The Potential Greenhouse Gas Liability from Landfill in Australia:

An Examination of the Climate Change Risk from Landfill Emissions to 2050

Final Version for Release

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THE POTENTIAL GREENHOUSE GAS LIABILITY FROM LANDFILL IN AUSTRALIA:

AN EXAMINATION OF THE CLIMATE CHANGE RISK FROM LANDFILL EMISSIONS TO 2050

FINAL VERSION FOR RELEASE

PREPARED BY
WARNKEN ISE

FOR

THE 'RESOURCE RECOVERY COLLABORATION' INCLUDING
GLOBAL RENEWABLES LIMITED
SITA ENVIRONMENTAL SOLUTIONS
TOTAL ENVIRONMENT CENTRE
VISY
WSN ENVIRONMENTAL SOLUTIONS

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The professional advice of Warnken ISE contained in this report is prepared for participants in the Resource Recovery Collaboration. The report is supplied in good faith and reflects the knowledge, expertise and experience of the consultants involved.

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In conducting the analysis in the report Warnken ISE has endeavoured to use the best information available at the time of preparation. This study is by necessity an overview taken at the national level. No inference is intended or should be drawn on specific landfill environmental performance as this will vary widely based on operating conditions, engineering and climatic conditions.

Warnken ISE's approach is to develop analyses from first principles, on the basis of logic and available knowledge. Unless stated otherwise, Warnken ISE does not warrant the accuracy of any forecast or prediction in the report. Although Warnken ISE exercises reasonable care when making forecasts and predictions, factors such as future technology development and market behaviour are uncertain and cannot be forecast or predicted reliably.

Front cover photos (top to bottom):

- typical working face of an urban waste landfill
- landfill gas can be captured for flaring and electricity generation
- landfill fire - sometimes fires occur in poorly run landfills.

About the Resource Recovery Collaboration

The 'Resource Recovery Collaboration' is a loose grouping of companies who are active in the business of recovering value from waste materials that are disposed of to landfill. In particular the recovery of resources from those materials with organic carbon, such as food, garden, wood and paper wastes.

Participant organisations include Global Renewables, Sita Environmental Solutions, Total Environment Centre, Visy, and WSN Environmental Solutions. The Resource Recovery Collaboration has contributed to this study in an effort to understand the implications of climate change for resource recovery and waste management.

It is highlighted that the views here do not necessarily reflect the views of participants in the Resource Recovery Collaboration.

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EXECUTIVE SUMMARY

The challenge of climate change is forcing all sections of the Australian economy to examine their 'carbon liability' in terms of greenhouse gas emissions. Emissions from the disposal of solid waste to landfill are no exception. This study examines the potential greenhouse gas liability from landfilling materials with degradable organic carbon in Australia and recommends limiting future liabilities by promoting the resource recovery of food, paper, garden and wood wastes.

The problem for the waste sector is that every tonne of degradable waste landfilled today represents a 2050 greenhouse gas liability. Unless action is taken immediately, the potential liability of landfill means that an increasingly disproportionate amount of Australia's carbon budget will not be available for future wealth creating activities.

The disposal of biologically active materials such as food, paper, garden and wood wastes to landfill causes the generation of landfill gas through the dissimilation of degradable organic carbon. Landfill gas is composed of between 40 to 60 per cent methane, and methane has a global warming potential 25 times that of carbon dioxide. Furthermore, because landfill gas is not spontaneously generated, it is the historical stock of landfilled materials with degradable organic carbon that cause the bulk of greenhouse gas emissions, resulting in a long term greenhouse legacy.

Business-as-usual (BAU) projections highlight the potential greenhouse gas liability arising from the generation of waste materials with degradable organic carbon. In this sense, BAU presents the potential carbon liability of solid waste disposal to landfill if effective action to reduce greenhouse gas emissions is not taken. BAU projections of greenhouse gas emissions from solid waste disposal in Australia show an increase from 15.4 million tonnes of carbon dioxide equivalent ($MtCO_2e$) in 1990 to 30.7 $MtCO_2e$ by 2020, and a further increase to 46.9 tonnes by 2050.

The implications of the greenhouse liability of landfill need to be viewed in light of, and factored into, national greenhouse gas reduction targets. The figure below shows the proportion of 'allowable emissions' allocated to the potential carbon liability of landfill under three potential emissions reduction targets. Target A is a 90 per cent reduction by 2050 on 1990 levels, Target B an 80 per cent reduction and Target C a 60 per cent reduction.

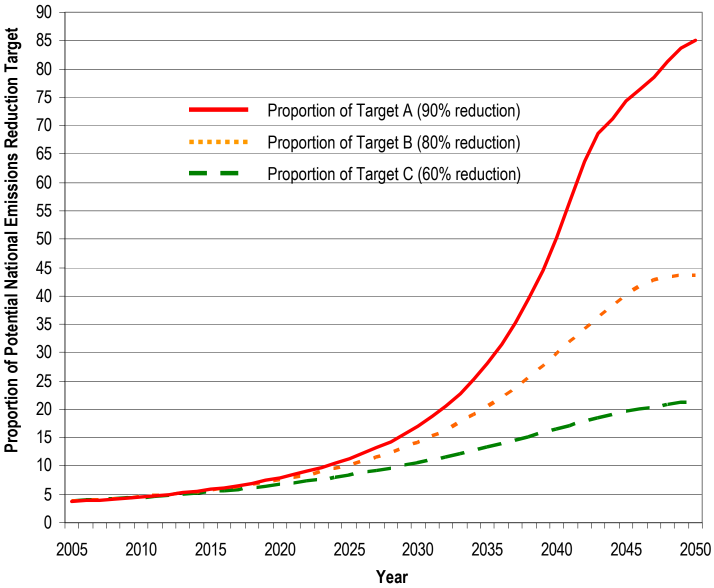

Figure – Potential BAU carbon liability from landfilling solid waste as a proportion of carbon budget

For Australia the above reduction proportions translate to potential targets of 220.8, 110.4, and 55.2 $MtCO_2e$ respectively, based on 1990 emissions of 551.9 $MtCO_2e$. (Note that individual year targets were based on illustrative reduction trajectories to meet the 2050 reduction target.)

The potential carbon liability arising from the BAU disposal of materials with degradable organic carbon, such as food, paper, garden and wood waste, ranges from 21 to 85 per cent of Australia's carbon budget at 2050, depending on the emissions reduction target. The potential impact of greenhouse gas emissions from solid waste with degradable organic carbon provides a powerful imperative to introduce greenhouse gas reduction measures.

There are principally two greenhouse gas reduction measures for solid waste disposal: improved landfill gas capture and combustion (combustion converts methane into carbon dioxide and water, dissipating the greenhouse impact); and avoiding the landfilling of materials with degradable organic carbon. The main issues for improved landfill gas capture and combustion include the generation rates of landfill gas, the lifetime efficiency of gas collection systems and the integrity of landfill capping systems.

Landfill gas is not generated immediately at the time of disposal. The rate of landfill gas generation depends on the decomposition of material type according to the climatic conditions of the landfill. What is important to note is the length of time over which materials with degradable organic carbon will decompose. For example, in 2002/2003 approximately of one-third of waste disposal was in a wet temperate climate (New South Wales), one-fifth in moist wet tropical climate (Queensland and Northern Territory) and the balance in dry temperate climate (Victoria, South Australia, Western Australia, Tasmania and Australian Capital Territory). First Order Decay (FOD) models used by the Intergovernmental Panel on Climate Change and the Australian Greenhouse Office predict that thirty years later an estimated 22.5 per cent of the degradable organic carbon pool will remain, with an estimated 11.0 per cent remaining 50 years after disposal. This means that every tonne of waste disposed of to landfill today is a 2050 greenhouse gas liability as it will still be contributing to greenhouse gas emissions in 2050.

The other challenge for landfill gas capture and combustion relates to 'whole-of-life' gas capture rates as the effectiveness of gas capture systems will decrease over time. For example, an operational landfill gas capture rate of 75 per cent in a moist and wet tropical landfill translates to a potential whole-of-life capture rate of 55 per cent when factors such as decreased efficiency of gas capture and length of material decomposition are included. (Note that the whole-of-life capture rate may even be lower for drier climates and old-fashioned style landfills). Using this estimate of whole-of-life landfill gas capture to calculate a national average according to AGO methodology gives a theoretical national maximum average of 40 per cent landfill gas capture, which means that at least 15.8 $MtCO_2e$ of landfill gas emissions would escape to the atmosphere in 2050.

This kind of carbon expenditure is unaffordable in a carbon constrained economy, especially given that the value delivered to society from solid waste emissions is at best a waste disposal solution, and that any continued landfilling of degradable organic carbon at 2050 would present an even larger (proportionally speaking) 2100 carbon liability.

The most effective way to mitigate against the potential greenhouse gas liability of landfill is to prevent landfilling of materials with degradable organic carbon.

Some policy responses to achieve this outcome include: implementation of a similar UK Landfill Allowance Trading Scheme for biologically active materials; a potential ban in capital cities on the disposal of biologically active materials, implemented between 2010 and 2015, with regional centres brought online by 2020; making landfills liable for future fugitive emissions arising from waste landfilled post 2010; and including the avoidance of landfill as an offset category in carbon trading schemes.

Action on the carbon liability of landfill needs to be early and effective in order to provide a long term reduction in emissions form the solid waste sector. For example, stopping the landfilling of all food, paper, garden and wood wastes at 2010 would still leave legacy carbon in landfills emitting 3 $MtCO_2e$ at 2050, highlighting the potential requirements for not only avoiding the disposal of materials with degradable organic carbon, but also the need for 'greenhouse' ongoing maintenance and potential remediation of existing and closed landfill sites.

In order to achieve the objective of eliminating the carbon liability of landfill, the following actions are suggested for consideration by Australian governments:

- phase out the disposal of food, paper, garden and wood wastes in landfill with regulatory underpinning through the use of a UK style landfill avoidance trading scheme, or some other form of targeted market based instrument, including increases to landfill levies
- use regulation such as a potential ban in capital cities on the disposal of biologically active materials, or a requirement for pre-processing of all waste before entering landfill to recover resources and biologically stabilise the waste, or pricing carbon as a pollutant under load based licensing
- use emissions trading to make landfills liable for future fugitive emissions arising from waste landfilled post 2010 through inclusion as 'stationary emitters', or including the avoidance of landfilling biologically active waste as an offset category and recognising the benefits of recycling in avoided greenhouse gas emissions
- mandate the installation of landfill gas capture and recovery or flaring systems for all landfills (including any 'inert' landfills that have accepted materials with degradable organic carbon, for example from Commercial and Industrial waste), including the closing of poorly run old-fashioned landfills in favour of fully engineered modern landfills with gas capture. This action is not a substitute for the above policy measures and would manage waste that is left after the above actions
- maximise efforts to capture and control landfill emissions, including ongoing maintenance of capping and increasing efficiency of landfill gas capture systems, with the potential remediation of future landfills that are still emitting landfill gas 15 years after closure
- institute a performance bond on all future landfills to ensure that future costs of greenhouse remediation are not externalised onto the community.

The benefits of taking early action to prevent the disposal of food, paper, garden and wood wastes in landfill are considerable. For example, a strong policy response would stop the landfilling of approximately one billion tonnes of these materials between 2010 and 2050, which would ultimately prevent the emission of up to two billion tonnes of CO_2e of greenhouse gas emissions in Australia. This action would also avoid a potential 2050 liability where a disproportionately large amount of Australia's carbon budget was allocated to solid waste emissions.

Furthermore, there is additional upside accompanying a resource recovery focus on materials with degradable organic carbon including additional recycling, renewable energy, and nutrient cycling, in conjunction with ongoing innovation in resource recovery technology. (These further greenhouse gas abatement benefits are not discussed further here but warrant further investigation).

Given the widespread community, scientific and political support for taking action on climate change mitigation, and the fact that every tonne of waste landfilled today represents a potential 2050 carbon liability, there would appear to be no future for the landfilling of food, paper, garden and wood within a decarbonising economy.

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1 BACKGROUND AND INTRODUCTION

There is a high level of public interest in global warming, as evidenced by attendance at Al Gore's 'Inconvenient Truth', media attention surrounding the economic analysis of the Stern Review, which identified that the benefits of early action to mitigate greenhouse gas emissions far outweighed any costs, and the current debate in Australia on greenhouse gas emissions trading, including the setting of emissions reduction targets. Given this level of interest and support for taking action on climate change it is appropriate for all sections of the Australian economy to examine their impacts in light of the risks associated with climate change – in particular to examine areas of risk and opportunities for early and effective action.

In the waste sector, the disposal of biologically active materials such as paper/cardboard, food waste, garden organics and wood/timber to landfill causes the generation of landfill gas. Landfill gas is composed of between 40 to 60 per cent methane, and methane has a global warming potential 25 times that of carbon dioxide. It is the historical stock of landfilled materials with degradable organic carbon that caused the 15.0 mega-tonnes (Mt) of carbon dioxide equivalent ($MtCO_2e$) emissions in 2004 from solid waste (2.7 per cent of the national net total). However, it is important to note that because biologically active waste generates methane over a time frame in excess of forty years, waste disposed of in 2010 will be a greenhouse liability in 2050.

The implications of the legacy issue of waste disposal to landfill for Australian efforts to reduce greenhouse gas emissions have yet to be fully examined. One potential aspect is that if landfill disposal continues under business-as-usual (BAU), the liability of landfill gas emissions could account for a disproportionately large portion of Australia's 2050 CO_2e allocation (depending on emissions reduction targets and global allocation of allowances).

This study examines the potential 2050 BAU emissions from the disposal of materials with degradable organic carbon in Australia and assesses the risk/value proposition of continued landfilling of materials that will emit greenhouse gases pollution over time.

1.1 Overview of Report

The structure of this report is presented in Figure 1 overleaf. Following this introduction, a summary of current waste disposal to landfill in Australia is presented, including a revision of estimates to correct for existing data limitations. An overview of the fundamentals of landfill gas generation and capture is also presented. Section 3 examines the Australian Greenhouse Office (AGO) methodology to account for greenhouse gas emissions from landfill. Current emissions from solid waste are reported, as are existing 2020 BAU forecasts from AGO. Section 4 uses current waste generation data, the AGO First Order Decay model and existing 2020 BAU forecasts to build an estimate of 2050 BAU emissions from solid waste landfilling. The impacts of 'with measures', including organic waste diversion and landfill gas capture, are also considered, including a critique of existing 'with measures' forecasts.

Section 5 provides an assessment of the 2050 BAU emissions from solid waste landfilling in the context of national greenhouse gas emission reduction targets of 60, 80 and 90 per cent. Potential policy responses in light of the greenhouse gas liability presented by landfills are also presented. The report concludes with a series of recommendations around limiting the national exposure to the greenhouse gas liability presented by landfill. A series of Appendices are included which contain much of the technical detail used in this study.

