trading scheme is defining the allowable offsets that are able to be traded under the scheme. Definitions are established to ensure that potential abatement credits meet additionality, permanence and measurement criteria. Additionality criteria includes environmental (project actually reduces emissions), regulatory/legal (project must be 'beyond compliance') and financial/investment considerations (project not completed under business-as-usual).[65] Until 'rules' for the creation of offsets under a national trading scheme are established, each project would need to undergo an in-depth life cycle assessment, as for example the Greenhouse Friendly Programme.[66]

As was noted previously, the production of carbon dioxide from degradable organic carbon is considered to be part of the natural carbon cycle and as such is greenhouse neutral. This means that the 'mass balance' results delivered above need to have the carbon dioxide component removed, and account only for fugitive methane emissions separate from carbon dioxide.

In considering the technology options for processing food waste there are two main positive offsets to consider that could be applicable in an emissions trading scheme: the diversion of waste from landfill (and hence avoided greenhouse gas emissions); and the generation of electricity from landfill gas and biogas,

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[65] *NETT, 2006, 'Possible Design for a National Greenhouse Gas Emissions Trading Scheme', National Emissions Trading Taskforce, Sydney, accessed at http://www.emissionstrading.net.au/key_documents/discussion_paper, February 2007.*

[66] *See http://www.greenhouse.gov.au/greenhousefriendly for more information.*

which displaces fossil fuel based electricity. The capture and combusting of landfill gas could be considered an offset category if it passed the 'beyond compliance' regulatory test.[67]

Given the trend of regulation mandating landfills to minimise landfill gas emissions, it is suggested that this additionality could be difficult to prove for landfills required by law to minimise landfill gas emissions. As such this category has not been included in this analysis. Other offset categories could be included, such as increasing soil carbon through composted products, or avoided use of fossil-fuel based fertilisers, however these are also not considered in this first order example.

Using the AGO factors and methods workbook, the landfilling of one tonne of food waste into a landfill would generate 0.945 tCO_2e in methane. Taking this as the starting point for estimating the greenhouse savings from avoiding the landfilling of one tonne of food waste means that every tonne of food waste avoided from landfill potentially prevents the emission of 0.945 tCO_2e. Thus the composting, AWT and anaerobic digestion options each are credited with this offset (being non-landfill technologies).[68]

The methane component of both landfill gas and biogas has an energy content that can be used to generate electricity. The calorific value of methane is 52.5 gigajoules per tonne (GJ/tn).[69] The landfill with 70 per cent gas capture option generated 35 tonnes of methane for energy generation, which gives 1,837.5 GJ of energy for electricity generation. Using a mid-point manufacturers electrical efficiency rating of 38.5 per cent means that the landfill gas could be used to generate 196.5 MWh of renewable electricity which avoids the emission of 212.8 tCO_2e.[70]

The anaerobic digestion option generated 94.1 tonnes of methane for energy generation with a total energy content of 4,940.25 GJ, of which 35 per cent is used to run the process of anaerobic digestion. Using a mid-point manufacturers electrical efficiency rating of 38.5 per cent (as for the landfill gas electricity generator) means that this amount of biogas could be used to generate 343.4 MWh of renewable electricity which avoids the emission of 371.9 tCO_2e.[71]

The combination AWT option is assumed to deliver half of this benefit, that is, 171.7 MWh of electricity with an avoided emission of 186.0 tCO_2e.

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[67] *For example the proposed National Emissions Trading Scheme suggests that abatement from landfill gas combustion could be able to create 'abatement over and above any prevailing regulatory requirements.' NETT, 2006, 'Possible Design for a National Greenhouse Gas Emissions Trading Scheme', National Emissions Trading Taskforce, Sydney, accessed at http://www.emissionstrading.net.au/key_documents/discussion_paper, February 2007.*

[68] *Business as usual is counted as the disposal of waste into landfill, as such the landfilling of waste is not eligible for any 'avoidance credit'. Personal Communication from an AGO independent verifier and LCA practioner under the Greenhouse Friendly programme. All technology types and projects are assessed by their individual merits under the Greenhouse Friendly programme. Any variant of option would also need to be assessed on its individual merits. Any national trading scheme would need to synchronise with existing programmes, which could be seen as setting precedents for offset creation rules.*

[69] *SEPA 2004, 'Guidance on gas treatment technologies for landfill gas engines, Environment Agency, Bristol, accessed at http://www.sepa.org.uk/pdf/guidance/landfill_directive/gas_treatment_tech.pdf, November 2006. CV methane is 37.5 MJ/ nm^3, density of methane is 0.71 kg/nm^3.*

