LCA of Kerbside Recycling in Victoria

Final Issue

Prepared for:

Sustainability Victoria

Contact: Marcus Fogarty

Issue: 30 October 2015

Version: 1.3

Authors:

Mr. Andrew Carre[1], Dr. Enda Crossin[2], Dr. Stephen Clune[3]

1. School of Property, Construction and Project Management, RMIT University
PO Box 2476, Melbourne VIC 3001, Australia
Tel: + 61 3 9925 3903

2. School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University
PO Box 71 Bundoora VIC 3083, Australia
Tel:+ 61 3 9925 9085

3. Lancaster Institute for the Contemporary Arts, Lancaster University
The LICA Building, Lancaster University, Lancaster LA1 4YW, United Kingdom
Tel: + 44 (0) 1524 510792

QA Review

Reviewed by	Date
Dr. Enda Crossin	11/6/2013
Dr. Enda Crossin	31/7/2013

Release and Revision Record

Revision Date	Release/Revision Description	Doc Version
3/7/2013	Response to initial feedback.	1.0
31/7/2013	Response to LCA reviewer feedback.	1.1
19/9/2013	Minor formatting and edits. Release to client.	1.2
30/10/2015	Public release.	1.3

Table of Contents

1 Executive summary 4
2 Introduction 9
2.1 Acknowledgements 9
2.2 Purpose of this report 10
3 Background 11
3.1 Terminology 11
3.2 Recycling in Australia and Victoria 11
3.3 The 'Packwaste' reports 14
3.4 Other reports 16
3.5 Alternative waste treatments 16
3.6 Summary of key outcomes from the literature 17
4 Goal of the study 18
4.1 Goal 18
4.2 Intended audience 18
4.3 Critical review 18
4.3.1 Review process completed 19
5 Scope 19
5.1 Description of systems under investigation 19
5.2 Functional unit 20
5.2.1 Reference flow 20
5.2.2 Materials excluded from the study 21
5.2.3 The Recycling System 22
5.2.4 The Alternative System 22
5.3 System boundary 22
5.4 Data quality requirements 24
5.4.1 Strategies employed to address data quality requirements 24
5.5 Data collection 25
5.6 Use of the Pedigree Matrix 25
5.7 Allocation procedures 26
5.8 Impact Assessment Method 27
6 Methodology 28
7 Study Limitations 29
8 Inventory 30
8.1 Inventory sub-systems 34
8.1.1 Collection 35
8.1.2 Landfill 36
8.1.3 Sorting – Materials Recovery Facility 41
8.1.4 Treatment of garden and green waste 42
8.1.5 Treatment of waste paper 43
8.1.6 Treatment of waste glass 44
8.1.7 Treatment of waste aluminium cans 46
8.1.8 Treatment of waste steel cans 48
8.1.9 Treatment of waste PET, HDPE and mixed plastics 50
8.2 Key assumptions for each material 56
8.3 Resulting Elementary flows 60
9 Results 61
10 Discussion 63
10.1 Directional conclusions 63
10.2 Global warming 64
10.3 Eutrophication 65
10.4 Photochemical Oxidation 66
10.5 Minerals Depletion 67
10.6 Fossil Fuels Depletion 68
10.7 Land Use 69
10.8 Water Use 70
10.9 Solid Waste 71
10.10 Cumulative Energy Demand 72

11 Validation ... 74
11.1 Comparison to the prior study ... 74
11.2 Sensitivity analysis ... 76
11.2.1 Collection system fuel consumption ... 76
11.2.2 International reprocessing ... 77
11.2.3 Garden and green waste assumptions ... 78
11.2.4 Glass cullet recovery rate ... 78
11.2.5 Methane capture and carbon storage in landfill ... 79
11.3 Consequential analysis ... 80
11.3.1 Introduction ... 80
11.3.2 Market assessment ... 81
11.3.3 Discussion ... 85
11.3.4 Conclusions to Consequential Analysis ... 87
12 Conclusion ... 89
13 Glossary ... 91
14 References ... 93
14.1 Databases ... 93
14.2 Literature ... 93
Appendix A – Life Cycle Assessment and Recycling ... 97
1.1. LCA Methodology ... 97
1.2. Goal and scope definition ... 98
1.3. Inventory analysis ... 98
1.4. Impact assessment ... 98
1.5. Interpretation ... 98
2. The application of LCA to studies of recycling ... 99
2.1. Allocation and partitioning ... 99
2.2. Consequential versus attributional perspectives ... 99
2.3. Characterising environmental impacts ... 101
2.4. More recent recycling LCA's ... 102
Appendix B – Inventory Report ... 104
Appendix C – Detailed Results by Material ... 105
Appendix D – Impact Assessment Method (Factors) ... 108
Appendix E – Reviewer comments ... 120
Appendix F – Reviewer letter ... 127

1 Executive summary

This report was commissioned by Sustainability Victoria (SV) in order to assess the life cycle impacts of kerbside recycling in Victoria using the Life Cycle Assessment (LCA) methodology. The report seeks to assess the net environmental benefits/burdens of recycling activity in Victoria, building upon the previous study "Stage 2 Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria" (Grant et al., 2001a). This objective is addressed by utilising the life cycle assessment methodology, as defined by ISO14044, to assess the potential environmental benefits/burdens of recycling versus an alternative approach involving landfill.

This life cycle study is limited to domestic waste that is collected from the kerbside in Victoria. In determining the benefits of the recycling system it is necessary to consider both the existing recycling system as well as an alternative system that might exist if recycling did not take place: the Recycling System and the Alternative System. Whereas the nature of the Recycling System can be established by looking at the existing recycling process, the nature of the Alternative System is not so clearly defined. It has been assumed that in the absence of recycling Victorians would most likely dispose of most waste materials to landfill. The Alternative System, therefore, represents a waste treatment system similar to that currently used for non-recyclable garbage.

In assessing the benefits/burdens of recycling in Victoria, the following functional unit was defined:

> "The management of recyclable[1] materials discarded at kerbside from the average Victorian household in one year"

The calculation of recycling benefits was undertaken using the model shown in Figure 1, adapted from (Grant et al., 2001a):

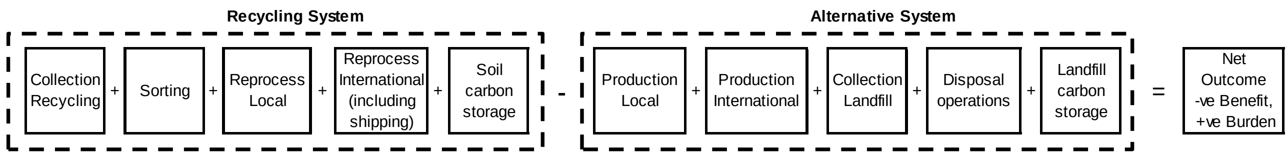


Figure 1 Definition of recycling benefit adapted from Grant et al (2001a).

A detailed inventory of the Recycling System and the Alternative System described above was developed based upon a mix of primary and secondary data sources. A summary of the key assumptions is shown in Table 1.

The inventory developed incorporates a range of data qualities, each of which were assessed using a pedigree matrix, and the aggregate uncertainty determined using Monte Carlo analysis. This approach facilitated the presentation of result ranges, within which 95% of simulation outcomes occurred. This approach helps place into context the point results shown in Table 3. Wider ranges indicate higher result uncertainty, and tighter ranges indicate lower uncertainty.

The largest uncertainty in the study is associated with the treatment of garden and green waste which undergoes processes with wide ranging potential outcomes. Development of the Alternative System was most challenging as it involved attempting to quantify the range of benefits provided by composted products, then replicating those benefits using synthetic means in order to achieve system comparability.

Another key area of uncertainty was associated with the destination of materials collected by sorting facilities and their level of contamination. These data were not provided by operators consulted and had to be estimated using third-party reports (WRAP, 2009).

---

[1] Recyclable materials in this context refers to those materials currently deposited into recycling bins, as opposed to garbage bins, and processed by the recycling system.

Table 1 Summary of inventory assumptions.