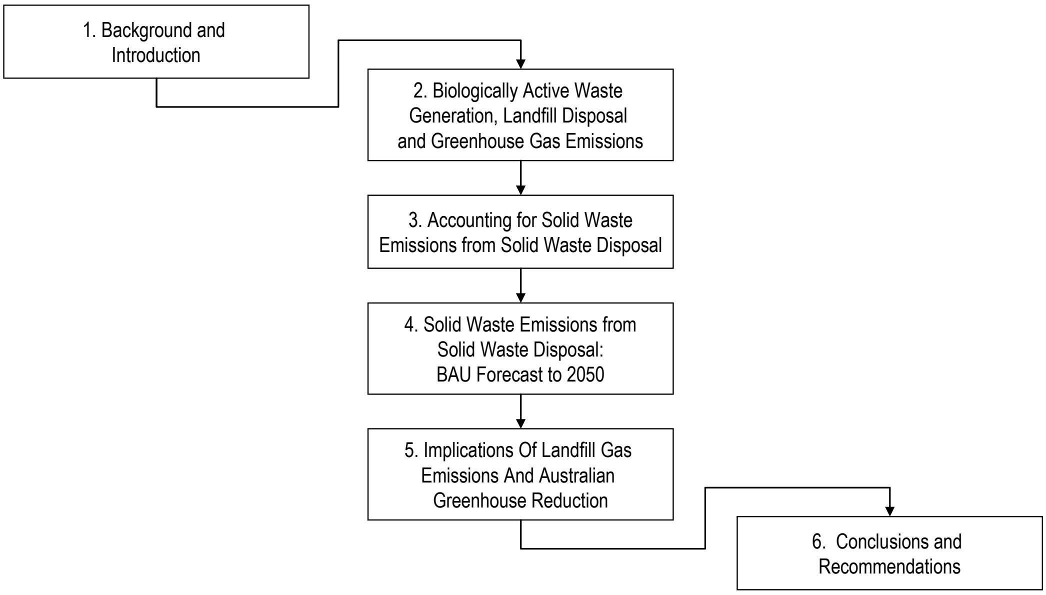

Figure 1 –Structure of report

1.2 Methodology and Approach

The methodology used in this study was designed to explore the potential implications of landfill gas emissions for Australia at 2050. This study is by necessity an overview taken at the national level. No inference is intended or should be drawn on specific landfill environmental performance as this will vary widely based on operating conditions, engineering and climatic conditions. As such the study rests on a number of assumptions and the use of models for estimating landfill gas generation on the basis of waste generation rates and materials composition. The following approach has been adopted:

- revise estimates of Australian waste generation and composition using averages from states with good data to supplement states with data gaps
- back cast per capita waste generation rates to 1940 in order to provide a basis for estimating the existing pool of dissimilatable degradable organic carbon in landfill across Australia
- use the Intergovernmental Panel on Climate Change and Australian Greenhouse Office first order decay (FOD) model to estimate methane generation from food, paper, garden and wood across three climatic zones

- comparison of results with AGO reported emissions and forecast BAU emissions to 2020
- adopt a conservative approach to forecasting waste generation rates to 2050 and associated greenhouse gas emissions
- revise best estimate model of methane capture to account for deceasing operational efficiency post-closure and predicted methane generation rates using the FOD model
- revise potential impact of 'with measures' under BAU for greenhouse gas reductions
- explore the implications of BAU emissions from solid waste disposal under three emissions reduction targets of 60, 80 and 90 per cent by 2050 based on 1990 emissions levels.

The intention of this study is not to present a life cycle analysis of landfills across Australia, but rather to highlight the future risks and implications of emissions from solid waste disposal using current available information and models for methane generation. Overall a conservative approach to estimating future BAU emissions has been adopted. One result of this approach could be an underestimation of the level of BAU emissions, especially as the global warming potential of methane has been set at 21, instead of the revised estimate of 25. Additionally a default oxidation factor of 10 per cent of methane generation has also been built into the BAU case (assumes 10 per cent of methane generation will be converted into carbon dioxide by an effective landfill cap). However in the model developed for this analysis, the underestimate could arguably be countered by improved greenhouse gas reductions, for example, if higher landfill gas capture rates were achieved than are assumed here.

The intention of this study is to make a contribution to the debate on climate change and waste management in Australia by examining the impacts of landfill and highlighting how the avoidance of landfilling materials with degradable organic carbon works to minimise the potential carbon liability of waste management.

1.3 Acknowledgement

Warnken ISE recognises the generous support for this study provided by the 'Resource Recovery Collaboration', a loose grouping of companies who are active in the business of recovering value from waste materials that are disposed of to landfill. In particular, those materials with organic carbon, such as food, garden, wood and paper wastes.

Participant organisations include Global Renewables, Sita Environmental Solutions, Total Environment Centre, Visy, and WSN Environmental Solutions. Note that while participant companies within the Resource Recovery Collaboration were consulted as part of the process in developing this project, nothing in this report should be taken as representing the views of any funding parties.

2 BIOLOGICALLY ACTIVE WASTE GENERATION, LANDFILL DISPOSAL AND GREENHOUSE GAS EMISSIONS

In 2003/2003 Australians generated approximately 1.9 tonnes of urban waste per capita, comprising materials recycled and materials landfilled. Part of the problem of landfilling 'biologically active' waste material is that it decomposes to form methane, a potent greenhouse gas. Some of this methane can be captured through landfill gas capture systems. This section provides an overview of current waste generation, decomposition of materials into methane and systems for capturing landfill gas.

2.1 Australian Waste Generation

Waste generation comprises the amount of materials that are recycled, and the amount of materials that are wasted to landfill. There are three main sources of urban waste in Australia:

- Municipal Solid Waste – MSW is includes materials that are primarily generated in the domestic sector and are collected in household garbage, recycling, garden organics and Council clean-up collections for bulky household waste such as appliances and furniture
- Commercial and Industrial waste – C&I includes materials generated from fixed point sources related to manufacturing, wholesale, retail, professional services and administration sectors
- Construction and Demolition waste – C&D materials are materials generated from construction and demolition activities both on a large scale (high rise) and small scale (residential housing).

A breakdown of Australia's waste generation in 2002/2003 according to source is presented in Table 1 below. This breakdown has been revised on the basis of calculations presented in Appendix 1.

Table 1 – Revised Australian waste generation by source for 2003[1]

Source	*Total Tonnes Generated*	*Total Tonnes Recycled*	*% Recycled*	*Total Tonnes Landfill*	*% Landfill*
Municipal Solid Waste (MSW)	10,435,000	2,973,000	28%	7,462,000	72%
Commercial and Industrial Waste (C&I)	11,098,000	4,582,000	41%	6,516,000	59%
Construction and Demolition Waste (C&D)	16,421,000	8,913,000	54%	7,508,000	46%
Totals	**37,954,000**	**16,468,000**	**43%**	**21,486,000**	**57%**

(Note that columns do not total with the state breakdowns in Appendix 1 - Table 13 because of rounding).

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[1] *Proportions 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, February 2007.*

Waste generation can also be characterised by material composition. The major material classifications and estimated tonnages are presented in Table 2 below.

Table 2 – Estimated composition of waste generation in Australia 2002/2003[2]

Material Type	*Total Tonnes Generated*	*Total Tonnes Recycled*	*% Recycled*	*Total Tonnes Landfilled*	*% Landfilled*
Food and other organics	*3,750,000*	*340,000*	9%	*3,410,000*	91%
Paper & Cardboard	*5,860,000*	*2,540,000*	43%	*3,320,000*	57%
Garden Organics	*4,450,000*	*1,700,000*	38%	*2,750,000*	62%
Wood/Timber	*2,420,000*	*480,000*	20%	*1,940,000*	80%
Sub Total Materials with Degradable Organic Carbon (DOCm)	*16,480,000*	*5,060,000*	31%	*11,420,000*	69%
Glass	1,020,000	410,000	40%	610,000	60%
Adjusted Non-Ferrous[3]	270,000	120,000	44%	150,000	56%
Ferrous	4,300,000	3,070,000	71%	1,230,000	29%
Plastic	1,980,000	210,000	11%	1,770,000	89%
Soil/Rubble and Other Clean Excavated Material	4,510,000	1,530,000	34%	2,980,000	66%
Concrete, bricks and asphalt	7,950,000	5,300,000	67%	2,650,000	33%
Other recyclables (inc Textiles)	1,150,000	770,000	67%	380,000	33%
Other (waste)	290,000	-	0%	290,000	100%
Sub Total Other 'Inert' materials (OIm)	21,470,000	11,410,000	53%	10,060,000	47%
Totals	**37,950,000**	**16,470,000**	**43%**	**21,480,000**	**57%**

2.2 Degradable Organic Carbon in Waste

The above materials are also grouped as to whether they are biologically active or inert from a global warming perspective. Biologically active materials contain 'degradable organic carbon' (DOC) that will decompose under the anaerobic conditions of landfill and form landfill gas. Landfill gas contains between 40 and 60 per cent methane, a potent greenhouse gas that directly contributes to climate change.

Based on the estimates of waste generation in Table 2 above, there are 16,480,000 tonnes of materials with degradable organic carbon (DOCm) generated in Australia, including food, paper, garden and wood wastes. This corresponds to a DOCm generation rate of 0.83 tonnes per capita.[4]

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[2] Proportions derived from NSW and Victoria in Hyder Consulting 2006 (ibid). Note that a weighted average was used to overcome classification of 'other' for NSW.

[3] 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.

[4] Population for Australia in 2003 was 19,872,646. ABS 2006, 'Population by sex, states and territories, 30 June, 1901 onwards', Australian Bureau of Statistics, Canberra, accessed at http://www.abs.gov.au - cat. no. 3105.0.65.001, February 2007.

The recycling rate for DOCm is 31 per cent with 5,060,000 tonnes recycled and the remaining 11,420,000 tonnes (69 per cent) landfilled.

'Inert' materials include glass, steel, plastic, concrete and the like. These materials do not break down into landfill gas. However a subset may be active in other conditions. For example landfills produce leachate, which is water that has percolated through the waste in landfill. Leachate dissolves soluble substances including chemicals, salts and heavy metals from materials, which means that while 'inert materials' do not contribute to landfill gas formation, they can not be completely described as 'inert'. Using the estimates of waste generation in Table 2 above, there are 21,470,000 tonnes of biologically inert materials generated in Australia. The recycling rate for these other 'inert' materials (OIm) is 53 per cent, with 11,410,000 tonnes recycled and the remaining 10,060,000 tonnes (47 per cent) landfilled.

The methane generation potential of biologically active waste materials depends on the amount of degradable organic carbon (DOC) they contain, and the amount of DOC that can be dissimilated into methane in landfill conditions. The default dissimilation factor is 0.5, meaning that half of the DOC landfilled is assumed to dissimilate through landfill gas into the atmosphere. The Australian Greenhouse Office publishes default DOC proportions for materials with degradable organic carbon (DOCm)[5] in addition to their own estimates on the amount of DOCm landfilled in Australia.[6] These estimates and default DOC proportions are presented in Table 3 overleaf.

The AGO estimates of DOCm and the revised estimates of waste generation presented in this study differ by 2,306,000 tonnes, with AGO 20 per cent less than the revised estimate. The following points are offered to explain this discrepancy:

- source data for the AGO estimate is likely to suffer the same underestimation fault as was discussed for Table 1 above, resulting in a lower AGO tonnage amount
- AGO estimate of 5,054,000 tonnes of paper and cardboard disposed to landfill is based on a harvested wood and paper products model that could provide an overestimate of disposal and/or not account fully for current levels of recycling.

However, the estimates of annul landfilling of DOC calculated in this study only differ by 155,000 tonnes from AGO estimates, which is only a 5 per cent difference. Because methane generation is determined by DOC content, the two estimates can be seen to be broadly consistent.

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[5] *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, February 2007.*

[6] *AGO 2006, 'National Inventory Report 2004 (Revised) - Volume 2 Part B', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/inventory/2004/pubs/inventory2004-nationalreportv2brev.pdf, February 2007.*

Table 3 – Degradable organic carbon disposed of to landfill in Australia 2003

Waste Type	*Default DOC proportion*[7]	*Estimated Tonnes DOCm Landfilled*	*Estimated Tonnes of DOC*	*AGO Estimated Tonnes DOCm Landfilled*[8]	*AGO Estimated Tonnes of DOC*
Food and other organics	0.15	3,410,000	511,500	1,416,000	212,400
Paper & Cardboard	0.4	3,320,000	1,328,000	5,054,000	2,021,600
Garden Organics	0.17	2,750,000	467,500	1,315,000	223,550
Wood/Timber	0.5	1,940,000	970,000	1,329,000	664,500
Totals	0	11,420,000	3,277,000	9,114,000	3,122,050

2.3 Landfill Gas and Waste Disposal

Materials with degradable organic carbon 'dissimilate' to form landfill gas. The process of dissimilation involves micro-organism activity in anaerobic conditions (absence of air)[9] to form primarily methane (CH_4) and carbon dioxide (CO_2). For example the decomposition of cellulose (a carbohydrate) to landfill gas is given by $C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3CO_2$ (cellulose plus water gives methane plus carbon dioxide). Although actual landfill gas composition varies from site to site, an indicative composition is given in Table 4 below.

Table 4 – Indicative composition of landfill gas[10]

Constituent	*Percentage (Volume)*	*Assumed Composition for this Analysis (%)*	*Equivalent Mass %*[11]
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%

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[7] *AGO, 2006, 'AGO Factors and Methods Workbook - For use in Australian greenhouse emissions reporting'.*

[8] *AGO 2006, 'National Inventory Report 2004 (Revised) - Volume 2 Part B'.*

[9] *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.*

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

[11] *Assumes ideal gas behaviour*

Methane causes the major greenhouse impact of landfill gas. The carbon dioxide component within landfill gas is considered to be part of the natural carbon cycle and is not counted as contributing to global warming for two reasons:

- the carbon emitted was only recently removed from the atmosphere through photosynthesis, and is likely to be reabsorbed by subsequent biomass growth
- the release of carbon dioxide would have occurred regardless of human intervention. (The human intervention of landfilling causes anaerobic conditions which convert DOC into methane).

Methane has a hundred year global warming potential (GWP) estimated as 21, 23 or 25 times that of carbon dioxide based on Intergovernmental Panel on Climate Change (IPCC) estimates from their Second *(21),* Third *(23)* and Fourth (25) Assessment Reports. This means that every tonne of methane released into the atmosphere is equivalent to the release of 25 tonnes of carbon dioxide (1 t CH_4 = 25 tCO_2e).[12] However, the GWP value of 21 tCO_2e has been used here to be consistent with current AGO methodology. The potential for methane generation from waste materials is presented in the following section.

Note that the trace constituents in landfill gas include gases such as hydrogen sulphide (H_2S) and non-methane volatile organic compounds (NMVOCs). NMVOCs include hydrocarbons such as xylene, propane and butane, and are generated in part by the decomposition process and in part from residuals contained in particular waste types. Unless site specific information is available, it is estimated that 2,000 mg/nm^3 are released, which is assumed to be 0.2 per cent of total landfill gas.[13] However NMVOCs are indirect greenhouse gases (as are carbon monoxide (CO) and nitrogen oxides (NO_x)), and as such are not included in Australia's greenhouse inventory.[14]

2.4 Methane Generation from Waste Disposal

The Australian Greenhouse Office (AGO) has calculated the greenhouse gas emission default factors for a variety of waste materials based on their potential to generation methane. The calculations are presented in Appendix 2 and the CO_2e emission factors for DOCm are presented in Table 5 overleaf. The methane generation potential for DOCm landfilled in 2003/2004 are also calculated. For example the landfilling of one tonne of garden organics will generate 52 kilograms of CH_4 with a greenhouse gas impact of 1.1 tonnes of CO_2e.