[70] *Electricity calculation is 1,837.5 GJ multiplied by electrical efficiency of 38.5% = 707.4 GJ of electricity = 707,400 MJ. Divide by 3,600 to convert MJ into MWh = 196.5 MWh (nearest 0.1 MWh). The full fuel cycle emissions for coal fired electricity from the 2006 AGO workbook and averaged across NSW, Vic, Qld, WA and SA for 2003 is 1083 $kgCO_2e$ per MWh. Multiplying 196.5 by 1.083 gives 212.8 tonnes of CO_2e abated (nearest 0.1 tonnes).*

[71] *Electricity calculation is (1-0.35) * 4,940.25 = 3,211.2 GJ for electricity generation. Multiply by electrical efficiency of 38.5% = 1,236.3 GJ of electricity = 1,236,300 MJ. Divide by 3,600 to convert MJ into MWh = 343.4 MWh (nearest 0.1 MWh). The full fuel cycle emissions for coal fired electricity from the 2006 AGO workbook and averaged across NSW, Vic, Qld, WA and SA for 2003 is 1083 $kgCO_2e$ per MWh. Multiplying 343.4 by 1.083 gives 371.9 tonnes of CO_2e abated (nearest 0.1 tonnes).*

9.2.8 Comparison of Potential Carbon Offsets

The calculation of potential offsets for greenhouse gas emissions is presented in Table 15 and Figure 4 overleaf.

Table 15 – Comparison of potential 'carbon offets' from processing 1,000 tonnes of food waste (presented in tCO_2e)

	Aerobic Compost (including AWT MBT)	*AWT MBT Combination of Compost and AD*	*MBT Anaerobic Digestion (AD)*	*Landfill with 70% Gas Capture*	*Landfill with BP Cap and No Gas Capture*
Avoided Emissions from Avoided Landfill	945.0	945.0	945.0	0	0
Displacement of Fossil Fuel Electricity	0	186.0	371.9	212.8	0
Potential Carbon Offsets	**945**	**1,131.0**	**1,316.9**	**212.8**	**0**

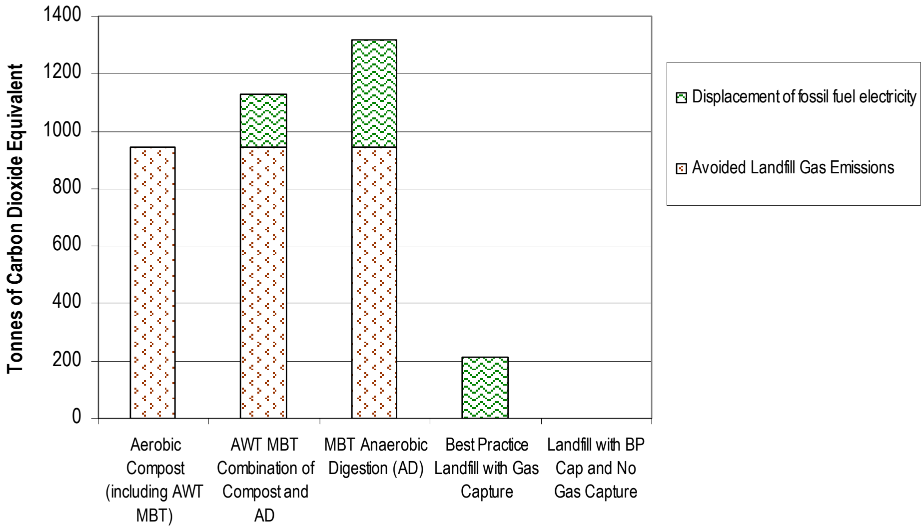

Figure 4 – Comparison of potential carbon offsets

On the basis of this preliminary analysis of potential offsets, the anaerobic digestion of 1,000 tonnes of food waste gives the best result, with potential abatement credits of 1,316.9 tonnes of CO_2e arising from avoided landfill gas emissions and the generation of electricity from biogas.

Landfill without gas capture gave the worst potential abatement outcome as there were no carbon offsets associated with that activity.[72] The landfill with gas capture created an offset of 212.8 tonnes of CO_2e from the generation of electricity from landfill gas.