Inventory sub-system	Recycling System	Alternative System
Collection	Fuel use for collection 12.3 l/t overall. Allocated to materials based on their in-truck specific volume.	Fuel use for collection 18.3 l/t overall. Allocated to materials based on their in-truck specific volume.
Landfill	Very little landfill considered (only that relating to contamination of recycling streams and reprocessing system wastes). Where considered assumptions as per the Alternative system.	Landfill model developed that considers facility construction and operation; greenhouse gas emissions due to material degradation and that water born emissions due to leachate. Key greenhouse gas assumptions include: Timeframe: 100 years; Methane capture rate: 57%; Methane combustion for energy: 92% of capture; Carbon storage: Carbon stored in landfill according to material specific factors
Sorting	Sorting was estimated to require 30 kWh of electricity per tonne of waste sorted (including glass colour sorting). 1.2 litres LPG gas was estimated for forklift operation. Sorting yields were estimated from U.K. data for facilities targeting similar materials (WRAP, 2009).	No sorting incorporated.
Treatment of garden and green waste	Assumes that all garden and green waste is processed using windrow composting. Once processed, 25% of composted products are utilised in agriculture applications and 75% of products are used in urban amenity applications. Carbon is assumed to be stored in soil under the agriculture applications, and not stored under urban applications. It is recognised that significant uncertainty exists in this area.	50% of garden and green waste is assumed to be treated in landfill, 25% is open burned and 25% is home composted. Additional benefits provided by compost in agriculture are assumed to be provided by synthetic feritilsers, herbicides and by additional water application. Quantities of these materials have been estimated using Recycled Organics Unit (2007).
Treatment of waste paper	Waste paper collected is assumed to be reprocessed into packaging paper, both within Australia (56%) and internationally (China, 44%). Reprocessing within Australia is assumed to be undertaken in a manner similar to that operated at Amcor's Botany paper plant. The inventory is based upon published data for the Botany plant, complemented by European data. For the China inventory, this process is adjusted to incorporate the use of coal for heat in place of natural gas.	Waste paper is assumed to be treated in landfill. Packaging paper production (equivalent to that produced by the Recycling System) is assumed to be via the Kraft process, similar to that employed by Visy at Tumut for packaging paper production. The inventory is based upon published data for the Tumut facility. The inventory is modified for paper production in China, to incorporate coal as the primary heat source, in place of gas. Quantities of materials produced through each inventory are equivalent to those produced by the Recycling System. Carbon stocks in forests and forests products are assumed to remain constant across the life cycle.
Treatment of waste glass	85% of waste glass collected at the kerbside is assumed to be reprocessed into glass packaging and the balance into aggregate substitute products (sands). All glass packaging is assumed to be reprocessed locally in Melbourne. The process inventory adopted is based upon a survey of German glass producers, which correlates well to key data elements published by the local industry (such as greenhouse gasses per tonne).	Waste glass is assumed to be processed in landfill. Packaging glass production is assumed to be produced locally using the same inventory as for the Recycling System. The inventory is adjusted to remove recycled cullet and increase raw materials and energy, in accordance with published ratios. Aggregate products are assumed to be provided by sand, which is mined locally. A sand mining operation from Queensland is used as the basis for the inventory.
Treatment of waste aluminium cans	48% of waste aluminium cans are assumed to be reprocessed at Yennora in NSW, and 52% are assumed to be reprocessed in South Korea. The reprocessing inventory is a European inventory, utilising similar technology to Yennora, and that correlates well with data fragments published for the Yennora facility. The Korea inventory is similar to Australia, however energy sources (electricity and natural gas) have been adjusted to suit Korean conditions.	Waste aluminium cans are assumed to be disposed of to landfill. Aluminium is assumed to be produced at the same quantity as the Recycling System, using a process inventory based upon Australian producer information, which is adjusted for recent improvements in perflourocarbon emissions. As no primary aluminium production occurs in South Korea, it is assumed that a quantity of aluminium is shipped from Australia to Korea to achieve functional equivalence to the Recycling System.
Treatment of waste steel cans	41% of steel cans recovered are assumed to be reprocessed locally whin Victoria in Electro Arc Furnaces (EAFs). 59% of steel cans are assumed to be shipped to Malaysia where it is assumed they undergo a de-tinning process prior to EAF melting to produce steel products. The EAF reprocessing inventory is based upon a study of Australian steel makers (Energetics, 2012). For Malaysia the Australian inventory is adjusted to suit local energy supplies and to incorporate a de-tinning process.	Waste steel cans are assumed to be processed in landfill. Steel quantities, as produced by the Recycling System, are assumed to be produced by the Blast Furnace – Basic Oxygen Steelmaking (BF-BOS) process. The inventory is based upon a published inventory of Australian steelmaking (Energetics, 2012). All steel is assumed to be produced in Australia, with a portion shipped to Malaysia to achieve functional equivalence to the Recycling system (steel is not generally produced from virgin resources in Malaysia).
Treatment of waste plastics	Homogeneous waste plastic streams (PET and HDPE) are assumed to be processed locally (46%) and internationally (China, 54%). Reprocessing is assumed to involve a cleaning and repelletisation process, similar to that modelled by (Franklin Associates., 2010) for U.S. processors. Mixed streams (including coloured HDPE) are assumed to be reprocessed entirely in China. Reprocessing is assumed to be largely manual (which are excluded from the LCA), with included burdens similar to those for homogeneous HDPE. It is acknowledged that reprocessing for these streams is highly uncertain.	Waste plastics are assumed to be treated in landfill. Unlike the other inventories above, plastics production is assumed to be produced through a generic inventory (utilising virgin feedstocks) for each plastic type produced by the Recycling System. These inventories are from the Ecoinvent database and are based upon data produced by Plastics Europe. They are not adjusted for regional energy supplies, and are used as is. Although the regional appropriateness of the datasets is questionable, their overall data quality is believed to be higher than if regional data sets were used, which have varying data qualities.

The inventory developed above was analysed using an impact assessment method generating the results shown in Table 3. The impact assessment method considered global warming, eutrophication, photochemical oxidation, minerals depletion, fossil fuels depletion, land use, water use, solid waste and cumulative energy demand, as shown in Table 2. Global warming, eutrophication, photochemical oxidation, minerals depletion, fossil fuels depletion could all be considered indicators of environmental impact, however the remaining indicators are more correctly considered pre-cursor indicators that may or may not indicate environmental impact. For example, cumulative energy demand tells us what quantum of primary energy is being used by a system, it does not tell us if that that energy has come from fossil or renewable sources. Therefore, the exact nature of the environmental impact is unknown.

The indicators chosen (Table 2) were selected to assess a range of issues that recycling would be likely to affect. They were also chosen to maintain consistency and comparability with the previous LCA study (Grant et al., 2001a), and due to known inventory constraints. Human toxicity and ecotoxicity were excluded as their inclusion would have involved significant additional inventory development.

Table 2 Characterisation method employed.

Indicator	Description
Indicators of environmental impact	
Global warming	Climate change effects resulting from the emission of carbon dioxide (CO_2), methane or other global warming gases into the atmosphere – this indicator is represented in CO_2 equivalents. Factors applied to convert emissions of greenhouse gas emissions into CO_2 equivalents emissions are taken from the IPCC Fourth Assessment Report (2007). The values used are based on a 100 year time horizon.
Photochemical oxidation	Measurement of the increased potential of photochemical smog events due to the chemical reaction between sunlight and specific gases released into the atmosphere. These gases include nitrogen oxides (NOx), volatile organic compounds (VOCs), peroxyacyl nitrates (PANs), aldehydes and ozone. This indicator is of importance in areas where photochemical smog is likely to be a problem, such as in urban transport environments.
Eutrophication	Eutrophication is the release of nutrients (mainly phosphorous and nitrogen) into land and water systems, altering biotopes, and potentially causing oxygen depletion effects such as increased algal growth. Factors applied to convert emissions into PO_4^{3-} equivalents are taken from the CML impact assessment method from 2000 (CML baseline 2000 all impact categories V2.04).
Mineral resource depletion	The additional investment required to extract minerals resources due to depletion of reserves, leaving lower quality reserves behind, which will require more effort to harvest. Factors to convert raw material inputs into $ equivalents are taken from the ReCiPe method (Version 1.07 - July 2012, © PRé Consultants, Radboud University Nijmegen, Leiden University, RIVM, www.lcia-recipe.net).
Fossil fuel depletion	The additional investment required to extract fossil fuel resources to depletion of reserves, leaving lower quality reserves behind, which will require more effort to harvest. Factors to convert raw material inputs into $ equivalents are taken from the ReCiPe method (Version 1.07 - July 2012, © PRé Consultants, Radboud University Nijmegen, Leiden University, RIVM, www.lcia-recipe.net).
Precursors to environmental impact	
Cumulative energy demand	All energy use including fossil, renewable, electrical and feedstock (energy incorporated into materials such as plastic).
Solid waste	Net solid waste generated. Total of all solid waste generated by the processes considered.
Land use	Gross land use for unit processes under consideration. Actual environmental impact is not assessed.
Water use	Gross water use. Total of all water used by the processes considered. The use of water in hydropower plant is excluded.

The inventory developed was entered into the Sima Pro modelling software and a characterisation result developed, employing the impact assessment method described above. The result represents the fundamental result of the study, showing the impacts for each impact category for the provision of one functional unit. The result reported is the net outcome described by Figure 1 – the net benefit of recycling. Results that are negative reflect benefits and results that are positive indicate burdens (Table 3).

Table 3 Characterisation result for 1 functional unit (including garden and green waste). Results rounded to two significant figures.