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[12] *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 revised the Global Warming Potential (GWP) of methane to 23 times that of carbon dioxide, which was revised again in their fourth assessment report to 25 times that of carbon dioxide (IPCC 2007, 'IPCC Fourth Assessment Report – Technical Summary of the Working Group I Report', Intergovernmental Panel on Climate Change, Geneva, accessed at http://ipcc-wg1.ucar.edu/wg1/wg1-report.html, July 2007.) 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.*

[13] *AGO, 2006, 'Australian National Greenhouse Inventory 2004', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/inventory/2004/index.html, February 2007.*

[14] *AGO, 2006, 'Waste Sector Greenhouse Gas Emissions Projections 2006', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/projections/pubs/waste2006.pdf, February 2007.*

Table 5 – Potential greenhouse gas liability from the landfilling of biologically active waste in 2003

Biologically Active Material Type	*Emissions Factor (tCO_2e)*[15]	*Tonnes Disposed of to Landfill*	*Tonnes of Methane Generation Potential*	*Tonnes CO_2e Liability*
Food and other organics	0.9	3,410,000	146,000	3,069,000
Paper & Cardboard	2.5	3,320,000	395,000	8,300,000
Garden Organics	1.1	2,750,000	144,000	3,025,000
Wood/Timber	3.2	1,940,000	296,000	6,208,000
Totals		**11,420,000**	**981,000**	**20,602,000**

The disposal of materials with degradable organic carbon in 2003/2004 will potentially generate 981,000 tonnes of methane, which carries a potential greenhouse liability of 20.6 Mt CO_2e.[16] This methane is not generated immediately at the time of disposal. The rate of decomposition depends on the material type and the climatic conditions of the landfill. These are key factors in setting the half life of the disimilatable DOC and are presented in Table 6 below. (Half life is a measure of the time it takes for 50 per cent of the starting mass to decompose).

Table 6 – Key factors in modelling methane generation[17]

Biologically Active Material Type	*Degradable Organic Carbon (DOC)*	*Dissimilatable Degradable Organic Carbon (DDOC)* [18]	*Half Life Values*		
			Wet Temperate Landfill (NSW)	*Dry Temperate Landfill (Vic, WA, SA, Tas, & ACT)*	*Moist and Wet Tropical Landfill (Qld & NT)*
Food and other organics	0.15	0.075	4	12	2
Paper and Cardboard	0.4	0.2	12	17	10
Garden Organics	0.17	0.085	7	14	4
Wood/ Timber	0.5	0.25	23	35	20

The table above identifies that materials with DOC will have carbon available for methane generation at a much greater rate in moist and wet climates. For example, Paper and Cardboard DDOC has a half life of 10 years when landfilled in a moist and wet tropical climate, compared to

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[15] 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, February 2007.

[16] 981,000 tCH_4 * 21 = 20.6 $MtCO_2e$ as methane has a global warming potential of 21 – 25 times that of carbon dioxide – See section 2.4 for further discussion on why 21 times is used in this report.

[17] 2006, 'National Inventory Report 2004 (Revised) - Volume 2 Part B', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/inventory/2004/pubs/inventory2004-nationalreportv2brev.pdf, February 2007.

[18] AGO uses IPCC default value of 0.5 for the fraction of DOC that is dissimilated – in other words DDOC = 0.5 * DOC.

17 years in a dry temperate climate. In theory, half of the Paper and Cardboard DDOC will dissimilate into landfill gas after 17 years in a dry temperate landfill, compared to 10 years in a moist and wet tropical landfill. After an additional 17 and 10 years respectively, half of the remaining DDOC in the Paper and Cardboard will be dissimilated, leaving 25 per cent of the original DDOC mass.

Applying these half lives on the 2002/2003 destination of disposal (one-third of waste disposal in wet temperate climate, one-fifth in moist wet tropical climate and the balance in dry temperate climate), means that there will be an estimated 22.5 per cent of the DDOC pool left 30 years after the year of landfilling, with 11.0 per cent remaining 50 years after disposal.

However a recent study on the decomposition of wood products in landfill identified slower decomposition rates than previous estimates had suggested. The conclusion was that 95 per cent of the carbon in wood remained after 30 years in landfill.[19] This work may suggest that even longer half lives for wood products may be appropriate, which would increase the amount of DDOC remaining in the national pool well beyond 50 years and place greater demands on post-closure management of landfill.

One key component of post-closure (and indeed operational life) management of landfill is the capture of landfill gas.

2.5 Landfill Gas Capture

The greenhouse gas intensity of landfill gas provides a strong imperative to capture it prior to release to atmosphere. Landfill gas also has an energy value that can be used to generate electricity. A generic landfill gas capture system includes the following key components (also shown schematically in Figure 2):

- gas capture infrastructure, which, depending on the system, may include a series of wells and extraction trenches, a blower to exert a vacuum on the system, condensate traps, and perhaps most importantly, the landfill cap and liner
- generators for electricity generation or, if the gas is not to be recovered for its energy value, equipment for the flaring of the gas
- if electricity is to be generated, a gas purification system may also be installed to render the gas suitable for this purpose.

There are two types of landfill gas capture systems, which are classified according to whether they use active or passive systems for gas capture. Passive gas systems allow gas to be released without using blowers or pumps. Passive systems typically vent to atmosphere and are used to prevent build-up of gases within the landfill site. These systems typically consist of perforated collection pipes which are placed in a granular or geotextile layer (which is manufactured of a polymer such as polypropylene) on top of the waste. The perforated pipe is connected to a vertical riser pipe through which gas is vented.

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[19] *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, February 2007.*

Active gas collection systems typically use negative pressure and apply a vacuum to pull gas out of the waste in the landfill via vertical extraction wells, horizontal extraction trenches, or a venting layer beneath the cover barrier system. Wells and trenches may either be installed during the operation of the landfill, or may be installed retrospectively.[20]

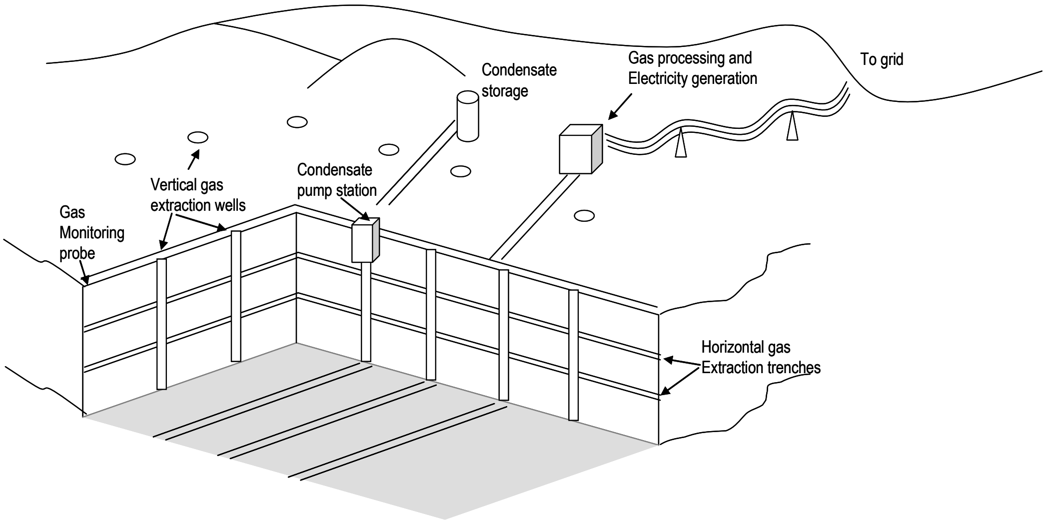

Figure 2 – Schematic layout of a landfill gas collection and energy recovery system

Landfill gas generation is not instantaneous. One study identifies five different phases in the generation and evolution of gas:[21]

- phase I: initially the site is aerobic and the main gases released are nitrogen and oxygen, in percentages roughly equal to those found in the atmosphere. This phase lasts a few hours to one week
- phase II: aerobic decomposition occurs, and the emitted gas has a high CO_2 content and little or no methane. This phase typically lasts one to six months
- phase III: the waste then enters a transition phase to anaerobic conditions, at the end of which methane and carbon dioxide concentrations have stabilised, and nitrogen is no longer present in the gas. The transition may take anything from three months to three years from the end of Phase II
- phase IV: once all of the oxygen has been consumed the site is anaerobic. Anaerobic decomposition can last for anywhere from eight to forty years from the start of Phase IV
- phase V: transition to stabilisation. All the carbonaceous material is consumed and any gas which is emitted will be air.

It should be noted that the default AGO half lives for the dissimilation of degradable organic carbon suggest that phase V (consumption of all carbonaceous material) is unlikely to be met until well after 75 years from closure (5 per cent of the DDOC pool predicted to be present at year 75). This means that the annual release of landfill gas represents a cumulative build-up from the past 75 years of waste disposal to landfill.

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[20] US EPA, 2004, 'Landfill Methane Outreach Program', United States Environment Protection Agency, Washington DC, accessed at http://www.epa.gov/lmop, February 2007.

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

In order to estimate the effective landfill gas capture rate, it is necessary to consider the whole-of-life emissions of methane from landfill. The key variables in determining the efficiency of landfill gas capture is the length of anaerobic decomposition, the efficiency of capture system operation, the life span of gas capture systems and the time taken to achieve stabilisation. Together these factors will determine the whole-of-life-cycle landfill gas capture rate. The methodology to account for these emissions at a national level is presented in Section 3 and Section 4. However, it is also important to consider that requirements for landfill gas capture are dependant on individual landfill licence conditions, which in turn are determined by the source of the waste. For example, Municipal Solid Waste as putrescible waste has stricter regulatory controls than the disposal of Construction and Demolition or Commercial and Industrial wastes. The classification of waste according to source raises a number of greenhouse gas issues that are dealt with in the following section.

2.6 Greenhouse Gas Emissions from Commercial and Industrial Waste Disposal

The Australian Greenhouse Office publishes default greenhouse gas emissions factors for waste streams based on the composition of waste materials within the stream and the emissions factors for food, paper, garden and wood wastes (as presented in Table 3). For example, one tonne of:[22]

- Municipal Solid Waste (MSW) will produce landfill gas with a greenhouse impact of 1.14 tonnes of carbon dioxide equivalent
- Commercial and Industrial (C&I) waste will produce landfill gas with an impact of 1.90 tCO_2e
- Construction and Demolition (C&D) waste will produce landfill gas with an impact of 0.31 tCO_2e.

The reasons for the differences relate to differing proportions of food, paper, garden and wood waste. MSW has greater proportions of food and garden waste than C&I or C&D, whereas C&I waste materials are dominated by paper and cardboard, in addition to wood, with very little garden and food waste. C&D wastes comprise large amounts of concrete, brick, dirt and tiles, with no food waste and relatively small amounts of paper, garden and wood. This accounts for its 'low' contribution to landfill gas.

The requirements for landfilling of MSW are stricter than for C&I and C&D materials because of odour and vermin potential. C&I and C&D materials are often landfilled in 'Inert' landfills where there are no regulatory requirements for landfill gas capture. Furthermore, because of the longer half-lives of paper and wood materials, the rate of landfill gas generation is much slower than for garden and food wastes, making it difficult to collect, and uneconomic for electricity generation. These 'Inert' type of landfills are thus likely to lose more (proportionally) landfill gas because of a lack of gas capture infrastructure and low gas generation rates over longer time frames.

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[22] *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, February 2007.*

Table 7 below presents the potential greenhouse gas liability from waste landfilled using waste stream default emission factors and waste generation estimates from Table 1.[23] C&I waste accounts for approximately 30 per cent of waste landfilled in Australia, however represents 53 per cent of the potential greenhouse gas liability, which is approximately 10.9 million tonnes of CO_2e for waste landfilled in 2003.

Table 7 – Emission factors by waste stream[24]

Emission Factor Year	*Municipal Solid Waste*	*Commercial and Industrial Waste*	*Construction and Demolition Waste*
Waste Stream Emission factor (CO_2e)/t waste	1.14	1.90	0.31
Total tonnes landfilled (from Table 1)	7,462,000	6,516,000	7,508,000
Proportion of waste landfilled	35%	30%	35%
Landfill gas generation potential (tCO_2e – nearest 100,000 tonnes)	8,500,000	12,400,000	2,300,000
Proportion of greenhouse gas liability	37%	53%	10%
Revised estimate using proportions against material specific GHG estimates (from Table 5)	7,600,000	10,900,000	2,100,000

C&I waste and C&D waste, the material streams that arguably have the greatest likelihood of being landfilled in a landfill without a landfill gas capture system, together account for nearly two-thirds of the greenhouse gas liability from current landfilling in Australia. Based on the tonnes of materials landfilled in 2003, this represents the generation of landfill gas with a greenhouse gas impact of approximately 13 million tonnes of CO_2e. As highlighted earlier, accounting for the actual release of landfill gas to the atmosphere involves calculating the whole-of-life landfill gas emissions based on decomposition rates, efficiency and lifespan of capture systems and the time to stabilisation. These factors are discussed in more detail in Section 3 and Section 4.

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[23] *Note that the total landfill gas generation potential of 23.2 million tonnes of CO_2e represents an overestimate of 2.6 $MtCO_2e$ from the Table 5 material specific estimate of 20.6 $MtCO_2e$ because of average rounding errors when using material stream default factors, as opposed to material specific factors, in addition to the AGO using different material composition of waste landfilled in Australia. What is important is the relative proportion of C&I and C&D streams from a greenhouse perspective, as opposed to MSW.*

[24] *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, February 2007.*

3 ACCOUNTING FOR SOLID WASTE EMISSIONS FROM SOLID WASTE DISPOSAL

Australia's net emissions from solid waste disposal were 15 million tonnes of carbon dioxide equivalent in 2004. This amount was estimated using a First Order Decay model for methane generation from landfill and subtracting landfill gas capture. The business-as-usual emissions from solid waste are calculated as the emissions that would have been released had initiatives such as the diversion of biologically active waste from landfill and landfill gas capture *not* been implemented. These calculations are presented in the sections below.

3.1 Accounting for Greenhouse Emissions from Solid Waste

The Australian Greenhouse Office (AGO) reports on the net emissions from solid waste disposal. In order to account for this 'net emission', total methane generation from all solid waste landfilling must be estimated. From this total, reported recovery of methane through landfill gas recovery and flaring is deducted, as is an estimate of the amount of methane that is oxidated in a landfill cap. The resulting net methane emitted to the atmosphere is converted into tonnes of carbon dioxide equivalent (CO_2e) by multiplying the tonnes of methane emitted by 21, which is the Kyoto first commitment period (2008-2012) estimate of the global warming potential of methane.[25]

To calculate the amount of methane generated from Australian landfills, it is necessary to estimate the amount of materials with degradable organic carbon (DOCm) that are landfilled in a given year 't', according to material type and landfill climatic conditions, in addition to the pool of dissimilatable degradable organic carbon (DDOC) existing across Australia in the previous year (year 't-1'), broken down by material type and climatic condition. This information is fed into a 'First Order Decay' (FOD) model of methane generation, which allows the calculation of emissions from materials landfilled and from the previous year's DDOC pool.

The AGO methodology for using the 'First Order Decay' (FOD) model of methane generation calculation is based on guidelines for national greenhouse gas inventories developed by the Intergovernmental Panel on Climate Change.[26] This approach develops a model for the historical stock of 'degradable organic carbon that is able to be dissimilated' (DDOC) in landfills across Australia, in addition to the amount that is added to this stock each year.

Key to the FOD model is the assumption that DDOC will decay according to an exponential function, with the rate of decay determined by material type and landfill location (climatic condition). (Note that specific landfill operating conditions and engineering standards are not modelled here). Table 6 from Section 2.3 above presented the various half lives of material types in the three main climate conditions of Wet Temperate (New South Wales), Dry Temperate (Victoria , Western Australia, South Australia, Tasmania, and Australian Capital Territory), and Moist and Wet Tropical (Queensland and Northern Territory).