The second best option was processing with an alternative waste technology involving mechanical biological treatment with both aerobic composting and anaerobic digestion, with potential abatement credits of 1,131.0 tonnes of CO_2e arising from avoided landfill gas emissions and the generation of some

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[72] *Some proponents have argued that the degradable organic carbon that does not dissimilate in landfill should be counted as a credit to the landfill. However, this would also need to be applied to the other management options which do not completely dissimilate all of the DOC, meaning that landfill would potentially not gain any relative advantage. Again, a more in-depth life cycle assessment would be required to determine the detail of this relativity. Furthermore, because landfill represents business as usual, regulatory additionality would in case be difficult to prove.*

electricity from biogas. This was followed by aerobic composting (also alternative waste technology – mechanical biological treatment with aerobic composting) with potential abatement credits of 945 tonnes of CO_2e arising from avoided emissions though avoiding landfill.

While these results are only preliminary, and any actual abatement credits and relative net position between options would need to be confirmed through a more in-depth life cycle analysis, they serve to highlight the fact that the definition of allowable offset categories will greatly influence the 'greenhouse preferred' technology option for treatment of degradable organic carbon. One challenge facing all options is that of regulatory additionality. For example, if it was mandatory to aerobically pre-treat all waste materials prior to landfill, there would be no, or a greatly reduced offset available.

In any case, this analysis serves to highlight the greenhouse gas implications associated with management of waste materials with degradable organic carbon, making this an important element in any decision making process around option selection.

10 CONCLUSIONS AND RECOMMENDATIONS

This study set out to examine the potential contribution that the resource recovery and waste management sectors could make to climate change mitigation efforts in Australia. There is a need for further analysis on the potential carbon abatement benefits of improved resource recovery and waste management activities, including the economic benefits and costs of each option and their life cycle considerations. However, this preliminary investigation has identified a potential 37.818 million tonnes of greenhouse gas ($MtCO_2e$) abatement that could be delivered through innovative resource recovery and improved waste management practices. A summary of this carbon abatement is shown in Table 16.

Table 16 – Summary of carbon abatement potential

Category of Improvement	*Potential Abatement (tCO_2e)*	*Theoretical Maximum Abatement (tCO_2e)*[73]
Improved landfill gas capture and use	8,583,000	17,166,000
Avoided landfill gas emissions by stopping the landfilling of waste with degradable organic carbon	13,614,000	17,017,000
Saving energy by recycling high embodied energy materials	11,053,000	16,200,000
Using renewable fuels derived from waste	2,643,000	3,117,000
Converting suitable waste materials to 'biochar' for land application	1,752,000	2,190,000
Using biodiesel for resource recovery and waste management vehicles	173,000	346,000
Totals	**37,818,000**	**56,036,000**

The greatest carbon abatement potential is associated with the avoidance of landfill gas generation through the diversion from landfill of waste materials with degradable organic carbon (13.614 $MtCO_2e$). This is followed by the embodied energy savings from recycling materials such as paper/cardboard, glass, ferrous and non-ferrous metals, and plastic (11.053 $MtCO_2e$) and improved landfill gas capture and use (8.583 $MtCO_2e$). These three measures account for nearly ninety per cent of the 37.818 $MtCO_2e$ abatement potential identified.

[Under perfect world conditions where 100 per cent resource recovery was possible, the potential for carbon abatement rises to 56.036 $MtCO_2e$, which is 10 per cent of Australia's net greenhouse gas emissions (2004 figures).]

In order to fast track the uptake of abatement potential within the resource recovery and waste management sectors a number of supporting actions are suggested:

a) make landfill owners liable for the fugitive landfill emissions – encourage the internalisation of long term carbon liability into landfill gate prices

b) include the carbon abatement benefits from avoided greenhouse emissions through the diversion of biologically active waste materials into any carbon emissions trading scheme – this

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[73] Note that the theoretical maximum involves directing waste as per the resource recovery model from Section 2.4, however flows have been increased to account for 100 per cent of the waste without double counting.

would monetise one of the positive benefits of resource recovery, and provide additional support for these technologies and practices

c) recognise the energy savings from recycling as a form of carbon abatement and include as an offset category in the development of any carbon emissions trading schemes – this would encourage the direct recycling of energy intensive materials

d) develop national standards for the use of renewable waste derived fuels – overcome discrepancies across jurisdictions preventing energy from waste and encourage the development of this resource recovery option

e) recognise charring of bio-based materials as an efficient form of carbon capture and storage, and incorporate into any carbon emissions trading schemes – this would monetise one of the advantages of biochar and support the development of this technology

f) develop support for B50 biodiesel distribution – ease of access will facilitate uptake and use.

The waste industry currently accounts for 2.7 per cent of net greenhouse gas emissions in Australia. However, this initial analysis has demonstrated that with improved performance in resource recovery, a significant abatement of approximately nearly 38 MtCO$_2$e could be made, which represents a 6.7 per cent reduction of Australia's net greenhouse gas emissions (2004 figures).