Net Outcome -ve Benefit, +ve Burden	Mass collected	GW	EU	PO	MD	FFD	LU	WU	SW	CED
	*kg per year**	kg CO2 eq	kg PO4--- eq	kg NMVOC	$	$	ha.a	kL H2O	kg	MJ LHV
Glass bottles	*72*	-38	-0.026	-0.17	0.0096	-0.39	-0.000021	-0.067	-79	-320
Steel cans	*8*	-14	-0.0028	-0.032	-0.83	-0.14	0.000014	-0.34	-7.1	-120
Alum. Cans	*3*	-50	-0.023	-0.23	-0.06	-0.69	-0.00023	-0.088	-14	-620
Paper - white	*1*	-1.3	-0.0021	-0.0041	0.00025	0.012	-0.00014	-0.011	-0.5	0.68
Paper - mixed	*110*	-50	-0.2	-0.2	0.027	0.97	-0.016	-1.2	-73	-40
Paper - card	*45*	-7.6	-0.072	-0.073	0.011	0.38	-0.0064	-0.5	-31	-21
Plastic - PET	*8*	-9.6	-0.022	-0.021	-0.1	-0.46	-0.0000068	-0.55	-7.9	-440
Plastic - HDPE	*4*	-3.3	-0.00016	-0.019	0.0011	-0.23	0.000014	-0.091	-3.6	-200
Plastic - HDPE (col)	*3*	-2.4	0.0002	-0.012	0.00097	-0.17	0.000011	-0.067	-2.7	-150
Plastic - mixed	*8*	-2.5	0.00034	-0.0097	0.0027	-0.27	0.000028	-0.21	-7.3	-240
Garden and green	*304*	-68	-0.037	-0.44	-0.0015	0.28	0.000066	-1.7	-51	94
Total System	***566***	**-250**	**-0.38**	**-1.2**	**-0.94**	**-0.72**	**-0.022**	**-4.9**	**-280**	**-2100**
Uncertainty										
2.5 percentile	*566*	-340	-0.68	-2.3	-1.1	-1.7	-0.046	-7.3	-280	-3200
97.5 percentile	*566*	-130	-0.19	-0.47	-0.79	1.2	-0.0091	-2.8	-260	4.2

GW-Global Warming, EU-Eutrophication, PO-Photochemical Oxidants, MD-Mineral Depletion, FFD-Fossil Fuel Depletion, LU-Land Use, WU-Water Use, SW-Solid Waste, CED-Cummulative Energy Demand.

The study determined that the existing materials recycled by Victorians generate a net environmental benefit versus the Alternative System, as shown in Table 3. Each indicator considered achieved a favourable outcome versus the alternative.

Materials collected contributed different amounts to different indicators. Global warming benefits were primarily driven by garden and green waste recycling followed by paper, aluminium and glass recovery. Water use benefits were largely driven by garden and green waste recovery and paper recovery. Energy benefits were seen to come mostly from aluminium recovery, which is notable given aluminium represents less than 1% of materials recovered.

In addition, each material recycling system was assessed individually, with the majority achieving beneficial outcomes in all indicators considered (Table 4). Instances where recycling did not achieve beneficial outcomes in all indicators were associated with paper recycling where fossil fuels depletion, mineral depletion and cumulative energy demand (white paper only) were more intense when recycling paper versus the landfill system. This outcome is due to the fossil fuels intensity of paper recycling versus production of paper from fibre derived from forests (much of which is powered by biomass). Garden and green waste recycling had an adverse outcome in fossil fuels depletion as well due largely to the avoidance of energy generated from landfill (from landfill gas combustion). Plastics recycling was also seen to have slightly adverse outcomes in the eutrophication, minerals depletion and land use indicators.

Table 4 Characterisation for 1 t of each material collected (rounded to 2 significant figures).

Net Outcome -ve Benefit, +ve Burden	Mass collected	GW	EU	PO	MD	FFD	LU	WU	SW	CED
	tonnes	kg CO2 eq	kg PO4--- eq	kg NMVOC	$	$	ha.a	kL H2O	kg	MJ LHV
Glass bottles	*1*	-530	-0.36	-2.3	0.13	-5.5	-0.00029	-0.94	-1100	-4500
Steel cans	*1*	-1700	-0.35	-4	-100	-18	0.0018	-42	-880	-15000
Alum. Cans	*1*	-17000	-7.7	-76	-20	-230	-0.078	-29	-4700	-210000
Paper - white	*1*	-1300	-2.1	-4.1	0.25	12	-0.14	-11	-500	680
Paper - mixed	*1*	-450	-1.8	-1.8	0.24	8.8	-0.14	-11	-660	-360
Paper - card	*1*	-170	-1.6	-1.6	0.24	8.5	-0.14	-11	-680	-470
Plastic - PET	*1*	-1200	-2.8	-2.6	-13	-57	-0.00084	-69	-990	-55000
Plastic - HDPE	*1*	-840	-0.041	-4.7	0.28	-58	0.0035	-23	-910	-51000
Plastic - HDPE (col)	*1*	-790	0.067	-4	0.32	-57	0.0036	-22	-910	-50000
Plastic - mixed	*1*	-320	0.043	-1.2	0.34	-34	0.0036	-26	-910	-29000
Garden and green	*1*	-230	-0.12	-1.5	-0.005	0.93	0.00022	-5.7	-170	310

Finally, a consequential analysis was undertaken. Under the base analysis it is assumed that all impacts caused by the system can be attributed to unit processes within the system. This approach assumes that the system is in ‘steady state’ and has achieved equilibrium. The approach is useful in undertaking quantification of a system ‘as is’ but can be problematic if the objective of the research is to understand how a system will respond to change. A common question with recycling is ‘what will happen if we do more recycling’. This question is not adequately addressed by an attributional model, because such a model does not consider the dynamic behaviour of the system if disturbed. For this reason, the attributional study was complemented by a consequential analysis that seeks to predict what might actually happen if recycling rates were to increase. The analysis utilised economic data to assess possible supply bottlenecks that could erode benefits achievable from increased recycling.

Overall the consequential analysis concluded that in the short-term future, recycling of material from the kerbside will continue to displace virgin material production. The displacement of virgin production is sensitive to the demand for end-products, as well as the economic viability of producing recyclate. The forecast for the local demand of these end-products is uncertain, particularly for glass packaging and aluminium cans. Although large global markets exist for aluminium recyclate, recovered glass cullet is not considered a viable product for export. The recycling benefits of glass are therefore dependent upon local production capacity.

The review also found that China's "Green Fence" policy could force additional infrastructure and processing costs upon local Material Recovery Facilities (MRFs), meaning that in the future, the generation of clear polyethylene terephthalate (PET), clear high density polyethylene (HDPE), mixed plastics and mixed paper and cardboard recyclate streams for export could become uneconomical. If this occurs, then these streams could be considered waste, meaning that environmental benefits associated with virgin production and landfill avoidance may not apply.

In the short term, however, the consequential analysis concluded that the recovery of all the materials assessed would most likely lead to the displacement of material production from virgin resources.

Overall, the study verified that recycling in Victoria generates a net environmental benefit for the state, in terms of the indicators considered. It also developed a platform upon which future studies of recycling can refer to quantify key environmental outcomes.

2 Introduction

This report has been commissioned by Sustainability Victoria (SV) in order to assess the life cycle impacts of kerbside recycling in Victoria using the Life Cycle Assessment (LCA) methodology. SV undertakes annual surveys of waste management across local governments in Victoria. As part of these reports, data from RMIT University's Centre for Design's (CfD) 2001 study (Life Cycle Assessment for Paper and Packaging Waste Management in Victoria) has been used to report on the environmental benefits of recycling. The management of waste across the state has changed substantially since 2001. For instance recyclables are now generally collected in comingled form, whereas they were mainly collected in separate streams in 2001, and reprocessing used to be largely undertaken locally in Victoria, whereas now a considerable fraction of reprocessing is undertaken internationally. As such, a new life cycle assessment (LCA) was identified as necessary in order to better reflect current environmental impacts and benefits of kerbside recycling in Victoria.

In addition to quantifying the impacts of the recycling system, the study seeks to:

- Identify processing impacts and constraints (bottle-necks or barriers) within the recycling supply chains;
- Identify the environmental impacts of transport;
- Better-inform the establishment of waste metrics

Although not a specific aim of this project, it is anticipated that the study may be used to inform potential waste policy in the future.

2.1 Acknowledgements

The authors would particularly like to thank the Stakeholder Review Panel (SRP) that provided their time to collectively review and discuss the reports as they were developed. The feedback provided by the panel has been invaluable. The SRP included:

Alwyn Babb (Hume City Council)
Dom Tenace (SKM)
Joe Pickin (Blue Environment)
Kel Dummett (Sustainability Victoria)
Marcus Fogarty (Sustainability Victoria)
Michael Wood (Enviromix)
Miro Krmpotic (Huhtamaki Group)
Nancy Wei (Visy)
Nick Chrisant (Sustainability Victoria)
Robert Francis (SITA Australia)

In addition to the SRP, we would also like to thank the following people who spent time and effort explaining industry systems, providing data and discussing future directions. Your help was critical to ensuring that models developed accurately reflected the situation in Victoria.