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[25] *See Section 2.4 for further discussion on why a GWP of 21 times CO_2 is used in this report.*

[26] *For more information see IPCC NGGIP, 2006, '2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5: Waste', Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme, Geneva, accessed at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf, February 2007.*

In order to model Australian methane generation, records on the stock of DDOC in Australia, broken down by climate type and material type need to be developed. The amount of DDOC dissimilated in any given year 't', is the amount of DDOC dissimilated from the historical pool at year 't-1', plus the amount of DDOC dissimilated from biologically active materials disposed of to landfill in year 't'. (This is invariably a small amount as it takes time for anaerobic degradation to commence).

The amount of methane generated in year 't' is then equal to the mass of DDOC dissimilated in year t, multiplied by the fraction of methane in landfill gas (default value of 0.5), multiplied by 16/12 (the methane to carbon ratio).[27] Current estimates of methane generation from solid waste landfilling are presented below.

3.2 Current Greenhouse Emissions from Solid Waste

Australia's net emissions of greenhouse gases in 2004 were 564.7 mega-tonnes of carbon dioxide equivalent ($MtCO_2e$). These net emissions are presented by source in Table 8.

Table 8 – Australia's net greenhouse gas emissions[28]

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**

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

- 15.0 $MtCO_2e$ from solid waste landfill on land (2.7 per cent of net national total)
- 4.1 $MtCO_2e$ from methane and nitrous oxide emissions from waste water management (0.7 per cent of net national total).

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[27] *The molecular weight of carbon is 12, while the molecular weight of methane is 16.*

[28] *AGO, 2006, 'Australian National Greenhouse Inventory 2004', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/inventory/2004/index.html, February 2007 – note that this 'net' total includes reduction in greenhouse gas emissions from carbon sinks such as avoided land clearing.*

The net landfill gas emissions were caused by the dissimilation of degradable organic carbon in landfill. The emission of 15.0 $MtCO_2e$ was calculated as the theoretical amount of methane generation arising from landfills minus the amount of methane captured by landfills and flared or used to generate electricity. [29]

In terms of methane generation, 836,000 tonnes of methane (CH_4) were generated in 2004, with a greenhouse potential of 17.6 $MtCO_2e$. [30] The recovery or flaring of methane through landfill gas capture systems prevented the release of 2.6 $MtCO_2e$, or 124,000 tonnes of methane, with the net emissions of 15.0 $MtCO_2e$ arising from the release of 712,000 tonnes of methane into the atmosphere.[31] This represented an average methane capture rate of 15 per cent across Australia.

3.3 Business as Usual Emissions from Solid Waste

Business-as-usual is defined as all waste with degradable organic carbon (DOC) going to landfill with no gas capture or recovery. Calculations by the Australian Greenhouse Office for BAU begin in 1990, which is marked as the start of increasing levels of resource recovery (diversion of DOC from landfill) and increasing capture of landfill gas. Prior to 1990 it is assumed that there was no resource recovery or landfill gas capture.[32]

The 1990 BAU emissions from solid waste were estimated to be 15.4 $MtCO_2e$. This involved the generation of 733,000 tonnes of methane, all of which was assumed to escape to atmosphere. In 1990 AGO estimated that 16,406,000 tonnes of waste was generated including 8,068,000 tonnes of food, paper, garden and wood wastes (materials with degradable organic carbon – DOCm), and 8,338,000 tonnes of other 'inert' materials (will not decompose to methane - OIm). All of this waste was sent to landfill giving a per capita landfill rate of 0.96 tonnes (0.47 DOCm and 0.49 OIm) and a per capita recycling rate of 0.0 tonnes.[33]

The 2004 BAU emissions from solid waste were estimated to be 19.7 $MtCO_2e$, involving 15.0 $MtCO_2e$ of methane emissions, 2.6 $MtCO_2e$ of recovery or flaring of methane (from Section 3.2 above) and avoided methane generation of 2.1 $MtCO_2e$.

(This means that the combined impact of DOCm recovery from 1990 to 2004 prevented the generation and release of 100,000 tonnes of methane in 2004.) In other words, the emissions from

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[29] *AGO, 2006, 'Waste Sector Greenhouse Gas Emissions Projections 2006', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/projections/pubs/waste2006.pdf, February 2007.*

[30] *The AGO uses a 100 year global warming potential for methane of 21 (1 t CH_4 = 21 t CO_2e).*

[31] *The generation amount of 836,000 tCH_4 is from AGO 2006, 'National Inventory Report 2004 (Revised) - Volume 2 Part B', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/inventory/2004/pubs/inventory2004-nationalreportv2brev.pdf, February 2007. Note that this revised inventory for 2004 uses United Nations Framework Convention on Climate Change (UNFCCC) accounting, which gives a slightly different result to the accounting system for Kyoto. For example the revised 2004 total estimate for net emissions from solid waste is 14.775 $MtCO_2e$, 2.8% of the revised total 525.7 $MtCO_2e$. This compares to the Kyoto accounting estimate for 2004 of 15.0 $MtCO_2e$, 2.7% of the Kyoto total of 564.7 $MtCO_2e$.*

Note that during the final editing stages of this report the Kyoto accounting and UNFCCC accounting estimates for Australia's 2005 greenhouse emissions were released by the AGO (see http://www.greenhouse.gov.au/inventory/2005/pubs/inventory2005.pdf and http://www.greenhouse.gov.au/inventory/2005/national-report.html respectively). The 'Kyoto' 2005 estimate was 14.7 $MtCO_2e$ and the UNFCCC 2005 estimate was 14.742 $MtCO_2e$.

However, because the AGO 2006 BAU projections for the waste sector used 2004 Kyoto accounting numbers, these have been reatined as the starting point for this analysis.

[32] *AGO, 2006, 'Waste Sector Greenhouse Gas Emissions Projections 2006', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/projections/pubs/waste2006.pdf, February 2007.*

[33] *BAU emissions from AGO 2006 Waste Sector Projections. Breakdown on waste generation from AGO 2006, 'National Inventory Report 2004 (Revised) - Volume 2 Part B', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/inventory/2004/pubs/inventory2004-nationalreportv2brev.pdf, February 2007. Australian population in 1990 was 17.1 million. ABS, 2006, 'Population by sex, states and territories, 30 June, 1901 onwards', Australian Bureau of Statistics, Canberra, accessed at http://www.abs.gov.au - cat. no. 3105.0.65.001, February 2007.*

solid waste in 2004 would have been 19.7 $MtCO_2e$ if there had been no landfill gas capture and if there had been no resource recovery.

The BAU DOCm diversion rate for 2004 is estimated to be 31.5 per cent, with 9,317,000 tonnes of DOCm estimated to be landfilled. This equates to a DOCm waste generation rate of 13,595,000 tonnes with 4,277,000 tonnes of DOCm recovered. This level of DOCm waste generation gives a per capita DOCm generation rate of 0.68 tonnes.[34]

However, revised estimates of waste generation in Australia for 2002/2003 from Section 2.1 give a per capita DOCm generation rate of 0.83 tonnes, based on DOCm waste recycling rates of 5,060,000 and DOCm waste landfilling of 11,420,000 tonnes.[35] Based on this estimate of DOCm waste generation, the AGO BAU 2004 numbers are likely to be underestimated.

Recalculating a BAU solid waste emission for 2004 using the AGO FOD model and revised waste generation estimates gives a slightly higher BAU of 20.9 $MtCO_2e$, involving 15.5 $MtCO_2e$ of actual methane emissions (0.5 $MtCO_2e$ higher than the AGO estimate), 2.6 $MtCO_2e$ of recovery or flaring of methane (same tonnes of methane capture as AGO estimate) and avoided methane generation of 2.8 $MtCO_2e$ (from the avoided generation of 134,000 tonnes of methane - 0.7 $MtCO_2e$ higher than the AGO estimate).

Forecast BAU emissions from solid waste disposal to 2020 and 2050 are presented in the following section.

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[34] *BAU organic diversion rate of 20.9% for 2000, and 34.1% for 2005. 31.5% is calculated on basis of assumed constant increase in recovery rate between 2000 and 2005. AGO 2006 Waste Sector Projections. Population for Australia in 2004 was 20,091,504. ABS 2006, 'Population by sex, states and territories, 30 June, 1901 onwards', Australian Bureau of Statistics, Canberra, accessed at http://www.abs.gov.au - cat. no. 3105.0.65.001, February 2007.*

[35] *Population for Australia in 2003 was 19,872,646. ABS 2006, 'Population by sex, states and territories, 30 June, 1901 onwards'. Total waste generation for 2002/2003 revised estimate of 37.95 Mt, comprising 16.48 MtDOCm and 21.47 MtOIm – from Table 4.*

4 SOLID WASTE EMISSIONS FROM SOLID WASTE DISPOSAL: BAU FORECAST TO 2050

In order to forecast BAU emissions from the solid waste sector it is necessary to forecast the stock of dissimilatable degradable organic carbon in each of the three climatic zones for landfill within Australia (by material type); the amounts of waste being landfilled in each of the three landfill zones; the amount of waste being recycled; and estimates on increases in waste generation over time. 'With measures' forecasts will reduce gross BAU emissions according to estimates of resource recovery of materials with degradable organic carbon, and according to estimated methane capture from landfill gas. These calculations are presented in the sections below.

4.1 Business as Usual Projected Emissions from Solid Waste to 2050

The AGO estimates that 31.7 $MtCO_2e$ would be released from solid waste under BAU in 2020, approximately twice the amount of emissions from solid waste BAU in 1990 (15.4 $MtCO_2e$).[36] If this estimate is extended to 2050, either as a direct proportional increase, or by following an exponential rate of growth, the accompanying waste generation of materials with degradable organic carbon is likely to be too high. A more conservative estimate of BAU emissions has been adopted, as shown below in Table 9 and detailed in Appendix 3.

Table 9 – Summary of BAU emissions from solid waste disposal 2020 and 2050.

BAU Estimate	*2020*			*2050*		
	$MtCO_2e$	*Per Capita DOCm Generation*	*DDOC Pool (Mt)*	*$MtCO_2e$*	*Per Capita DOCm Generation*	*DDOC Pool (Mt)*
AGO BAU	31.7	1.1	52	n/a	n/a	n/a
AGO BAU proportional	*31.7*	*1.1*	*52*	65.3	1.5	101
AGO BAU exponential	*31.7*	*1.1*	*52*	79.2	2.2	126
Revised BAU	30.7	1.0	50	46.9	1.1	77

The business as usual emissions from solid waste disposal in 2050 is likely to be at least 46.9 $MtCO_2e$. However the BAU case assumes no waste diversion through recycling and no methane capture, only oxidation at the default AGO rate of 10 per cent.[37] The two carbon abatement measures of diversion and capture would reduce the amount of methane emitted to atmosphere. The effect of 'with measures' is investigated below.

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[36] *AGO, 2006, 'Waste Sector Greenhouse Gas Emissions Projections 2006', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/projections/pubs/waste2006.pdf, February 2007.*

[37] *Note that the BAU estimate would increase to 52.1 $MtCO_2e$ if no oxidation factor for landfill capping was used, and then increase to 62.1 $MtCO_2e$ if a global warming potential for methane of 25 is used. Appendix 6 shows the impact of removing an oxidation factor and using a GWP of 25 for methane.*

4.2 With Measures Projected Emissions from Solid Waste to 2050

There are two measures that can be undertaken to lower greenhouse gas emissions from the landfilling of solid waste. Firstly the diversion (through resource recovery) of materials with degradable organic carbon (DOCm); and secondly through the capture of landfill gas for flaring or energy generation.

4.2.1 Diversion of DOCm

The AGO estimates that the increasing amounts of solid waste diversion (DOCm) up to 2020 will prevent the release of 13.7 $MtCO_2e$ of greenhouse gas emissions from landfill. This represents an avoided release of 0.65 $MtCH_4$ and would require a recycling rate for DOCm of 72.5 per cent. Using the estimated DOCm generated under the AGO BAU scenario indicates that 18.4 million tonnes would be recycled as a result of diversion measures. By way of comparison, current recycling rates (2003/2004) are at 31 per cent with 5.1 million tonnes of DOCm recycled.

It is suggested that tripling of the amount of DOCm recovered by 2020 is overly optimistic, especially given that there are no mandated State initiatives to recover resources or to divert biologically active waste from landfill. It is likely that without intervention landfill will remain the main disposal option for materials with degradable organic carbon.

A more conservative estimate of almost doubling the amount of DOCm recovery by 2020, to 9.6 million tonnes has been assumed (recycling rate of 42 per cent). This amount of diversion corresponds to the avoidance of 10.1 $MtCO_2e$ of greenhouse gas emissions, (0.48 Mt of methane).

The rate of resource recovery is assumed to continue increasing slightly to 2050, to 13.4 million tonnes of DOCm recovered (estimated recycling rate of 45 per cent). At 2050 the cumulative effect of keeping this DOCm out of landfill will prevent the emission of 19.4 $MtCO_2e$ of greenhouse gas emissions (0.92 Mt of methane).

4.2.2 Landfill Gas Capture

The other measure for reducing greenhouse gases is the capture of landfill gas for flaring or energy generation. AGO estimates that the nationwide recovery of methane in landfill gas in 2020 would be 75 per cent. However there are a number of key issues with the assumptions built into this amount of methane capture. These are discussed in the following section.

4.3 Future National Average Landfill Gas Capture Rates

In order to estimate the future average landfill gas capture rates it is necessary to understand the context of existing 'operational' landfill gas capture rates presented in the public domain, in addition to understanding the impact of deteriorating landfill gas capture systems on efficiency, the legacy of existing landfills, and the potential impact of landfilling Commercial and Industrial Waste.

4.3.1 Estimated Landfill Gas Capture Rates

There are a range of estimates around landfill gas capture rates, with the majority focussed on capture rates as measured during the operational phase of the landfill. For example, a UK waste management company reported capture of 70 per cent of gas generated from landfills managed in 2003/04, as compared to 68 per cent in 2002/03.[38] Other studies suggest a wide variety of landfill gas capture rates. One study in France looked at capture rates from three landfill sites and concluded that methane recovery from sites with active gas recovery ranged from 41 to 94 per cent, with the actual amount dependant on the design of the engineered landfill cover. This study was used to set default values for French landfills under the European Pollutant Emission Register (EPER) which ranged from 35 per cent for an operating landfill cell with active gas recovery system, to 90 per cent for a geomembrane final covered cell with an active gas recovery cell.[39]

A US study estimated landfill gas recovery rates for the state of Wisconsin based on estimated landfill gas generation rates and reported gas capture from 24 of the 32 landfills that received Municipal Solid waste. Here the estimated recovery rate (excluding 8 landfills) was 81 per cent.[40] A US EPA survey reported collection efficiencies that ranged from 60 to 85 percent, with an average of 75 per cent as the most commonly assumed value used in modelling where no capture data is available.[41]

An average EU collection efficiency of 54 per cent was estimated for 2000 in a report to the European Commission, based on individual country estimates which ranged from 20 per cent to 70 per cent, with the potential for modern best practice put at 80 per cent.[42] This benchmark of best practice achievable was comparable to the UK Environment Agency's Guidance on the Management of Landfill gas, which suggested that the efficiency goal should be 85 per cent.[43]

In Australia a recent Productivity Commission Inquiry into Waste Management concluded that collection efficiencies of up to 75 per cent were reasonable to assume,[44] while the National Landfill Division of the Waste Management Association of Australia suggests that a reasonable collection efficiency estimate is 60 per cent.[45]

However, there are two main difficulties with estimating landfill gas capture rates: the modelled amount of landfill gas generated, and differentiating between operational and whole-of-life recovery rates. For example, in the Wisconsin study presented above, the analysis was done using almost the lowest rate of methane generation in landfills in the range presented for consideration. If a mid-point between the high and low values of methane generation was used, then gas generation would

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[38] *Biffa Waste Services, 'Climate Change', accessed at http://www.biffa.co.uk/publications/CorporateResponsibility/climatechange.php, February 2007.*

[39] *K. Spokas, J. Bogner, J.P. Chanton, M. Morcet, C. Aran, C. Graff, Y. Moreau-Le Golvan and I. Hebe, 'Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection systems?', Waste Management, Volume 26, Issue 5 , 2006, Pages 516-525.*

[40] *M.S. Michels and G.M. Hamblin, 'LFG Collection Efficiency is Improving in Wisconsin' accessed at http://dnr.wi.gov/org/aw/wm/solid/gas/finalpaperLFGefficiency2006-Michels.pdf, February 2007.*

[41] *US Environment Protection Agency, 1997, 'Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills', accessed at http://www.epa.gov/ttn/chief/ap42/ch02/bgdocs/b02s04.pdf, February 2007.*

[42] *A. Smith, K. Brown, S. Ogilvie, K. Rushton and J. Bates, 2001 'Waste management options and climate change. Final report to the European Commission', accessed at http://ec.europa.eu/environment/waste/studies/pdf/climate_change.pdf, February 2007.*

[43] *United Kingdom Environment Agency, 2004, Guidance on the management*

of landfill gas, accessed at http://www.sepa.org.uk/pdf/guidance/landfill_directive/management_landfill_gas.pdf, February 2007.