In order to realise the positive carbon abatement potential from resource recovery and waste management, co-operation between government and industry is essential. Government can display leadership by creating the right market interventions and supporting regulation to drive desired changes. Industry can also show leadership through the development of innovative technology for resource recovery and through incorporating carbon issues into business decision making.

11 APPENDICES

11.1 Appendix 1 – Australian Greenhouse Office Default Emission Factors

The Australian Greenhouse Office 'Factors and Methods Workbook' was released in December 2006 (see http://www.greenhouse.gov.au/workbook/pubs/workbook2006.pdf). The latest workbook contains several updates on emissions factors, based on improved national greenhouse gas inventory data and new international guidelines on the estimation of greenhouse gas emissions.

Importantly for the waste sector, estimates on the amount of greenhouse gas emissions associated with the disposal of solid waste to landfill have increased by approximately 50 per cent for Municipal Solid Waste (MSW) and Construction and Demolition (C&D) waste, and 100 per cent for Commercial and Industrial (C&I) waste (see the table below). One tonne of MSW landfilled will generate landfill gas with a greenhouse impact of 1.14 tonnes of carbon dioxide equivalent (tCO_2e - up from 0.74 tCO_2e in the previous workbook); one tonne of C&I waste landfilled has a 1.90 tCO_2e impact (up from 1.04 tCO_2e); and one tonne of C&D waste an impact of 0.31 tCO_2e (up from 0.20 tCO_2e).

Emission Factor Year	*Municipal Solid Waste*	*Commercial and Industrial Waste*	*Construction and Demolition Waste*
Previous 2005 Workbook Emission factor (CO_2e)/t waste	0.74	1.04	0.20
Current 2006 Workbook Emission factor (CO_2e)/t waste	1.14	1.90	0.31

There are two main reasons for these increases:

- the default value of degradable organic carbon proportion in wood and straw has been increased from 0.3 to 0.5 to bring the value in line with other AGO databases and greenhouse accounting methodology (for example, modelling carbon sinks). This means that there is more carbon available for decomposition to methane in wood waste than previously estimated. Every tonne of wood disposal is considered to release 3.2 tCO_2e (up from a previous value of 1.9 tCO_2e) of greenhouse gas emissions. Accordingly there has been an increase in the emission factors for MSW, C&I and C&D based on the relative amounts of wood contained in these streams
- the composition of material types in the MSW, C&I and C&D waste streams used to estimate default emission factors has changed. In particular the amount of paper has been increased to match up with improved data.

The proportions of waste products used to calculate the emissions factors for each waste stream, and their relative change is presented in the table overleaf.

Waste Type	*Municipal Solid Waste*		*Commercial and Industrial Waste*		*Construction and Demolition Waste*	
	Previous	Current	Previous	Current	Previous	Current
Food	18%	16%	12%	6%	0%	0%
Paper and Textiles	12%	30%	20%	55%	1%	3%
Garden and Green	18%	15%	6%	3%	2%	2%
Wood	3%	3%	16%	14%	8%	6%
Other (inert materials such as Concrete/metal/plastic/glass)	50%	36%	47%	22%	89%	88%

Note that totals may not equal 100% because of rounding errors.

The current default degradable organic carbon (DOC) proportions and their relative conversion factors to CO_2e for ‘biologically active’ wastes are presented in the table below.

Waste Types	*Default DOC proportion*	*Conversion factor CO_2e (t=tonnes)*
Paper and paper board	0.4	t x 2.5
Textiles	0.24	t x 1.5
Textiles synthetics	0	t x 0
Wood and straw	0.5	t x 3.2
Garden and Park	0.17	t x 1.1
Food	0.15	t x 0.9
Co-mingled	0.15	t x 0.9
Medical waste (tissue, fluids, pharmaceuticals	0.05	t x 0.3
Concrete/metal/plastic/glass	0	t x 0

The above table shows that if one tonne of paper and paper board is disposed of to landfill, it will generate 2.5 tonnes of carbon dioxide equivalent greenhouse gas emissions. This is based on the fact that paper and paper board has a default degradable organic carbon (DOC) content of 40 per cent, half of which is assumed to produce landfill gas, which contains approximately 50 per cent methane, a global warming potential 21 times as much as carbon dioxide. The above conversion factors are used to calculate the default emission factors for MSW, C&I and C&D respectively. The default greenhouse gas emission factor for MSW is calculated as $0.16*0.9 + 0.3*2.5 + 0.15*1.1 + 0.03*3.2 + 0.36*0 = 1.14$ tCO_2e (with some allowance for rounding of percentages).