Bernie Maddern (West Wimmera Shire)
Neville Bond (Dasma Group)
Craig Hudson (CR Hudson and Associates)
Enzo Valente (City of Yarra)
Gary Combes (Owens Illinois)
John Williams (Hume City Council)
Joshua Russell (Murrindindi Shire)
Lillias Bovell (Publishers National Environment Bureau)
Peter Whittle (City of Yarra)
Robyn Evans (West Wimmera Shire)
Sally Stewart (Glen Eira City Council)
Sam DiGiovanni (Boroondara City Council)
Steve Balmforth (Norske Skog)

2.2 Purpose of this report

This report follows the issue of four prior reports:

a) Literature review and initial scoping Report, issued to SV only
b) Draft Goal and Scope Report, issued to SRP
c) Final Goal and Scope Report, incorporating SRP feedback
d) Draft Report for SRP consideration

This fifth and final report is intended to present final findings of the study, incorporating feedback from the SRP and other reviewers.

3 Background

The following literature review addresses the existing body of knowledge regarding quantification of environmental benefits attributable to recycling.

3.1 Terminology

It is worthwhile drawing attention to the issue of language and the definition of terms. The discussion of recycling requires defining terms which are often used inappropriately. As an example, the terms ‘recycling’, ‘recyclate’, ‘waste’ all mean slightly different things to different people. To avoid confusion in discussing recycling, glossaries from key reports (DEWHA and EPHC, 2010, Sustainability Victoria, 2012b) have been used to create a glossary of terms to be used in this report. In some cases, where conflict exists regarding a term, such as ‘recyclate’ a base definition has been selected.

3.2 Recycling in Australia and Victoria

Waste disposal practices in Australia are effectively characterised in Hyder Consulting (2009), which incorporates data provided by state agencies such as SV. Table 5 describes per capita generation of municipal waste for Australia versus comparable countries. The table illustrates that, amongst the group selected, Australia fairs better than some when it comes to diversion of generated waste, however opportunity still exists to increase diversion rates (Figure 2). This table also provides an opportunity to illustrate the use of terms. The use of the term ‘recycled’ here actually means ‘recovered for recycling’ or ‘diverted from waste’ – the term ‘recycled’ infers that materials may have been reprocessed, which is not the intended meaning in this context.

Table 5 Per capital municipal solid waste generated disposed of and recycled per annum 2006/07 (Hyder Consulting, 2009).

Country	Disposed (kg)	Recycled (kg)	Generated (kg)	Diversion rate
Canada	292	118	411	29%
United States	625	302	927	33%
Germany	215	341	555	61%
England	398	176	574	31%
Australia	364	242	606	40%

Both Table 5 and Figure 2 below illustrate that opportunity exists to increase municipal solid waste (MSW) diversions from landfill in Australia.

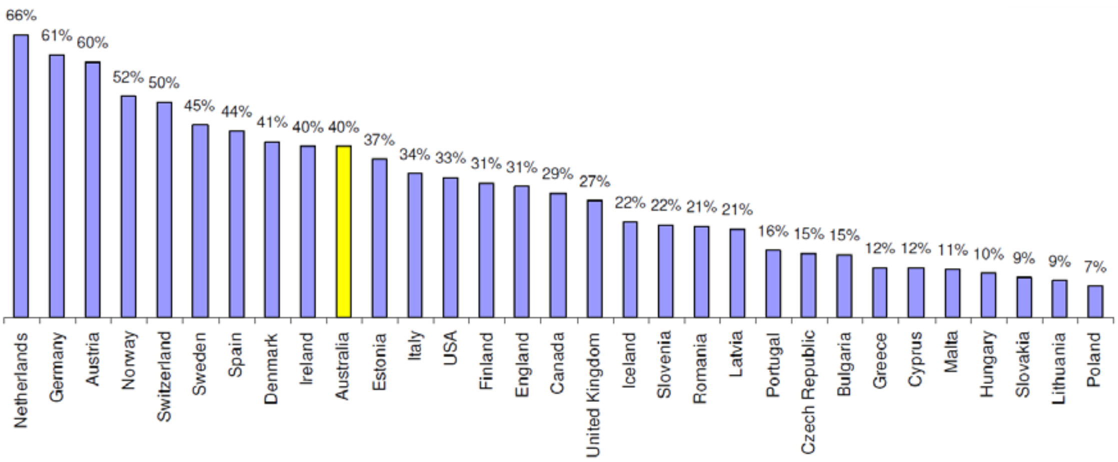


Figure 2 Diversion rate for municipal waste 2006/07 (Hyder Consulting, 2009). Australia is highlighted in yellow.

Table 6 describes national waste disposal, diversion (‘recycled’ in the table) and generation rates by state. The table shows that, in 2006/07, Victoria generated 10,285,000 t of waste, of which 6,360,000 t were diverted from landfill. This equates to a diversion rate of 62% across all sectors. In their 2012 strategic plan Sustainability Victoria has committed to increase this diversion rate to 75% by 2015, as well as committing to reduce total waste generated within the state, Figure 3 (2012).

Increased recovery of resources (75% recovered for reuse, recycling or energy generation)	Arrested / reduced growth in waste generated (1.5 million tonnes reduced)	Reduced littering (25% reduction in littering behaviours cf 2003)

Figure 3 Sustainability Victoria's recovery objectives (Sustainability Victoria, 2012).

As the focus of this study is on kerbside recycling, it is worth considering the municipal waste sector which is composed predominantly of collected kerbside waste[2]. In Victoria, in 2006/07, 1,056,000 t of municipal waste were diverted from landfill of a total of 2,783,000 t generated, equating to a 38% diversion rate, slightly lower than the national diversion rate of 40% Table 6 (Victorian and municipal sectors highlighted).

Table 6 Waste generation by sector across the states of Australia 2006/07 (Hyder Consulting, 2009). Victorian state results, and municipal sector results highlighted.

State / territory	Disposed ('000 tonnes)				Recycled[1] ('000 tonnes)				Generated ('000 tonnes)			
	Municipal	C&I	C&D	Total	Municipal	C&I	C&D	Total	Municipal	C&I	C&D	Total
NSW	2,408	2,921	2,036	7,365	1,483	2,297	4,216	7,995	3,891	5,218	6,251	15,360
VIC	1,727	1,060	1,138	3,925	1,056	2,357	2,946	6,360	2,783	3,417	4,084	10,285
QLD[2]	1,735	1,101	1,466	4,302	1,365	1,797	617	3,779	3,100	2,898	2,083	8,081
WA[3]	1,015	585	1,939	3,539	408	891	409	1,708	1,424	1,476	2,348	5,247
SA[4]	344	496	304	1,144	408	610	1,155	2,173	753	1,106	1,460	3,318
ACT[5]	85	91	21	197	278	102	206	587	363	194	227	784
TAS[6]	287	145	14	446	53	22	0	75	340	167	14	521
NT[7]	44	57	51	151	30	Unknown	Unknown	30	74	57	51	181
Australia	7,645	6,456	6,968	21,069	5,082	8,076	9,549	22,707	12,727	14,532	16,517	43,777

From a Victorian perspective, SV has undertaken its own reporting that shows that waste diversion rates have increased from 62% in the 2006/07 timeframe to 66% in the 2009/10 timeframe (Figure 4).

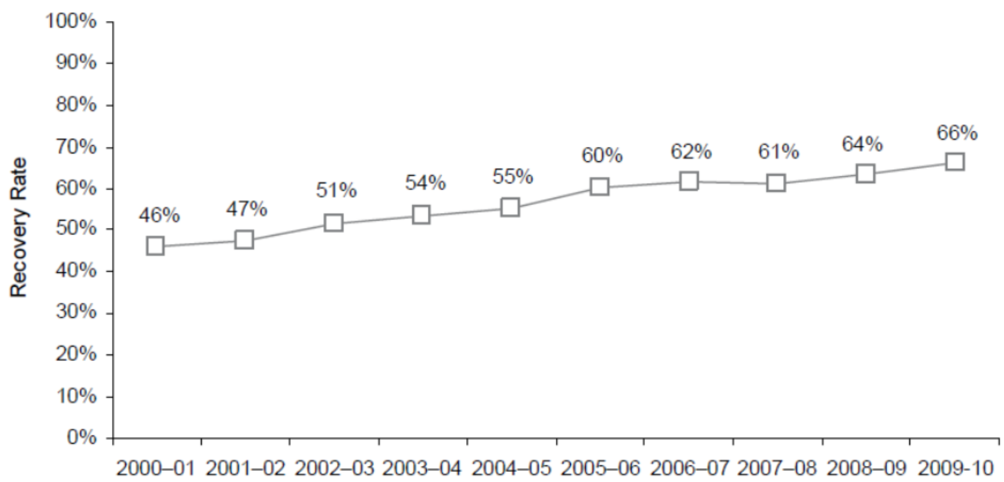


Figure 4 Resource recovery rate of solid waste (Sustainability Victoria, 2011b).