[44] *PC, 2006, 'Waste Management', Productivity Commission, Melbourne, at http://www.pc.gov.au/inquiry/waste/finalreport/waste.pdf, February 2007.*

[45] *Waste Management Association of Australia, National Landfill Division, 'Responses to the Discussion Paper on a Possible Design for a National Greenhouse Gas Emissions Trading Scheme', accessed at http://www.emissionstrading.net.au/__data/assets/pdf_file/5342/WMAA_-_National_LandfillDivision.pdf, February 2007.*

have increased by one third, and overall landfill gas capture rates would have decreased to 61 per cent. Furthermore, this collection efficiency refers only the operational year in question and does not account for the whole-of-life recovery rates, especially for landfill gas generated post closure. The issue is that landfill gas capture systems, and landfill capping systems do not last forever. One estimate was that working systems on landfill have a life expectancy of 30 years.[46] Operational levels of gas capture efficiency do not account for system deterioration over time. Some of the post closure issues related to whole-of-life recovery rates are presented below.

4.3.2 Whole-of-Life Landfill Gas Recovery Rates

Landfill gas capture systems will deteriorate over time due to corrosion, breakages in gas capture infrastructure and operational issues. Some elements of landfill gas have a corrosive potential, such as the formation of carbonic acid, and halogenated or sulphuretted compounds. These elements will accelerate wear on plant and equipment, and reduce overall effectiveness of gas capture. Other problems can be caused by the flooding of horizontal gas collection pipes, broken pipes and plant and incorrect operation including excessive suction, and poor gas clean-up prior to use.[47] Many of these issues can be exacerbated in the post closure phase of a landfill, where lower levels of supervision, management and maintenance are to be expected.

Furthermore slower rates of decay for woody materials suggest a longer tail of dissimilation for woody based DOC. This suggests that a greater amount of methane could be generated while the capture efficiency of the landfill gas system deteriorates.

For example consider the decomposition of DOCm in a moist wet tropical landfill. It is assumed that the reduced half life values would be similar to an engineered landfill in a temperate climate with forced leachate recirculation. The hypothetical landfill accepts equal proportions of food, paper, garden and wood waste materials adding to one million tonnes per year. Over its 30 year life, 30 million tonnes of DOCm would be landfilled.

It is assumed that gas capture rates ramp up to 75 per cent by year 10 of operation. (This estimate of 75 per cent gas capture efficiency from the Productivity Commission[48] has been adopted as the starting point for estimating whole-of-life recovery rates for landfills across Australia.)

Peak efficiency is maintained until year 35, at which time the landfill gas capture system starts to degrade with an assumed loss of 10 per cent each year. Using AGO FOD methodology with moist wet tropical climate half life values for the DOC decomposition rates gives methane generation and methane capture rates (assuming 0.1 oxidation through the landfill cap) as shown in Figure 3 overleaf.

Figure 3 demonstrates that even with an operational efficiency for a landfill gas recovery system of 75 per cent, the effects of gas capture system deterioration and delays in decomposition of waste materials means that the theoretical maximum capture rate will be reduced. Here it is estimated that the maximum whole-of-life methane capture rates would be approximately 55 per cent

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[46] *Cossu, R., 2006, 'University of Padova: Research Contributions to Waste Management Sustainability', Presentation to the Waste Management Association of Australia Tour, 16 November 2006.*

[47] *UK EA, 2004, 'Guidance on the management of landfill gas' United Kingdom Environment Agency, accessed at http://www.sepa.org.uk/pdf/guidance/landfill_directive/management_landfill_gas.pdf, February 2007.*

[48] *PC, 2006, 'Waste Management', Productivity Commission, Melbourne, at http://www.pc.gov.au/inquiry/waste/finalreport/waste.pdf, February 2007.*

(calculated as the area under the landfill gas capture curve compared to methane generation over 100 years).[49] (The implications the carbon intensity of electricity made from landfill gas generation on the basis of whole-of-life capture rates are explored in Appendix 4.)

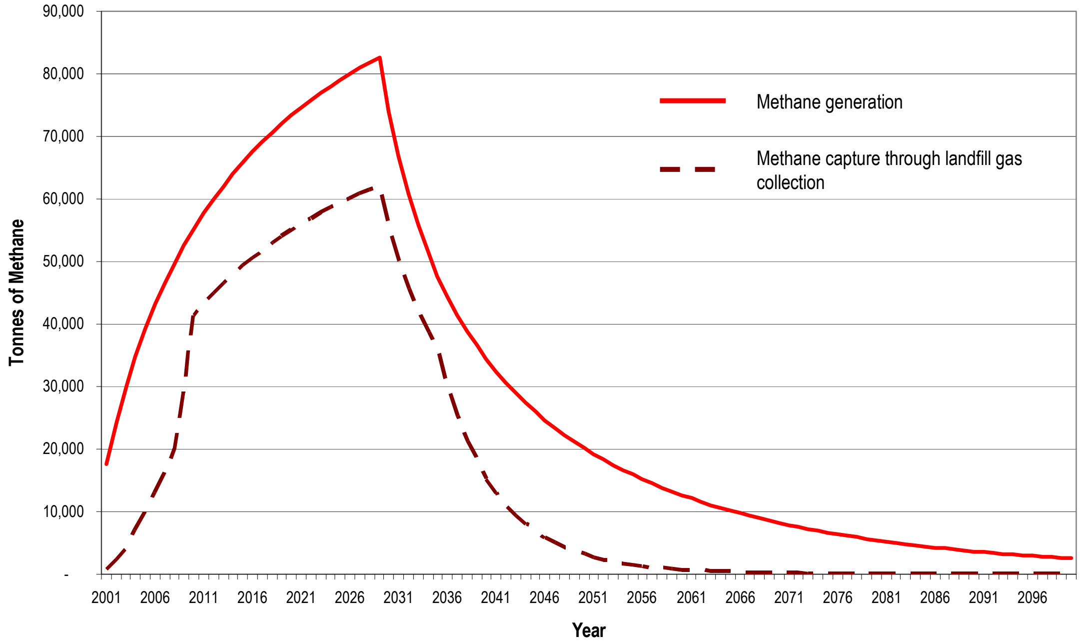

Figure 3 – Diminishing capacity of landfill gas capture systems over time and impact on whole-of-life cycle gas capture rates

4.3.3 Legacy of Landfilled Degradable Organic Carbon

There is also a landfill legacy issue for greenhouse gas emissions. This is illustrated by considering the situation where all DOCm was banned from landfill in 2010, preventing the ongoing build up of DDOC in landfills. Methane emissions, however, would continue because of the existing pool of DDOC spread across Australia. The long tail of methane generation, and hence carbon liability, is presented in Figure 4 overleaf.

Using the Australian Greenhouse Office FOD model suggests that if all materials with degradable organic carbon were banned from landfill in 2010, there would still be 9.4 $MtCO_2e$ of emissions at 2020 and 3.0 $MtCO_2e$ at 2050.[50] Because of this existing landfill carbon legacy, and implications from deteriorating effectiveness of landfill gas capture systems over time, the AGO estimate of 75 per cent for national average landfill gas capture rates at 2020 has not been used (see Appendix 5 for more information on AGO estimates).

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[49] *At year 100 it is estimated that 3.0 MT of CH_4 would have been generated, with 1.65 Mt captured, 0.135 Mt oxidated in the landfill cap, and 1.215 Mt emitted. Extending the time of assessment to 150 years reduces whole off life performance from 55% capture efficiency to 54% efficiency.*

[50] *Here national methane recovery rates are assumed to peak at 2010 at 21% and then decline at 5% per annum. Oxidation remains at 0.1 for the period.*

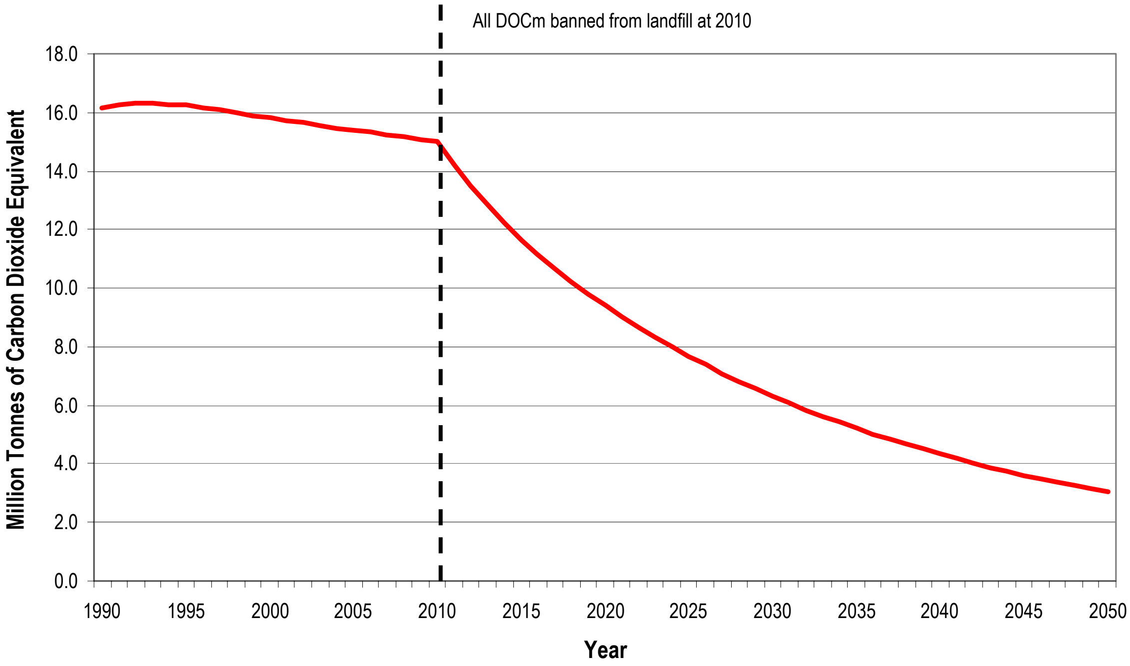

Figure 4 – Effect of long half-life of degradable organic carbon in landfill – waste landfilled in 2010 is a 2050 carbon liability

4.3.4 Likely Australian National Landfill Gas Capture Rates

Based on the preceding discussion and calculations, a national landfill gas capture rate of 33 per cent has been assumed at 2020,[51] while at 2050 a national landfill gas capture rate of 40 per cent is used.[52] This means that at 2050 it is assumed that virtually all biologically active wastes for disposal are going to an engineered landfill with a 30 year operational life, operational life landfill gas capture rate of 75 per cent and whole-of-life capture rates of 55 per cent.

It is noted that this level of methane recovery may be questionable as a 55 per cent whole-of-life landfill gas capture rate makes no allowance for fissures, geysers, landfill fires, breakdown of landfill gas flaring equipment, or falling levels of methane generation making electricity generation uneconomic. Some of these releases are difficult to assess with methane monitoring methodologies, especially geysers (landfill gas forces breakout through landfill cap), and fissures (landfill cap deteriorates allowing gas to escape). Furthermore the above scenario assumes that all Commercial and Industrial waste will be landfilled in landfill sites with the same licence conditions for landfill gas capture as for Municipal Solid Waste. Also the maximum factor for the oxidation of methane in landfill caps has been used, making no allowances for saturation of landfill capping systems or other potential dysfunction that would decrease oxidation in the landfill cap. Thus the following 2050 BAU estimates of 'with measures' may be optimistic.

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[51] *80 per cent of population has access to an engineered landfill, 90 per cent of waste sent to an engineered landfill, 85 per cent 'landfill coverage' and 55% whole-of-life landfill gas capture rate. 80% x 90 % x 85% x 55% = 33%. (See Appendix 5 for AGO original estimate.*

[52] *85 per cent of population has access to an engineered landfill, 95 per cent of waste sent to an engineered landfill, 90 per cent 'landfill coverage' and 55% whole-of-life landfill gas capture rate. 85% x 95 % x 90% x 55% = 40%*

4.4 Revised BAU and BAU 'With Measures' Emissions Estimates

The potential effect of 'with measures' in reducing BAU emissions from solid waste disposal from 1990 to 2050 is presented in Figure 5 below. In 2050 BAU emissions are estimated to be 46.9 $MtCO_2e$ arising from the generation of 2.5 $MtCH_4$ and the oxidation of 0.25 $MtCH_4$. Approximately 19.4 $MtCO_2e$ could be avoided through increasing rates of DOCm recovery. Applying the potential maximum national rate of landfill gas capture calculated in this study provides an estimated overall capture rate of 11.7 $MtCO_2e$ of landfill gas that is flared or used to generate electricity. The net BAU 'with measures' estimate for 2050 is thus 15.8 $MtCO_2e$ of landfill gas escaping as fugitive emissions. Net emissions are expected to trend downwards to around 2020 as a result of increased rates of DOCm diversion from landfill and increased capture of landfill gas. At around that time, however, the anticipated rate of increase in waste generation starts to outpace the abatement effects of DOCm recovery and landfill gas capture. Hence net emissions trend slightly upwards from 2020-2050. A summary of the BAU revised estimates of landfill gas greenhouse gas emissions is presented in Table 10 below.

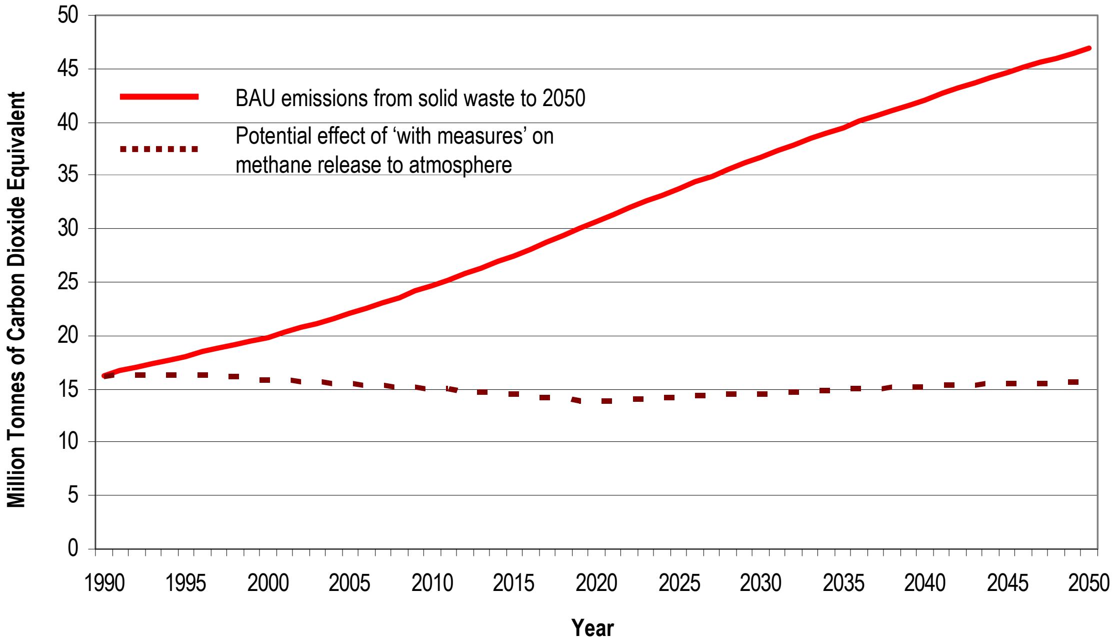

Figure 5 – Potential effect of 'with measures' in reducing greenhouse gas emissions from landfill

Table 10 – Summary of BAU emissions 'with measures' from 1990 to 2050 ($MtCO_2e$).

Scenario	*1990*	*2000*	*2010*	*2020*	*2030*	*2040*	*2050*
BAU – no waste diversion, no methane capture, but with landfill cap oxidation	16.2	19.9	24.7	30.7	36.7	42.1	46.9
Potential effect of DOCm diversion from landfill	0.1	1.7	5.2	9.3	13.3	16.6	19.4
Potential effect of methane capture from landfill	0	2.4	4.5	7.6	8.9	10.3	11.7
Net emission – BAU 'with measures'	16.1	15.8	15.0	13.8	14.5	15.2	15.8

It is important to highlight that the BAU estimate presents the risk profile of greenhouse gas emissions from solid waste. This is especially the case given that BAU estimates presented here are conservative, and the ability of 'with measures' to reduce these emissions is contingent on significant amounts of resource recovery and on the majority of waste being landfilled with high operational life recovery rates of landfill gas. Furthermore, applying an oxidation factor of 0.1 across all landfills from the operation of landfill cap is likely to be over-optimistic. If this was removed from the BAU estimates, and a global warming potential of 25 used for methane, the 'with measures' estimate would be increased to 24.6 $MtCO_2e$ (see Appendix 6 for further discussion on these factors). The implications of BAU estimates for future Australian greenhouse gas 'budgets' are presented in Section 5.

5 IMPLICATIONS OF LANDFILL GAS EMISSIONS AND AUSTRALIAN GREENHOUSE GAS REDUCTIONS

The debate around climate change has shifted from questioning whether global warming is actually occurring, to now consider timelines and targets for emission reductions, in addition to enabling mechanisms such as emissions trading. The target set for emission reductions in Australia at 2050 will effectively set the carbon budget for the nation and force all sectors of the economy to consider their Business-as-Usual projections for sectoral growth in order to develop effective strategies for decarbonisation. The implications of the landfill carbon liability at 2050 are discussed below.

5.1 Potential Australian Emission Reduction Targets for 2050

Australia has yet to set any national binding targets on emission reductions. However, states like NSW, Victoria and South Australia are on record as aiming for a 60 per cent reduction by 2050.[53] Other leaders from around the world are adopting more ambitious targets, for example California has adopted an 80 per cent reduction target for 2050 (based on 1990 levels),[54] and many environment groups are calling for reduction targets as high as 90 per cent by 2050.[55]

Target A is a 90 per cent reduction by 2050 on 1990 levels, Target B a 80 per cent reduction and Target C a 60 per cent reduction. These three reduction targets are presented in Figure 6 below. (Note that trajectories are purely for illustration purposes).

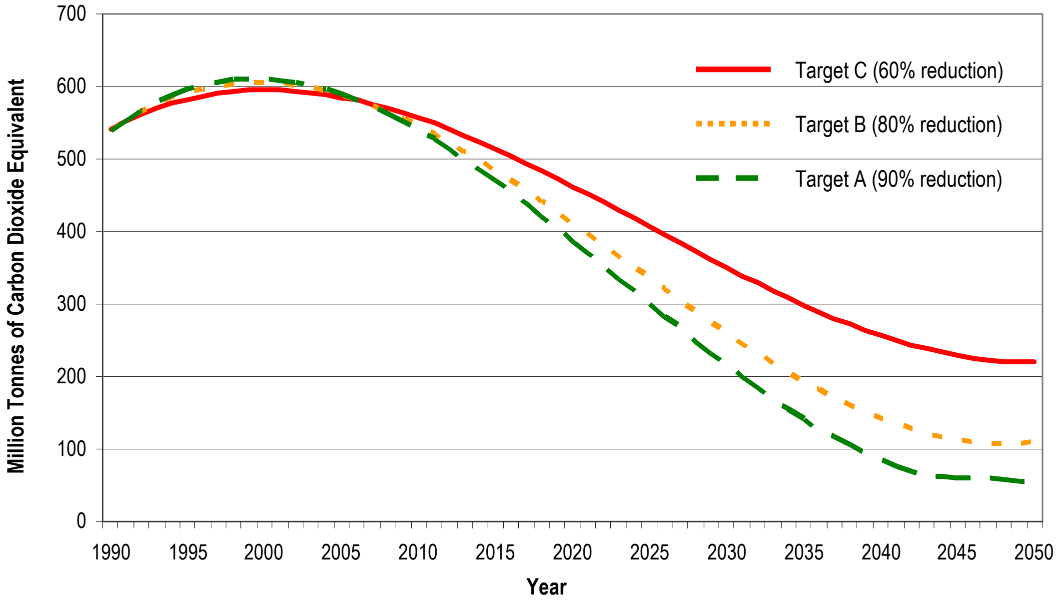

Figure 6 – Potential Australian greenhouse gas reduction targets

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[53] *NSW Greenhouse Office, 2005, 'NSW Greenhouse Plan', New South Wales Government, Sydney, accessed at http://www.greenhouseinfo.nsw.gov.au/__data/page/927/28-11_FINAL_NSW_GH_Plan_web.pdf, February 2007. Vic DSE, 2005, 'Victorian Greenhouse Strategy Action Plan Update 2005', Victorian Department of Sustainability and Environment, Melbourne, accessed at http://www.greenhouse.vic.gov.au/greenhouse/images/VicGreenhouse-ActionPlan.pdf, February 2007. SA DEH, 2006, 'Tackling Climate Change: Reducing Adapting Innovating. South Australia's Draft Greenhouse Strategy', South Australia Department of Environment and Heritage, accessed at http://www.climatechange.sa.gov.au/PDFs/draft_strategy.pdf, February 2007.*

[54] *Office of the Governor, 2006, 'Gov. Schwarzenegger Signs Landmark Legislation to Reduce Greenhouse Gas Emissions', Press Release, accessed at http://www.climatechange.ca.gov/documents/2006-09-27_AB32_GOV_NEWS_RELEASE.PDF, February 2007.*

[55] *See for example, Australian Conservation Foundation at http://www.acfonline.org.au/default.asp?section_id=6.*

5.2 BAU Emissions from Solid Waste and Emission Reduction Targets for 2050

The projected reduction targets, based on Australian 1990 greenhouse gas emissions of 551.9 MtCO$_2$e are presented in Table 11 and Figure 7 below, as is the proportion of the nations 'carbon allowance' that is taken up by BAU and BAU 'with measures' solid waste emissions.

Table 11 – Summary of BAU emissions and implications for future national carbon budget

Scenario at 2050	*60% Reduction*	*80% Reduction*	*90% Reduction*
National carbon budget (MtCO$_2$e)	220.8	110.4	55.2
BAU from solid waste landfilling	46.9	46.9	46.9
Proportion of national carbon budget	21%	42%	85%
BAU 'with measures' from solid waste landfilling	15.8	15.8	15.8
Proportion of national carbon budget	7%	14%	29%

The potential carbon liability arising from the BAU disposal of materials with degradable organic carbon, such as food, paper, garden and wood waste, ranges from 21 to 85 per cent of Australia's carbon budget at 2050, as shown in Figure 7 below.

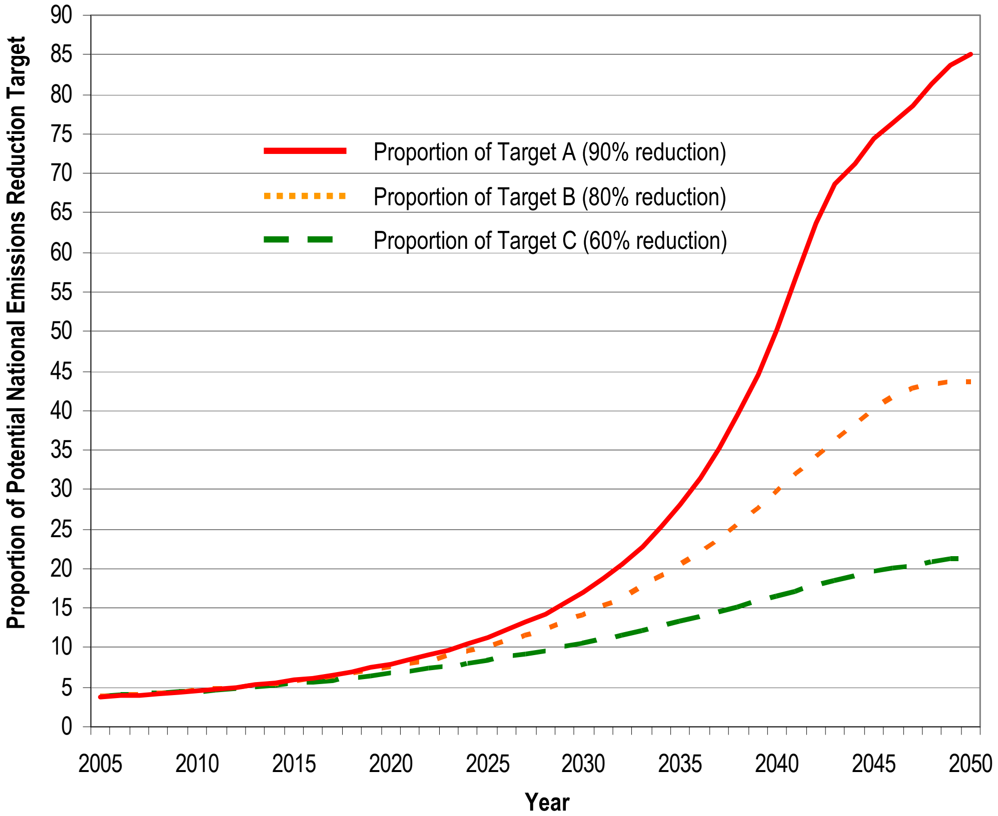

Figure 7 – Potential BAU carbon liability from landfilling solid waste as a proportion of national carbon budget

(Note that individual year targets were based on illustrative reduction trajectories to meet the 2050 reduction target. See Appendix 7 for a presentation of the BAU liability on a tonnes basis.)

Even applying measures such as increased recovery of waste and capturing landfill gas emissions sees waste occupy a disproportionately large amount of the nations carbon allowance. For example, under an 80 per cent reduction target (Target B), the continued disposal of waste with degradable organic carbon is likely to account for 14 per cent of net national greenhouse gas emissions. The major risk being that the 'with measures' fail, which could see waste account for up to 42 per cent of net national emissions at 2050 (80 per cent reduction target).

Even if the solid waste sector wanted to maintain its relative contribution to national greenhouse gas emissions (2.7 per cent in 2004), emissions would need to reduce to 3 $MtCO_2e$ under an 80 per cent reduction target. This would require stopping all waste with degradable organic carbon from being landfilled from 2010 onwards. If the sector wanted to reduce the proportional contribution to greenhouse emissions, less than 3 $MtCO_2e$ would need to be emitted in 2050, requiring not only the cessation of landfilling materials with degradable organic carbon, but also the 'greenhouse' remediation of existing landfills. This form of remediation is likely to involve re-engineering or re-installing landfill gas capture systems and recapping of landfills, with potential landfill excavation, stabilisation of carbonaceous content, and site rehabilitation also options.

Another potential consequence of the BAU and BAU 'with measures' projections is that the pool of degradable organic carbon at 2050 will present as a 2100 carbon liability. Given that emission reduction targets are likely to increase towards the end of the century, it is conceivable that the carbon legacy at 2050 could account for Australia's entire 2100 carbon budget.

The potential for emissions from solid waste disposal to dominate Australia's 2050 carbon budget clearly demonstrates the greenhouse gas liability of the disposal of materials with degradable organic carbon (biologically active). The most effective way to mitigate against this potential liability is to prevent landfilling of materials with degradable organic carbon. Some policy responses to achieve this outcome are investigated in the next section.

5.3 Potential Policy Options to Divert Materials with Degradable Organic Carbon Waste from Landfill

The above discussion has articulated the carbon liability of continued landfilling of materials with degradable organic carbon waste. There is an additional problem with landfill carbon liability that makes these emissions all the more costly from a societal perspective. This is the lack of value returned to society for the emission of one tonne of carbon dioxide equivalent from landfill.

For example, other sectors in the economy can claim to benefit society in terms of delivering value for each tonne of CO_2e released. The generation of electricity is available to run appliances, combustion of hydrocarbon fuels transports us (or our consumables) from point A to point B, and agricultural emissions provide us with food to eat. The best that solid waste emissions can offer society in terms of value is a waste disposal solution to ensure the protection of public health (sanitation). However resource recovery provides this 'disposal' function as a by-product of returning value to the economy. Emissions from solid waste disposal can thus be categorised as 'negative value' emissions. In a carbon constrained economy this kind of carbon expenditure is unaffordable. In other words, the 'allowance to emit greenhouse gases' is wasted on waste.

Furthermore, if more severe cuts are required in the future, for example to half a tonne per capita,[56] emissions from solid waste disposal to landfill will need to be completely eliminated. The most effective solution to reduce or eliminate the carbon liability of landfill is to prevent materials with degradable organic carbon from being landfilled.

There are a range of policy interventions that could deliver this objective, including:

- implementation of a similar UK Landfill Allowance Trading Scheme for biologically active materials – the stated objective of UK LATS is to reduce the landfilling of biodegradable municipal waste (BMW) by setting an allocation of tradable landfill allowances amongst waste disposal authorities in United Kingdom (England, Ireland, Scotland and Wales). Each allowance conveys the right to dispose of biodegradable municipal waste (BMW).[57] However to be truly effective the scheme would need to be extended to cover commercial and Industrial and Construction and Demolition waste streams
- a potential ban in capital cities on the disposal of biologically active materials, implemented between 2010 and 2015, with regional centres brought online by 2020 – this approach would prohibit the landfilling of materials with degradable organic carbon, in a similar fashion to current restrictions on the disposal of hazardous wastes
- making landfills liable for future fugitive emissions arising from waste landfilled post 2010 – a bond would need to be paid by landfill operators on the basis of their whole-of-life methane emissions. The bond could be released where it is shown that landfill operators improve on emissions capture and prevention. (Note that this policy is not intended to be retrospective in focus (making landfills liable for emissions from past landfilling of waste), rather to address future landfilling of waste)
- including the avoidance of landfill as an offset category in carbon trading schemes – monetising the prevented greenhouse gas emissions from the diversion of DOCm from landfill would provide a direct incentive to those businesses that recover value from DOCm that would otherwise be disposed of to landfill.