---

[2] The reports considered indicate municipal waste is largely composed of kerbside collected waste, however it also includes waste collected/generated at council depots.

Sustainability Victoria (2011b) presents the breakdown of the total waste diversion rate in a manner that makes it difficult to discern the total waste disposed of by the municipal sector, making it impossible to calculate a municipal diversion rate comparable to the 38% rate described in (Hyder Consulting, 2009).

Utilising Sustainability Victoria (2011a) data, it is possible to directly calculate a diversion rate for kerbside services provided state-wide in 2009/10. This shows that 44% of waste disposed of at the kerbside is currently diverted from landfill. This figure includes organic materials. It is unclear if the reported total kerbside waste of 1,987,618 t includes hard rubbish disposal (external to provided bins) of 71,000 t (potentially 3.5% of total waste disposed-of at the kerbside).

Table 7 Kerbside waste collected by local government 2009/10 (Sustainability Victoria, 2011a).

<table>
<tr><th>Stream</th><th>Mass (t)*
2009/10</th><th>Diversion
2009/10</th><th>Memo: Diversion 2006/07</th></tr>
<tr><td>Garbage (disposed to landfill)</td><td>1,056,641</td><td>NA</td><td>NA</td></tr>
<tr><td>Recyclables</td><td>613,141</td><td rowspan="2">44%</td><td rowspan="2">42%</td></tr>
<tr><td>Organic waste</td><td>317,836</td></tr>
<tr><td>Total</td><td>1,987,618</td><td>NA</td><td>NA</td></tr>
</table>

*Figures shown taken from (Sustainability Victoria, 2011a p.17).

The total yield of recyclables is stated as 283 kg per household per year, which includes 21kg (7.5%) of contamination (Sustainability Victoria, 2011a).

Sustainability Victoria (2011a), breaks the contents of the kerbside recyclables waste stream down by material type (excluding contamination), as shown in Figure 5. Figure 5 provides the basis for investigating the life cycle impacts of reprocessing systems.

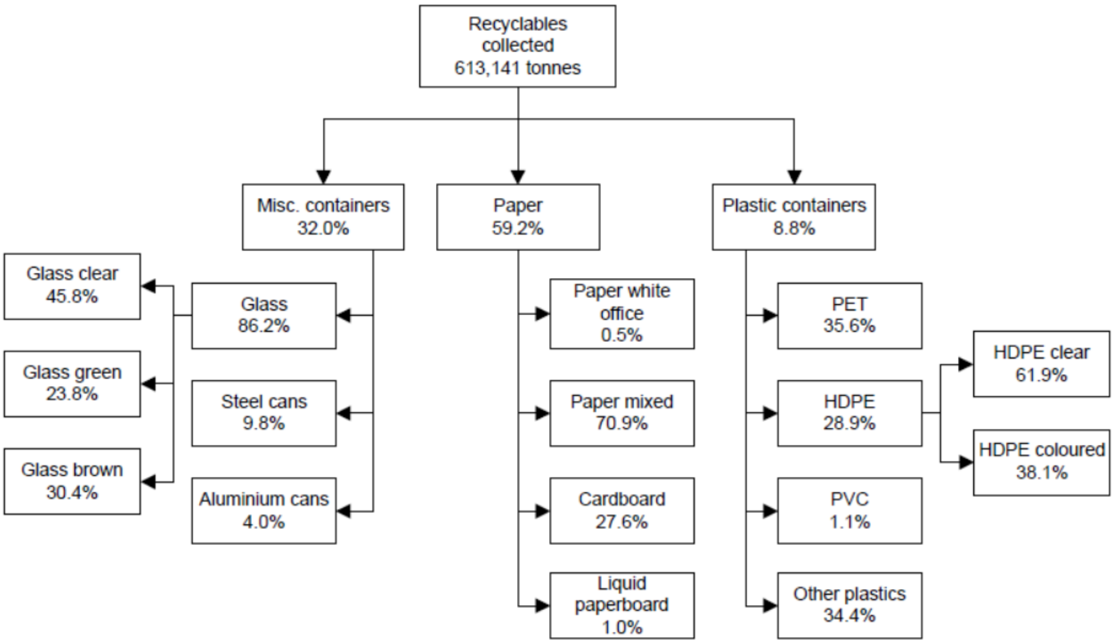


Figure 5 Kerbside recyclables by type of item collected 2009/10 (Sustainability Victoria, 2011a). Percentages shown are on a mass basis.

In addition to the 'recyclable' stream, kerbside collection includes 317,836 t of organic waste. This equates to 304 kg of organic waste per household per year (Sustainability Victoria, 2011a).

Overall, the above information provides a basis for characterising the contents of the kerbside waste stream in Victoria. The SV reports mentioned also provide information regarding the variability that exists between local governments, especially those differences that exist between rural and metropolitan environments. Figure 6 shows the distribution of cost of collecting kerbside recyclables for all councils considered in the survey. Although cost is not a measure of environmental impact, it may be a precursor to impacts, such as those impacts associated with diesel use.

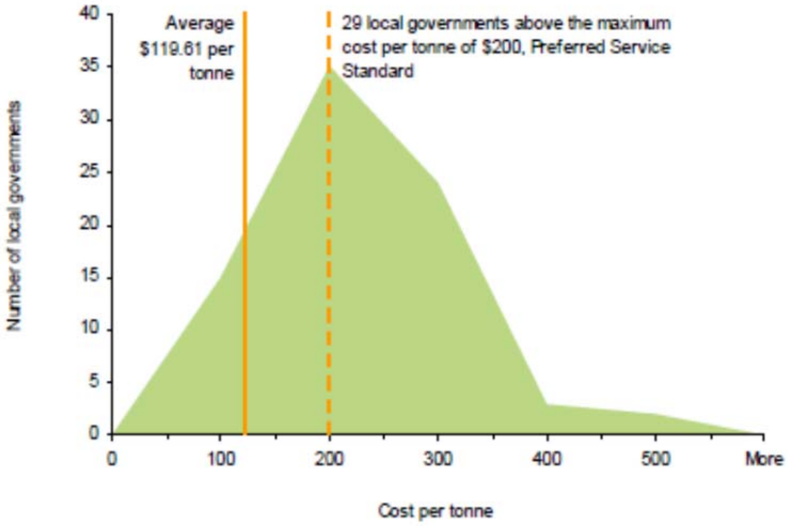


Figure 6 Cost of recycling collection across councils 2009/10.

3.3 The ‘Packwaste’ reports

An important benchmark, and the starting point for this study is the recycling study undertaken by Grant et al (2001a). This study forms the basis of environmental quantification undertaken by SV when discussing recycling. The report applied LCA methodology in assessing the recycling system and derived ‘factors’ that SV currently uses to convert material recovery tonnages into environmental impact avoidances (such as tonne CO_2-eq avoided when discussing global warming).

In 1997, economic reporting had been released that stated that a ‘cost gap’ existed with respect to kerbside recycling in Melbourne (the difference between revenues and expenses was estimated at $24 million p.a. Grant et al., 2001a) and in Sydney. Although community commitment to recycling existed, the cost issue raised questions regarding the environmental efficacy of recycling, leading to the principle question of the ‘Packwaste’ study which concluded in 2001 with a stage 2 report[3]:

> Does the current recycling system result in a net reduction in environmental impacts and if so what is the magnitude of the saving? (Grant et al., 2001a)

The study sought to answer this question employing the LCA methodology as defined by the ISO 14040 series of LCA standards. The scope of the project was limited to the Melbourne metropolitan area, incorporating a sensitivity study that involved the Bendigo waste management system. The project scope of this previous study is outlined in Table 8.

[3] The stage 1 report GRANT, T., JAMES, K., DIMOVA, C., SONNEVELD, K., TABOR, A. & LUNDIE, S. 1999. Stage 1 of the National Project on Life Cycle Assessment of Waste Management Systems for Domestic Paper and Packaging.

Table 8 Scope of LCA presented in Grant et. al. (2001a)

Included in Study	Excluded from Study
Activities	
• Victorian domestic kerbside recycling collection.- Melbourne metropolitan; • Victorian domestic garbage collection.- Melbourne metropolitan; • Bendigo domestic kerbside recycling and garbage collection (sensitivity analysis).	• Commercial and Public Place Recycling • Drop-off recycling • Victorian domestic kerbside recycling (rural) • Victorian domestic garbage collection (rural)
Product	
• Primary packaging including auxiliary materials of caps and labels.	• Secondary and tertiary packaging (of primary package) • Residues and contaminants
Life Cycle Stages	
• Life cycle stages from point of discard in home through kerbside collection, transport, sorting, processing, transport, reprocessing, and market entry as recycled product. • Raw Material extraction and processing of alternative product that is displaced by recycled product (i.e., the avoided product)	• Life cycle stages from raw material extraction, transport, processing and manufacture, distribution and use of package.