A policy response that phased out the landfilling of food, paper, garden and wood waste from 2010 would avoid the landfilling of approximately one billion tonnes of these materials between 2010 and 2050, which would ultimately prevent the emission of up to two billion tonnes of CO_2e of greenhouse gas emissions in Australia.[58] Whatever the policy response state jurisdictions choose to implement, one thing is clear: action needs to be early and effective in order to provide a long term reduction in greenhouse gas emissions from the waste management sector.

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[56] *The Stern Review presents the argument that eventually global emissions will have to fall below 5 $GTCO_2e$ globally. In 2100 this corresponds to a global carbon 'birthright' of approximately half a tonne per person (estimated population of 9.1 billion), or a target for Australia of below 15 $MtCO_2e$ (estimated population of 31 million). In such a tightly carbon constrained economy there is literally no room for emissions from landfill. 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, February 2007.*

[57] *DEFRA, 2004, 'United Kingdom Landfill Allowance Trading Scheme', Department for Environment, Food and Rural Affairs, London, accessed at http://www.defra.gov.uk/environment/waste/localauth/lats/index.htm, February 2007.*

[58] *This includes the avoided emissions going forward from 2050. Approximate generation between 2010 and 2050 of 210 Mt of food, 395 Mt of paper, 290 Mt of garden and 145 Mt of wood to give 1,040 Mt DOCm. Applying AGO 2006 workbook default emission factors to these tonnages means that 1,960 $MtCO_2e$ would be avoided (210*0.9=189 $MtCO_2e$ from food, 395*2.5=988 $MtCO_2e$ from paper, 290*1.1=319 $MtCO_2e$ from garden and 145*3.2=464 $MtCO_2e$ from wood).*

5.4 Additional Upside from Recovering Resource Value from Materials with Degradable Organic Carbon

The preceding sections have focussed on the greenhouse gas risks of landfilling materials with degradable organic carbon that will dissimilate into methane and escape into the atmosphere, and on the benefits from avoiding these risks by avoiding the landfill of these materials in the first instance. However, this is only part of the value calculation, as there is additional upside from a resource recovery focus on food, paper, garden and wood materials, over and above avoided landfill gas emissions. For example:

- direct materials recycling – the technology to process and divert DOCm from landfill creates an opportunity to recycle materials such as metal, plastic and glass which would otherwise have been landfilled. There will also be incentives to increase the amount of paper and cardboard recycling
- reduced greenhouse gas emissions through recovery of embodied energy – the recycling of metal, plastic, glass, and paper and cardboard uses less energy than manufacturing these commodities from virgin resources. The lower embodied energy of recycled materials contributes in turn to lower greenhouse gas emissions through avoided energy use
- displacement of fossil fuel energy – food, paper, garden and wood materials can all be used as energy inputs. In the case of food, anaerobic digestion is required to produce biogas and a nutrient rich digestate, which can be used in horticultural products. Paper, garden and wood materials can be used directly to displace fossil fuel usage in cement kilns and power stations, or indirectly through gasification to produce a combustible syn-gas
- nutrient cycling – anaerobic digestion and/or composting of food and 'wet' garden materials provide the opportunity to cycle nutrients back into agricultural practices
- new technology innovation and development – there are a range of emerging technologies that have the capacity for improved resource recovery. For example, the production of biochar from garden and wood materials through pyrolysis has the potential to generate renewable energy in the form of gas and bio-oils,[59] in addition to stabilising the degradable organic carbon into a form with a half-life in the hundreds, if not thousands of years, in addition to providing several benefits as a soil improver.[60]

The above benefits accompanying a resource recovery focus for paper, food, garden and wood materials, while being beyond the scope of analysis for this study, provide additional impetus to the landfill avoidance imperative.[61] In short, avoiding the landfilling of materials with degradable organic carbon will not only avoid the emission greenhouse gases from landfill, but will also make a positive contribution to recycling, renewable energy, nutrient cycling and provide a driver for ongoing innovation in resource recovery technology.

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[59] *Pyrolysis is a technology that heats biomass materials in the absence of oxygen to release volatile components in the form of combustible gas and oil, leaving behind a stabilised biochar product.*

[60] *IAI 2007, 'Proceedings: International Agrichar Initiative (IAI) 2007 Conference Terrigal, NSW Australia', Renew the Earth, Virginia.*

[61] *For more discussion on the environmental upside of resource recovery see ACOR, 2006, 'Productivity Commission Inquiry into Waste and Resource Efficiency: Submission by Australian Council of Recyclers', ACOR, Sydney, http://www.pc.gov.au/inquiry/waste/subs/sub040.pdf. For additional discussion on the potential for market based incentives for resource recovery see Warnken ISE, 2004, '' Market Based Instruments and Sustainable Resource Recovery', Total Environment Centre, Sydney, http://www.tec.org.au/dev/index.php?option=com_docman&task=doc_download&gid=109.*

6 CONCLUSIONS AND RECOMMENDATIONS

The current level of interest and support for taking action on climate change is forcing all sections of the Australian economy to examine their ‘carbon liability’. Emissions from the disposal of solid waste to landfill are no exception. The business-as-usual (BAU) emissions from solid waste disposal in 2050 are likely to be 46.9 million tonnes of carbon dioxide equivalent ($MtCO_2e$). However even though the BAU case assumes no waste diversion through recycling and no methane capture (only oxidation at the default AGO rate of 10 per cent), it sets up the potential carbon liability from solid waste landfilling.

The two carbon abatement measures of diversion and capture would reduce the amount of methane emitted to atmosphere. The effect of diverting materials with degradable organic carbon (DOCm) from landfill could prevent the emissions of 19.4 $MtCO_2e$ of greenhouse gas emissions in 2050, if resource recovery rates are able to offset the increase in waste generation. This equates to a resource recovery rate of approximately 45 per cent with 13.4 million tonnes of DOCm recycled. Avoided landfilling of DOCm is the only way to ensure there is no ongoing legacy carbon liability associated with landfill and proactive measures to drive resource recovery could theoretically remove most of the carbon risk associated with solid waste disposal.

In order to estimate the potential abatement effect of landfill gas capture it is necessary to estimate the nationwide recovery rate of landfill gas. The nation-wide rate of 75 per cent gas capture of landfill gas emissions estimate by AGO at 2020 was rejected as unachievable, especially given that the whole-of-life cycle emissions from landfill with an operational phase gas capture system efficiency of 75 per cent is a theoretical maximum of 55 per cent over a 100 year period.

A nation wide gas capture rate of 40 per cent was adopted on the basis that not all waste would be disposed of in engineered landfills. On this basis it is estimated that at least 15.8 $MtCO_2e$ of greenhouse gas emissions would be released at 2050 from the fugitive escape of 0.75 million tonnes of methane ($MtCH_4$). However, it is noted that should any of the ‘with measures’ fail to deliver modelled performance, greenhouse gas emissions would increase. Thus the BAU estimate of 46.9 $MtCO_2e$ of emissions at 2050 gives a better indication of the carbon liability presented by the continued landfilling of materials with degradable organic carbon.

The liability implications of greenhouse gas emissions from solid waste disposal are highlighted when potential national targets for greenhouse gas reduction are considered. The three emission reduction targets that are under consideration by countries around the world include 60, 80 and 90 per cent reductions on 1990 emission levels. For Australia, this translates to potential targets of 220.8, 110.4, and 55.2 $MtCO_2e$ respectively on 1990 emissions of 551.9 $MtCO_2e$.

The potential carbon liability arising from the BAU disposal of materials with degradable organic carbon, such as food, paper, garden and wood waste, ranges from 21 to 85 per cent of Australia’s carbon budget at 2050, depending on the national emissions reduction target.

Given that the value delivered to society from solid waste emissions is at best a waste disposal solution, and that any landfilled degradable organic carbon at 2050 presents an event larger 2100 carbon liability, this kind of carbon expenditure is unaffordable in a carbon constrained economy.

The most effective solution to reduce or eliminate the carbon liability of landfill is to prevent materials with degradable organic carbon from being landfilled. Action also needs to be early and effective in order to provide long term CO_2e emissions reduction from the landfill sector. For example, stopping the landfilling of all food, paper, garden and wood wastes at 2010 would still leave legacy carbon emitting 3.0 $MtCO_2e$ at 2050, highlighting the potential requirements for not only avoiding the disposal of materials with degradable organic carbon, but also the potential need for ‘greenhouse’ remediation of existing and closed landfill sites.

In order to achieve the objective of eliminating the carbon liability of landfill, the following actions are recommended:

- phase out the disposal of food, paper, garden and wood wastes in landfill with regulatory underpinning through the use of a UK style landfill avoidance trading scheme, or some other form of targeted market based instrument, including increases to landfill levies
- use regulation such as a potential ban in capital cities on the disposal of biologically active materials, or a requirement for pre-processing of all waste before entering landfill to recover resources and biologically stabilise the waste, or pricing carbon as a pollutant under load based licensing
- use emissions trading to make landfills liable for future fugitive emissions arising from waste landfilled post 2010 through inclusion as ‘stationary emitters’, or including the avoidance of landfilling biologically active waste as an offset category and recognising the benefits of recycling in avoided greenhouse gas emissions
- mandate the installation of landfill gas capture and recovery or flaring systems for all landfills (including any ‘inert’ landfills that have accepted materials with degradable organic carbon, for example from Commercial and Industrial waste), including the closing of poorly run old-fashioned landfills in favour of fully engineered modern landfills with gas capture. This action is not a substitute for the above policy measures and would manage waste that is left after the above actions
- maximise efforts to capture and control landfill emissions, including ongoing maintenance of capping and increasing efficiency of landfill gas capture systems, with the potential remediation of future landfills that are still emitting landfill gas 15 years after closure
- institute a performance bond on all future landfills to ensure that future costs of greenhouse remediation are not externalised onto the community.

The benefits of taking early action to prevent the disposal of food, paper, garden and wood wastes in landfill are considerable, with up to two billion tonnes of carbon dioxide equivalent prevented from entering the atmosphere. This action would also avoid a potential 2050 liability where a disproportionately large amount of Australia’s carbon budget was allocated to solid waste emissions.

Furthermore, there is additional upside accompanying a resource recovery focus on materials with degradable organic carbon including additional recycling, renewable energy, and nutrient cycling, in conjunction with ongoing innovation in resource recovery technology.

Given the widespread community, scientific and political support for taking action on climate change mitigation, and the fact that every tonne of waste landfilled today represents a potential 2050 carbon liability, there is no future for the landfilling of food, paper, garden and wood in a decarbonising economy.

7 APPENDICES

7.1 Appendix 1 – Revised Estimates of Waste Generation in Australia

A breakdown of Australia's waste generation in 2002/2003 according to source is presented in Table 12 below.

Table 12 – Australian waste generation in 2002/2003 by source[62]

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%**

This estimate of waste generation includes the disposal to landfill of 17,423,000 tonnes, and the recycling of 14,959,000 tonnes. In other words 54 per cent of the 32,382,000 tonnes of waste generated in 2002/2003 were disposed of to landfill, while 46 per cent was recycled. However, there are several limitations with these estimates. For example the amounts of waste generated:[63]

- do not include any data for Tasmania and the Northern Territory
- use a total disposal figure for WA is for metropolitan Perth
- have a waste generation rate per capita of 1.0 tonnes for Queensland compared to 1.8 for New South Wales and 1.7 for Victoria.[64]

These factors suggest that estimates for waste generation, landfilling and recycling have been underestimated. Revised estimates on the basis of a waste generation rate of 1.85 tonnes for Queensland, Tasmania and the Northern Territory is presented in Table 13 overleaf:

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[62] *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, February 2007.*

[63] *Ibid.*

[64] *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, February 2007.*

Table 13 – Revised Australian waste generation by state[65]

State	*Total Tonnes Generated*	*Total Tonnes Recycled*	*% Recycled*	*Total Tonnes Landfill*	*% Landfill*
New South Wales	12,171,000	5,830,000	48%	6,341,000	52%
Victoria	8,609,000	4,429,000	51%	4,180,000	49%
Queensland	7,038,000	2,216,000	31%	4,822,000	69%
Western Australia	4,770,000	973,000	20%	3,797,000	80%
South Australia	3,433,000	2,156,000	63%	1,277,000	37%
Tasmania	889,000	280,000	31%	609,000	69%
Australian Capital Territory	674,000	467,000	69%	207,000	31%
Northern Territory (Darwin)	370,000	117,000	32%	253,000	68%
Totals	**37,954,000**	**16,468,000**	**43%**	**21,486,000**	**57%**

The revised estimates increase the amount of waste generated by 5,553,000 tonnes, an increase of 17 per cent. The estimated amount of waste landfilled is 21,473,000 tonnes (57 per cent of the revised total), while the amount of waste recycled is 16,462,000 tonnes (43 per cent of the revised total). This data is presented by source in Table 1 in Section 2.1.

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[65] *Base data 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, February 2007. Population data for 2003 from ABS, 2006, 'Population by sex, states and territories, 30 June, 1901 onwards', Australian Bureau of Statistics, Canberra, accessed at http://www.abs.gov.au - cat. no. 3105.0.65.001, February 2007. The per capita waste generation rate was based on data from NSW, Vic, SA and ACT The split between recycling and landfill was based on existing data for Qld and applied also to Tas and NT. Estimates for WA taken from Warnken ISE 2006.*

7.2 Appendix 2 – Basis of AGO Emissions Factors

The calculations used by AGO to estimate emission factors for materials with degradable organic carbon are based on the following equation:[66]

GHG emissions (tCO2e) = $[((Q*DOC*DOCf*F1*16/12-R)*(1-OX))*21]$, 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 (based on molecular mass)

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.

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[66] *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, February 2007.*

7.3 Appendix 3 – Estimation of BAU Emissions from Solid Waste at 2050

The AGO estimates that 31.7 MtCO$_2$e would be released from solid waste under BAU in 2020, approximately twice the amount of emissions from solid waste BAU in 1990 (15.4 MtCO$_2$e).[67]

The AGO 2020 BAU estimate of 31.7 MtCO$_2$e would arise from the generation of 1.51 MtCH$_4$[68] caused by a the deposit of approximately 25.4 million tonnes of paper, food, garden and wood waste (58.5 million tonnes of waste if inert materials to landfill are included at current proportions) and a 'dissimilatable degradable organic carbon' (DDOC) pool of 51.6 million tonnes. Given that the mid-range population forecast for Australia in 2020 is 23.5 million,[69] this corresponds to a per capita DOCm generation rate of 1.1 tonnes (recycling rate of 0.0 tonnes).