The functional unit is the unit by which all environmental impacts are assessed. For the previous study (Grant et al., 2001a), the functional unit was defined as:

> The management of the recyclable[4] fractions of paper board, liquid paper board, HDPE, PVC, PET, other plastics, glass, steel and aluminium packaging and old newspapers discarded at kerbside from the average Melbourne household in one week.

The functional unit described the materials considered by the study and inferred that the study would measure impacts in terms of recycling as a means for disposing of waste. The benefit or impact of recycling was measured relative to the predominant kerbside waste disposal method in Victoria; disposal in landfill. This approach was further described in the definition of recycling benefit described in the study shown in Figure 7. In this definition, recycling benefit (net savings from recycling) was defined as the sum of impacts associated with recycling collection plus the impacts associated with sorting and reprocessing of recovered materials, less the impact of avoided virgin material production and the impacts of avoided collection of materials for disposal in landfill (Figure 7).

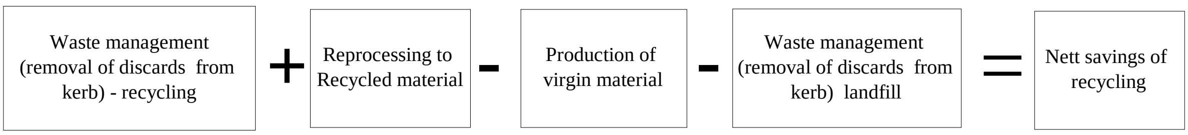


Figure 7 Definition of recycling benefit from Grant et al (2001a).

The definition of recycling benefit adopted assumes that all material recovered necessarily avoids (reduces) the extraction of resources from the environment. Proponents of a 'consequential' approach to LCA might challenge this assumption as it is not explicitly substantiated with evidence such as market information. A consequential approach would consider how the marginal change in the supply of reprocessed material might affect demand for that material (often by considering supply and demand constraints), driving secondary changes that may lead to alternative environmental outcomes. Both these approaches are discussed in Appendix A – Life Cycle Assessment and Recycling.

Materials considered by the study were those of interest at the time of writing, and most continue to be relevant today. A comparison of materials studied in Grant et al (2001a) and in the most recent review of materials recovered by local councils (Sustainability Victoria, 2011a) is shown in Table 9.

---

[4] Recyclable is defined, as a package/material for which there is an established recycling system (Minutes, Jan 15, 1998).

The table illustrates a relatively consistent list of materials considered by system operators for recovery and reprocessing.

Table 9 Materials addressed in (Grant et al., 2001a) and (Sustainability Victoria, 2011a).

Material in (Grant et al., 2001a)	Noted in (Sustainability Victoria, 2011a)
Newspapers	Not mentioned
Paper and board packaging (corrugated containers and box-board);	Paper (white, mixed) Cardboard
Liquid paperboard (LPB) (gable top and aseptic cartons);	Liquid paper board
High density polyethylene (HDPE) bottles;	HDPE (clear, coloured)
Polyvinyl chloride (PVC) bottles;	PVC
Polyethylene terephthalate (PET) bottles;	PET
Other, mixed packaging plastics (flexible and rigid);	Other plastics
Glass bottles and jars;	Glass (green, brown, clear)
Steel cans; and	Steel cans
Aluminium cans.	Aluminium cans

The reprocessing of each material shown in the first column of Table 9 was assessed using the LCA technique, as were system-wide processes such as collection and the MRF. In addition to processes directly associated with the recycling system, the definition of benefit (Figure 7) used required that impacts be assessed for the processing of waste in landfill, and for the production of materials from virgin (extracted from nature) sources.

When characterising the results of the LCA, (Grant et al., 2001a) employed five environmental indicators to characterise impacts as follows:

- Greenhouse emissions
- Smog precursors
- Energy embodied
- Water Use
- Solid Waste

Finally, the report was completed in a manner consistent with the ISO 14040 series of standards, as they were at the time. Since the study was completed, new and updated LCA standards have been published.

3.4 Other reports

In addition to studies that directly relate to recycling systems are those that address components of recycling systems and their alternatives. These include studies of collection systems, MRFs, landfill systems and recyclate reprocessing methods. In this report many such sources have been drawn upon and feature in the documentation of the inventory (Appendix B – Inventory Report) and in the discussion of LCA methodology (Appendix A – Life Cycle Assessment and Recycling).

3.5 Alternative waste treatments

Although considered 'out of scope' for this report, other waste treatments have been considered in the past using the LCA methodology in Victoria. Grant et al. (2003b) investigated 15 waste treatment scenarios that addressed disposal technologies in addition to landfill and recycling as follows:

- Aerobic Stabilisation
- Anaerobic Digestion
- Incineration
- Gasification/Pyrolysis

The report is well suited to readers interested in exploring options beyond those considered in this report.

3.6 Summary of key outcomes from the literature

- Terminology is important. Key terms must be defined within the document to avoid confusion.
- Opportunity and commitment exists to increase diversion rates in Victoria, therefore analysis should attempt to understand the consequences of a growth in recycling rates, in addition to the impacts of the existing system.
- Material streams of interest to SV are clearly defined in SV waste reports.
- LCA is well suited to analysing the impacts of the recycling system subject to limitations such as differences of view with respect to consequential and attribution approaches.
- Recent LCA's provide information across a range of reprocessing pathways, recycling subsystems (such as collection and materials recovery facilities) and extensive work has been undertaken reviewing LCA's that relate to waste treatment. Many of these studies are based on international experience and may require additional information to make them locally relevant.
- Information with respect to the key aspects of the recycling system is available in the literature, however much of this information is derived from international sources.
- Information with respect to the primary waste disposal alternative in Victoria, landfill, is available to support climate change impact assessment, but may be harder to find for other indicators.

4 Goal of the study

4.1 Goal

Primary goal:

> **To assess the net environmental benefits or burdens of recycling activity in Victoria by updating and building upon the study "Stage 2 Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria" (Grant et al., 2001a).**

Secondary goals:

- Identify impacts associated with unit processes within the recycling system, including transport, sorting, reprocessing and landfill.
- Identify the marginal benefits and burdens of the recycling system under a future scenario that assumes increased diversion from landfill. This analysis will focus upon systems where constraints are identified that would be expected to cause non-linear responses to marginal changes in recycling behaviour.

The decision to base the report upon the Grant et al, 2001 was made by the commissioning party in order to achieve consistency of results with past reports and to improve project cost effectiveness.

4.2 Intended audience

The study will be used by a range of groups including policymakers, councils, waste treatment system operators and associations, recyclers, reprocessors, and SV. Within SV, the report is expected to be used to help quantify environmental benefits associated within existing waste reporting such as Sustainability Victoria (2011a). The report is also expected to be made available to the general public.

4.3 Critical review

To counter the subjective nature of many decisions undertaken during the course of an LCA, a critical review process involving stakeholders and LCA experts is typically undertaken. As stated by Weidema (1997):

> "Life cycle assessments have in common with scientific work the difficulty of establishing objective quality criteria. Many of the judgements a practitioner will have to make in the course of a life cycle assessment cannot be said to be true or false, but only more or less justifiable. Therefore, the ultimate quality judgement can only be subjective - although based on professional experience." (Weidema 1997)

The most common form of peer-review, and the recommended approach for this study, is to conduct a review using the requirements of the ISO14044:2006 LCA standard, which states:

> "The critical review process shall ensure that:
>
> - the methods used to carry out the LCA are consistent with thus International Standard,
> - the methods used to carry out the LCA are scientifically and technically valid,
> - the data used are appropriate and reasonable in relation to the goal of the study,
> - the interpretations reflect the limitations identified and the goal of the study, and
> - the study report is transparent and consistent.
>
> The scope and type of critical review desired shall be defined in the scope phase of an LCA, and the decision on the type of critical review shall be recorded."

ISO14044:2006 also recommends that a "Critical review by panel of interested parties" be undertaken in circumstances where the LCA is undertaken to support a "comparative assertion". Although the outcomes of this study will not represent a 'product vs. product' assertion, the public scrutiny the study may receive when released, and its potential impact on policy, warrant a thorough review process.

It was therefore decided that a "Critical review by panel of interested parties" would be undertaken, as described in ISO14044:2006:

> "6.3 Critical review by panel of interested parties
>
> A critical review may be carried out as a review by interested parties. In such a case, an external independent expert should be selected by the original study commissioner to act as chairperson of a review panel of at least three members. Based on the goal and scope of the study, the chairperson should select other independent qualified reviewers. The panel may include other interested parties affected by the conclusions drawn from the LCA, such as government agencies, non-governmental groups, competitors and affected industries.
>
> For Life Cycle Impact Assessment (LCIA), the expertise of reviewers in the scientific disciplines relevant to the important impact categories of the study, in addition to other expertise and interest, shall be considered.
>
> The review statement and review panel report, as well as comments of the expert and any responses to recommendations made by the reviewer or by the panel, shall be included in the LCA report." (ISO 14044:2006)

4.3.1 Review process completed

For this study the approach adopted employs elements from Weidema (1997) and James et al (2002), that is also compliant with ISO14044:2006.

A Stakeholder Review Panel was established, incorporating interested parties, including representatives from local governments, waste and recycling operators, material recovery facility operators, plastics industry, glass industry and selected reprocessing industries. Also included in the SRP was an expert LCA reviewer who's role it was to guide the group with respect to technical aspects of LCA. The SRP was chaired by a representative from SV, who was not associated with the study.

The SRP met at two key points of the study. The first meeting formally reviewed the goal and scope of the study, and the second meeting reviewed the draft findings. In both instances feedback was sought during review meetings and directly in writing. Written feedback and author responses were documented and are presented in Appendix E – Reviewer comments.

In addition to the SRP process, the LCA expert reviewer also undertook a review of the report vis-a-vis the ISO14044 standard. Review comments and assessment letter are attached in Appendix F – Reviewer letter.

5 Scope

5.1 Description of systems under investigation

The LCA study is limited to domestic waste that is collected from the kerbside in Victoria. In studying the recycling system it is necessary to consider both the existing recycling system as well as an alternative system that might exist if recycling did not take place: the Recycling System (including organics) and the Alternative System. Whereas the nature of the Recycling System can be established by looking at the existing recycling process, the nature of the Alternative System needs to be estimated (refer Section 5.3 for a complete discussion).

Drop-off recycling is not directly addressed by the study, however results are presented in sufficient detail to enable 'collection' related impacts to be removed. The exclusion of 'collection' to simulate drop-off recycling would be a crude approximation as it assumes that the transport of waste to the collection facility is not allocable to the recycling system.

5.2 Functional unit

The primary function of both the Recycling System and the theoretical Alternative System is to dispose of waste generated by households.

The Recycling System also has an important secondary function as it generates reprocessed materials for use in manufacturing. This secondary function is an important outcome from the system and therefore is considered as a necessary function of the Alternative System as well.

The functional unit for this study is defined as:

> "The management of recyclable[5] materials discarded at kerbside from the average Victorian household in one year, including:
>
> - Glass (clear, green, brown)
> - Steel cans
> - Aluminium cans
> - Paper/card (white, mixed, newsprint, LPB, cardboard)
> - Plastics (PET, HDPE, PVC, PP, PS, mixed)
> - Organics (garden waste)"

This functional unit is similar to the functional unit used in the previous study, with the exception that the scope is expanded to include all of Victoria (not just Melbourne), the study includes organics recycling and the timeframe has been expanded from one week to one year. The functional unit previously used was:

> "The management of the recyclable fractions of paperboard, liquid paperboard, HDPE, PVC, PET, other plastics, glass, steel and aluminium packaging and old newspapers discarded at kerbside from the average Melbourne household in one week" (Grant et al., 2001a)

5.2.1 Reference flow

The functional unit chosen requires a definition of 'recyclable materials discarded' in one year, which becomes the reference flow. The average Victorian household disposes of 587 kg of waste materials (283 kg non organic, 304 kg organic) for kerbside recycling collection every year (Sustainability Victoria, 2011a), equating to 11.29 kg of waste per week. Table 10 breaks this figure down by the materials considered in the definition of the functional unit. The 'Reference Flow' column of Table 10 defines the mass flow of waste described by the functional unit.

[5] Recyclable materials in this context refers to those materials currently deposited into recycling bins, as opposed to garbage bins, and processed by the recycling system.

Table 10 Calculated breakdown of average household recycling collection in Victoria (values shown are in kg).

	Yield (1)	Nett Yield (2)		Reference Flow (3)	
Recyclable materials collected from the kerbside 587	Non organics 283	Recovery at MRF 262	Misc Containers 83	Glass packaging	72
				Steel cans	8
				Aluminium cans	3
			Paper 156	Paper (white)	1
				Paper (mixed)	110
				Paper (newsprint)	
				Paper (magazines)	
				Paper (cardboard, incl LPB)	45
			Plastic containers 23	Plastic (PET)	8
				Plastic (HDPE - clear)	4
				Plastic (HDPE - coloured)	3
				Other plastics (PVC, PP, PS, other)	8
		Contam. 21		Non organics contamination	21
	Organics 304			Garden and green	304
				Total	587

Notes:
All recycling breakdown information is taken from (Sustainability Victoria, 2011a):

1) Yield calculated from (non-organics p.27, organics p.38)
2) Nett yield (after removal of contaminants) determined from (non-organics p.28, organics assumed 100% yield)
3) Collection breakdown for non-organics from p.34

'Contam.' refers to contamination.

5.2.2 Materials excluded from the study

The following materials are excluded from the study:

- Bioplastics
- Nappies (including compostable)
- Textiles
- Sewerage
- Electronic waste
- Engineered wood products
- Mining and agricultural waste
- Waste from energy generation (including fly ash)
- Rubber/ waste tyres

5.2.3 The Recycling System

The Recycling System consists of those unit processes needed to recover and reprocess materials collected from kerbside recycling and green waste bins. Such processes include: collection and transport, materials recovery and sorting, reprocessing (both organic and inorganic), transport and some landfill. Background processes include but are not limited to electricity generation, natural gas extraction and supply and water supply. Material reprocessing pathways considered by the study are those associated with materials mentioned in the definition of the functional unit. The processes that comprise the Recycling System are shown to the left of Figure 8.

5.2.4 The Alternative System

The Alternative System can be defined as a 'shadow' of the Recycling System. It includes unit processes sufficient to generate the same primary and secondary functions as the Recycling System, however by different means. In the Alternative System, waste is disposed of to landfill and materials (equivalent to those produced by the Recycling System) are produced from virgin[6] feedstocks. The processes that comprise the Alternative System are shown to the right of Figure 8.

5.3 System boundary

The system boundary describes the unit processes which are included in the analysis.

Figure 8 describes the system boundary used in the study. Note that for clarity the following background processes are not shown on the diagram but are included within the system boundary:

- electricity generation and supply (including supporting supply chains, such as coal extraction)
- natural gas extraction and supply
- reticulated water supply
- fossil fuel extraction and processing (transport fuels)
- infrastructure

Excluded from the system boundary are processes associated with human labour.

The reprocessing and manufacturing processes shown in the Recycling System and Alternative Systems have been simplified to allow for presentation on a single diagram.

---

[6] Materials extracted directly from the environment.