The percentage change in greenhouse gas emissions between 1990 and 2020 under BAU is predicted by AGO to be 108 per cent. Applying this same increase rate over the next 30 years to 2050 gives a BAU estimate of 65.3 MtCO$_2$e (3.11 MtCH$_4$). However, extrapolating the growth curve, as opposed to the average percentage increases, gives a 2050 BAU estimate of approximately 79.2 MtCO$_2$e (3.77 MtCH$_4$).[70]

These two BAU estimates would require a pool of 101 MtDDOC and 126 MtDDOC respectively, in addition to the disposal of 42.9 Mt of paper, food, garden and wood waste (98.8 million tonnes of waste generated including OIm) and 60.8 Mt of paper, food, garden and wood waste (140.1 million tonnes of waste including OIm) for the lower and higher BAU estimate respectively.[71] Given that the mid-range population forecast for Australia in 2050 is estimated to be 28 million (increased from 23.5 million in 2020),[72] these amounts of waste generation represents a per capita DOCm generation rate of 1.5 and 2.2 tonnes.

Both of these DOCm estimates for 2050 are unlikely to involve unrealistic rates of increase in DOCm generation, especially given that food and garden waste generation are unlikely to be directly linked to economic growth. Using revised amounts of waste generated according to the 2002/2003 breakdown (16.5 million tonnes of DOCm generation - 0.83 tonnes per capita), and lower increases in waste generation rates produces a more conservative BAU estimate for 2020 and 2050. The lower assumed growth rates include:

- 3 per cent and 0.5 per cent growth in recycling per capita rates between 2004 – 2019 and 2020-2050 respectively
- 0 per cent and 0.1 per cent growth in landfilling per capita rates between 2004 – 2019 and 2020-2050 respectively
- average annual increase in per capita waste generation rates of 0.7 per cent.

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[67] *AGO, 2006, 'Waste Sector Greenhouse Gas Emissions Projections 2006', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/projections/pubs/waste2006.pdf, February 2007.*

[68] *31,700,000 divided by 21 (the IPCC Second Assessment Report estimate of the global warming potential of methane)*

[69] *Actual estimate for 2021 of 23,662,576 extrapolated backwards on a five year average basis. ABS, 2005, 'Projected Population, Components of Change and Summary Statistics - Australia', Australian Bureau of Statistics, Canberra, accessed at http://www.abs.gov.au - cat. no. 3222.0, February 2007.*

[70] *Fitting a quadratic equation of $y=15.4+0.233x+0.177x^2$approximates the AGO BAU curve at (0,15.4, 20,22.8 and 30,31.7). Extrapolating out to 60 (2050) gives 70.9 MtCO$_2$e, which is divided by 21 to give 3.77 MtCH$_4$.*

[71] *Estimated by increasing waste generation rates in the FOD model built for this analysis until target emissions levels were reached. No methane capture, methane generated is oxidated at a factor of 0.1, and no DOCm waste diversion.*

[72] *Actual estimate for 2051 of 28,080,815 extrapolated backwards on a five year average basis. ABS, 2005, 'Projected Population, Components of Change and Summary Statistics - Australia', Australian Bureau of Statistics, Canberra, accessed at http://www.abs.gov.au - cat. no. 3222.0, February 2007.*

Applying the above growth rates gives an estimated 2020 BAU DOCm generation of 23.1 million tonnes (1.0 tonne per capita) and a nationwide BAU pool of 50 MtDDOC. At 2050 BAU it is estimated that there will be 29.9 million tonnes of DOCm generated (1.1 tonnes per capita) and a pool of 77 MtDDOC. This amount of DOCm generation would give a BAU solid waste emission of 46.9 $MtCO_2e$ (2.34 $MtCH_4$). A summary of BAU estimates around DOCm and methane generation is presented in Table 9 in Section 4.1.

7.4 Appendix 4 - Landfill Gas Recovery for Energy and Fugitive Emissions

Electricity generated from landfill gas is currently recognised as a renewable source of electricity under the Mandatory Renewable Energy Target, and may be recognised as such under the upcoming Victorian Renewable Energy Target (VRET) and NSW Renewable Energy Target (NRET).[73] However this could be problematic if the whole-of-life emissions from landfill are taken into account. Table 14 below presents the carbon intensity of landfill gas electricity generation per MWh of generation, using the generation of one tonne of methane as an example. 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 and the calorific value of methane is assumed to be 52.5 giga-joules per tonne.[74]

Table 14 – Carbon intensity of electricity generated from landfill gas, accounting for fugitive emissions from landfill

Whole-of-life landfill gas capture rate	15%	25%	35%	45%	55%	65%	75%
Methane Captured for e- (tonnes)	0.15	0.25	0.35	0.45	0.55	0.65	0.75
Energy for e- (GJ)	3.03	5.05	7.07	9.10	11.12	13.14	15.16
Electricity generated (MWh)	0.84	1.40	1.97	2.53	3.09	3.65	4.21
Methane Oxidated (tonnes)	0.09	0.08	0.07	0.06	0.05	0.04	0.03
Methane emitted (tonnes)	0.77	0.68	0.59	0.50	0.41	0.32	0.23
Greenhouse Intensity (tCO_2e/MWh)[75]	19.1	10.1	6.3	4.1	2.8	1.8	1.1

As Table 14 identifies, electricity generation at a whole-of-life landfill gas capture rate of 55 per cent will produce electricity with a greenhouse gas intensity of 2.8 tCO2e/MWh. By way of comparison, the greenhouse gas intensity for electricity generation in Victoria is 1.24 tCO_2e per MWh, sourced primarily from brown coal, while the carbon intensity for electricity generation in NSW is 0.97 tCO_2e per MWh, sourced primarily from black coal.[76]

According to the methodology developed for this study, a total landfill gas capture rate during the landfill operational phase of 95 per cent or better, would only deliver a whole-of-life gas capture rate of approximately 75 per cent. Here the whole-of-system greenhouse intensity of electricity generation offers no benefit over coal based fossil fuel electricity generation because of the greenhouse implications of fugitive methane emissions.

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[73] *ORER, 2006, 'Australia's REC System', Office of the Renewable Energy Regulator, Canberra, accessed at http://www.orer.gov.au/publications/pubs/rec-system0506.pdf, February 2007. S V 2006, 'Victorian legislation and guidelines: Victorian Renewable Energy Target Act', Sustainability Victoria, Melbourne, accessed at http://www.sustainability.vic.gov.au/www/html/1632-victorian-legislation-and-guidelines.asp, March 2007. DEUS, 2006, 'NSW Renewable Energy Targets – Explanatory Paper', Department of Energy, Utilities and Sustainability, Sydney, accessed at http://www.deus.nsw.gov.au/Publications/NRET%20Explanatory%20Paper%20FINAL.pdf, March 2007.*

[74] *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, February 2007.*

[75] *Note that a global warming potential for methane of 21 has been used for this conversion. Using a GWP of 25 times that of carbon dioxide makes the greenhouse intensity 'worse' by an additional 19%.*

[76] *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, February 2007.*

7.5 Appendix 5 – AGO Future Estimates of National Average Landfill Gas Capture Rates

The assumptions for methane capture from landfills in Australia used by the Australian Greenhouse Office to estimate future greenhouse gas capture rates were based on a report for the AGO 'The impact of Australian State/Territory measures on Greenhouse Gas Emissions in the Waste Sector 2004-2020' undertaken by Hyder Consulting.[77]

The 2010 nationwide methane capture rate of 40 per cent was calculated as:

- 69 per cent of Australia's population live in capital cities and regional urban centres (greater than 50,000 people)
- 93 per cent of all of the waste from capital cities and regional urban centres is sent to an engineered landfill
- 75 per cent 'landfill coverage' - taken to be an adjustment to account for those landfills around the nation that don't have the same landfill gas capture rates of an engineered landfill
- 85 per cent landfill capture rate at an engineered landfill. [78]

However, in order to achieve the estimated nationwide recovery rate of 75 per cent of methane generation at 2020 using the same variables, the following levels of performance would be required:

- 96 per cent of Australia's population live in capital cities and regional urban centres with access to an engineered landfill
- 96 per cent of all of the waste from capital cities and regional urban centres is sent to an engineered landfill
- 96 per cent 'landfill coverage'
- 85 per cent landfill capture rate at an engineered landfill.[79]

Thus a nationwide 75 per cent landfill gas capture rate assumes that the majority of waste in Australia would be disposed of in an engineered landfill with an 85 per cent landfill gas capture rate, and that the majority of smaller landfill sites currently operational have been closed and are inactive, or are also capturing emissions at an 85 per cent recovery rate.

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[77] *AGO, 2006, 'Waste Sector Greenhouse Gas Emissions Projections 2006', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/projections/pubs/waste2006.pdf, February 2007.*

[78] *69%*93%*75%*85% = 40%.*

[79] *96%*96%*96%*85% = 75%.*

7.6 Appendix 6 – Potential BAU Carbon Liability without Oxidation Factor and GWP for Methane of 25

The BAU estimates presented in this study have used an oxidation factor of 10 per cent to account for the oxidating effect of landfill caps. A global warming potential for methane of 21 has also been used. The 2050 BAU estimate would increase from 46.9 $MtCO_2e$ to 52.1 $MtCO_2e$ if no oxidation factor for landfill capping was used, and then increase to 62.1 $MtCO_2e$ if a global warming potential for methane of 25 is used. Figure 8 below shows the impact of these increases on the proportional amount potentially 'used up' of emission reduction targets by these revised BAU estimates.

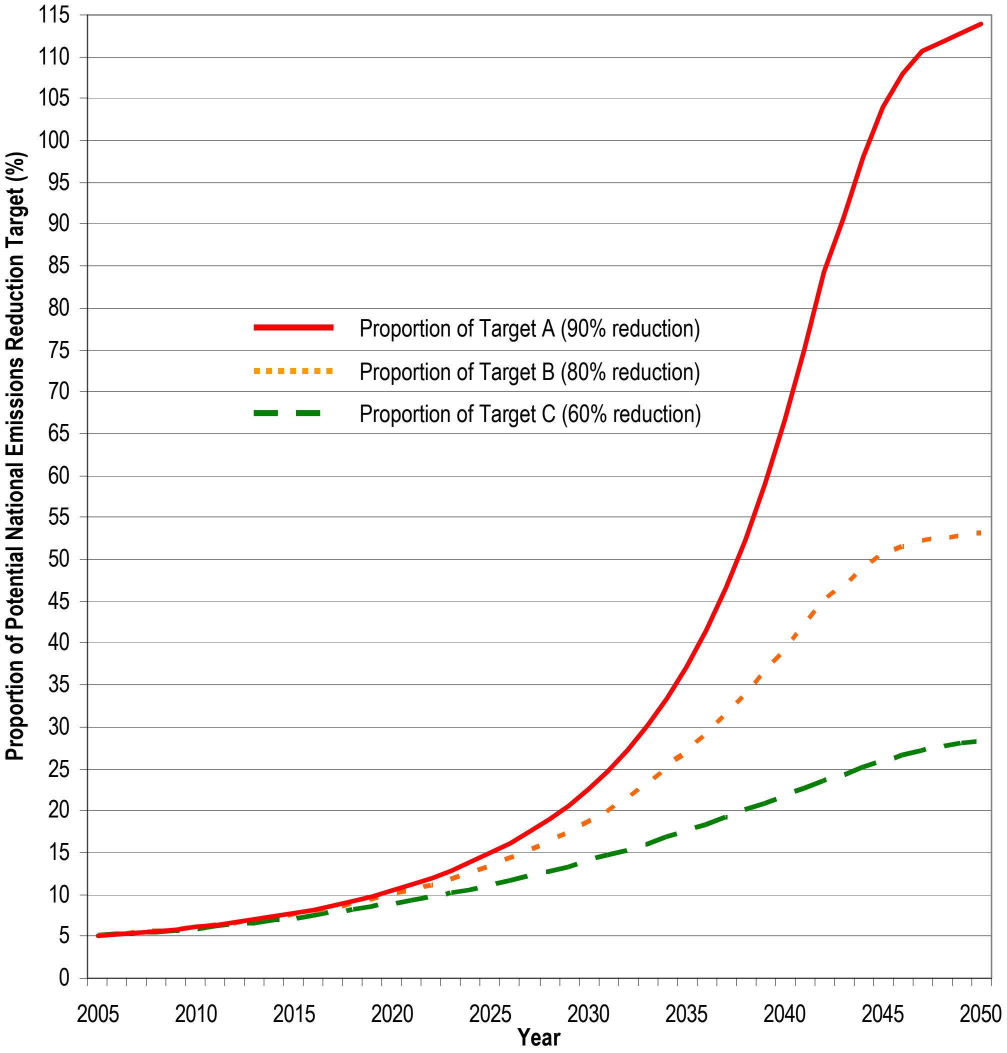

Figure 8 – Potential BAU carbon liability from landfilling solid waste as a proportion of national carbon budget (no oxidation factor and GWP for methane of 25)

The potential carbon liability arising from the revised estimate of BAU disposal of materials with degradable organic carbon, such as food, paper, garden and wood waste, ranges from 28 to 114 per cent of Australia's carbon budget at 2050 (up from 21 to 85 per cent in Section 5.2).

7.7 Appendix 7 – Potential BAU Carbon Liability from Landfilling Solid Waste on a per Tonne Basis

The potential carbon liability arising from the BAU disposal of materials with degradable organic carbon, such as food, paper, garden and wood waste, was presented in Figure 7 (Section 5.2) on a proportional basis). The same information is presented in tonnes in the figure below.

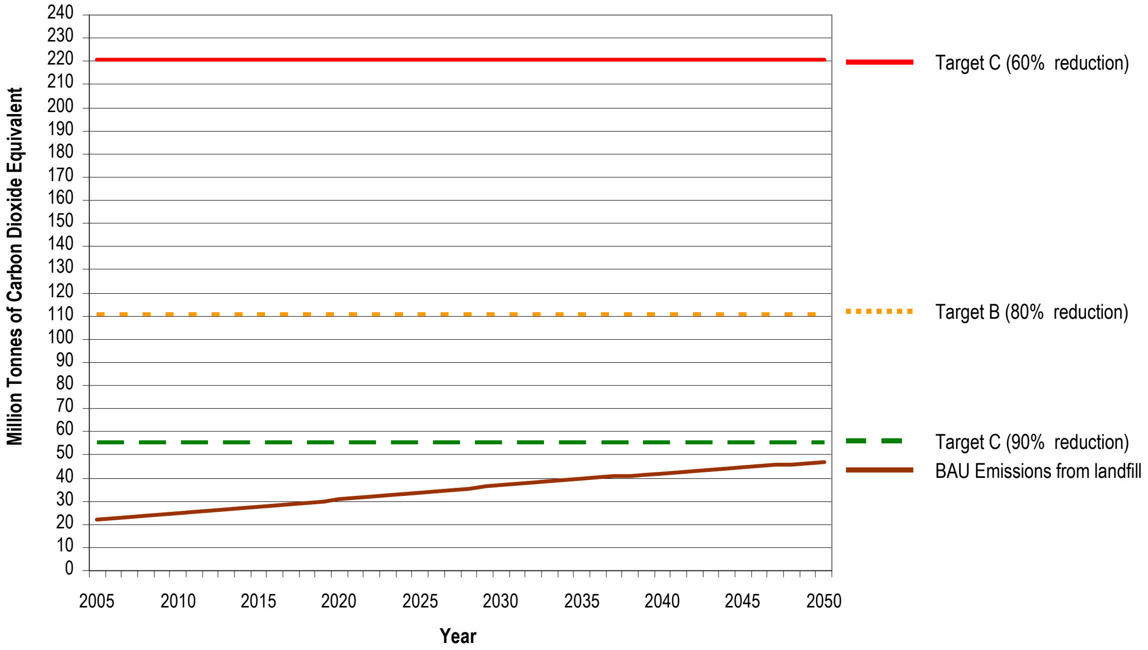

Figure 9 – Potential BAU carbon liability from landfilling solid waste (in tonnes)