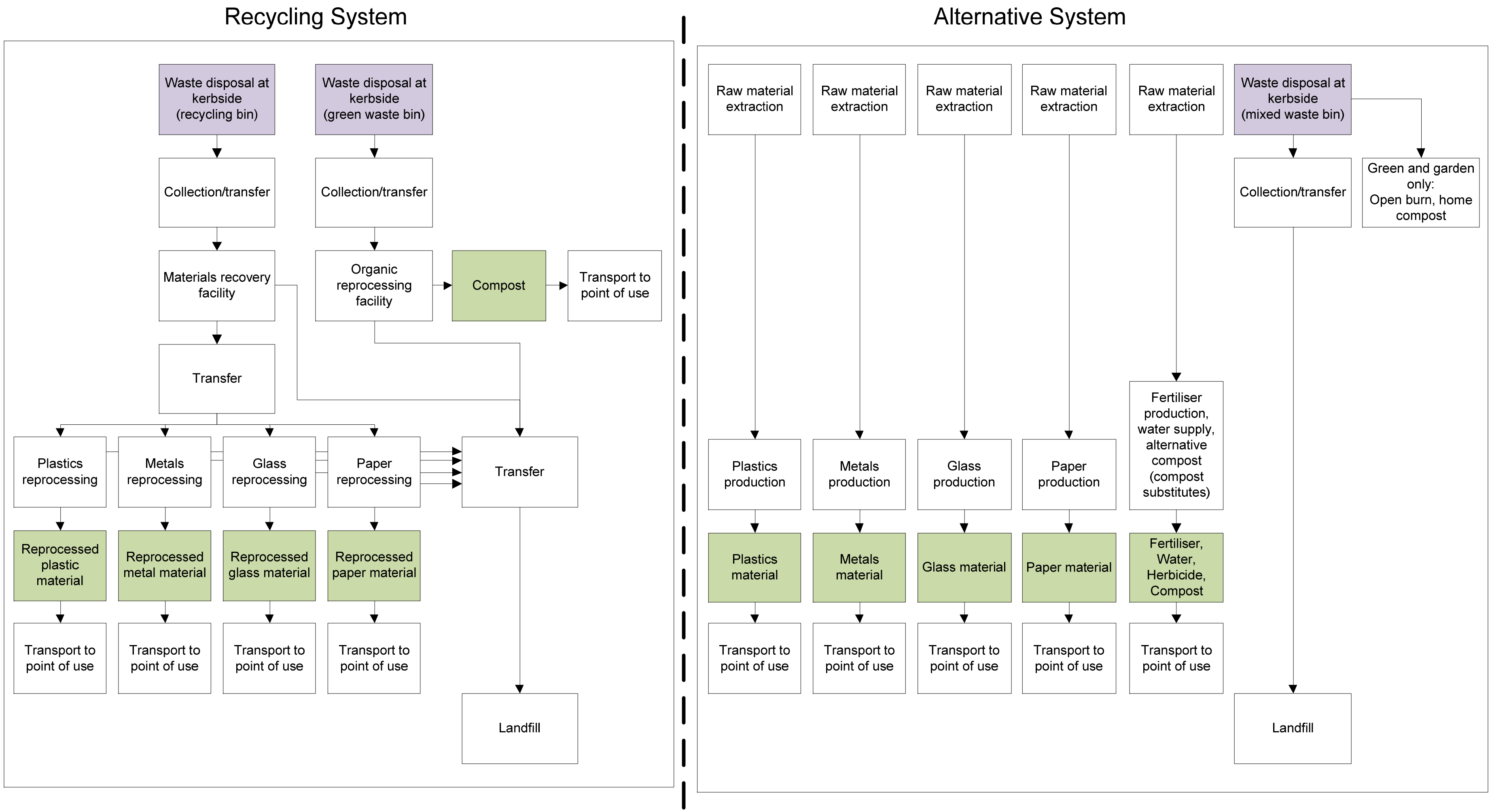


Figure 8 System boundary diagram.

5.4 Data quality requirements

The goal of the study is to quantify the benefit of recycling in Victoria, in terms of specific environmental indicators. To achieve this goal, two systems are assessed, the Recycling System and the Alternative System. Both these systems cover a broad scope, as described by Figure 8. Individual subsystems within these systems, such as landfill waste processing present significant assessment challenges and are worthy of dedicated LCA studies in their own right. Therefore, to achieve the study aim, significant reliance upon secondary data sources (other LCA studies and environmental reports) is required in order to cover the system scope.

Incorporation of secondary LCA studies requires that studies utilised are sufficiently transparent to enable assumptions to be evaluated and where necessary adjusted to suit the attendant situation. Transparency in secondary data sources is therefore a key priority.

The quality of secondary sources must also be evaluated. Data sources must be able to be compared to other similar studies, and selected based upon a ‘triangulation’ of multiple study outcomes. Adoption of singular studies that cannot be evaluated by comparison is avoided.

Despite a large library of secondary LCA studies being available, unique elements of the Victorian recycling system must be evaluated using primary data. The most important data for this purpose is the definition of the quantity and type of waste collected and disposed of (Table 10) at the kerbside, and it’s ultimate fate in the system. A key node of mass flow in a comingled waste system is the MRF as it determines how materials disposed of in a recycling bin are directed to reprocessors. In this study, lack of transparency of the MRF has been a significant data impediment.

Other primary data is required to assess unique systems such as collection and garden and green waste processing. Garden and green waste processing, in particular, must be considered over annual periods at a minimum due to the seasonal nature of waste flows.

5.4.1 Strategies employed to address data quality requirements

The wide range of data sources utilised in compiling the study brings with it a range of data quality. System complexity combined with this range of data qualities makes it difficult to subjectively assess the overall quality of the inventory, as the sensitivity of study outcomes to individual inventories is not necessarily clear. Recycling is particularly susceptible to this as it often (as in this study) involves the comparison of two systems with common elements. As the study outcome is determined by the difference between systems, not the systems in an absolute sense, predicting data quality implications becomes tricky. To address this issue, two strategies are employed:

a) Standardised data quality assessment and uncertainty analysis
b) Sensitivity analysis

The first strategy employs the Pedigree Matrix (Weidema and Wesnæs, 1996) to assess the quality of each foreground data element included in the inventory. The matrix highlights data quality issues, but more importantly allows data uncertainty to be calculated which can be aggregated (Frischknecht and Jungbluth, 2004). Uncertainty simulation across the entire inventory can then be undertaken and an aggregate uncertainty reported, which takes into account each elemental uncertainty. Of particular importance is the ability of the technique to address the offsetting effects of uncertainty in a difference equation, such as the recycling equation. More detail regarding this approach is described in Section 5.6.

The other strategy used is the ‘tried and trusted’ technique of sensitivity analysis, whereby an uncertain data point is deliberately altered and the impacts on the study conclusions assessed.

The above strategies in combination with an emphasis on selecting secondary data sources which are transparent and which can be verified is believed to have been sufficient to address the study goals. In contrast to other LCA studies and the prior report, the approach has also enabled a range of possible outcomes for each indicator to be determined – clearly conveying aggregate uncertainty to the reader.

5.5 Data collection

The study utilised detailed survey information regarding waste collection by local governments as the basis for characterising the recycling system (compiled by Sustainability Victoria). This information included collection quantities, locations, recycling rates, service frequencies and other information, providing a basis for waste mass flows across the state. From this basic flow information, secondary data sources were used to estimate distances to landfill and MRF locations and reprocessors. Regional and metropolitan waste management association reports were also utilised as a part of this exercise.

Although primary data was requested from sorting facilities, data was considered to be of a sensitive nature and was not able to be released. Although clear reasons were not provided, the MRF industry is made up of few organisations making results easily identifiable. In the absence of comprehensive primary data regarding recyclate flows from MRF's, a model of recyclate reprocessing was developed based upon a combination of national and Victorian secondary data sources.

The complex nature of recyclate reprocessing makes each process considered an LCA all of its own. For this reason, the highest quality outcome was considered to be achieved through the use of existing reprocessing studies which were adjusted as necessary to suit known local conditions. In many cases adjustment involved ensuring background processes, such as electricity generation where appropriate to process location.

Globalisation of the recyclate reprocessing industry has been identified as a key change in the nature of the recycling system since the original study in 2001. This has necessitated the modelling of systems in countries where data can be scarce. Where possible, models have utilised secondary data from reports appropriate to the locality. In some cases data quality is acknowledged as poor.

The vast scale of the recycling system and the diverse nature of data qualities used in the report has necessitated a rigorous approach to data quality assessment and aggregation. To cater to the range of qualities employed in the study, a uniform data pedigree matrix has been employed to assess and present the quality of data. Importantly, the resulting foreground data uncertainties have also been employed in a comprehensive data uncertainty analysis, the results of which transparently indicate the veracity of the study findings.

5.6 Use of the Pedigree Matrix

This study has made extensive use of the data Pedigree Matrix which is utilised by Ecoinvent to assess the quality and uncertainty of foreground data. The method utilised was developed by (Weidema and Wesnæs, 1996) and subsequently modified by Ecoinvent for utilisation in the data inventory they developed. In this study the data Pedigree Matrix utilised by Ecoinvent (Frischknecht and Jungbluth, 2004) is used and identical 'basic uncertainty' factors adopted.

The method requires that each data point be assessed in terms of the dimensions described in Table 12 and given a score out of 5. These scores are used with underlying 'basic uncertainties' to develop a lognormal standard deviation measure for the respective data point.

Throughout the inventory, data uncertainties are presented as well as a pedigree summary from which the uncertainty was determined. These summaries and uncertainties are useful in their own right for highlighting areas of data uncertainty, however are also utilised in the calculation of aggregated uncertainties for each of the results considered.

Data points within the inventory are also marked with a quality indicator. The indicator describes the quality of the data element according to its calculated standard deviation and an arbitrary scale. A red dot reflects poor quality data (standard deviation greater than 2), a yellow medium quality (standard deviation between 1.5 and 2) and green good quality (standard deviation less than 1.5). The scale is unashamedly arbitrary however, it seems to accord well with an instinctive assessment of data quality, highlighting those elements where quality is a concern (Table 11).

Table 11 Example of Pedigree Matrix implementation in inventory.

Flow description	Flow Amount	Unit	Flow Amount Source	Pedigree	Uncertainity
Zinc, primary/AU U	0.065	kg	Ecoinvent based on EAA (2000)	1,1,2,5,3,3	1.24
Ammonia	0.00002	kg	Ecoinvent based on EAA (2000)	1,1,2,5,3,3	1.58
Chlorine	0.00000049	kg	Ecoinvent based on EAA (2000)	1,1,2,5,3,3	1.58
Hydrocarbons, chlorinated	0.00005	kg	Ecoinvent based on EAA (2000)	1,1,2,5,3,3	2.07

Table 12 Data Pedigree Matrix.

Reliability	Score	Completeness	Score	Temporal correlation	Score	Geographical correlation	Score	Further technological correlation	Score	Sample size	Score
a. Verified data based on measurements	1	a. Representative data from all sites relevant for the market considered over an adequate period to even out normal fluctuations	1	a. Less than 3 years of difference to our reference year (2010)	1	a. Data from area under study	1	a. Data from enterprises, processes and materials under study (i.e. identical technology)	1	a. >100, continous measurement, balance of purchased products	1
b. Verified data partly based on assumptions OR non-verified data based on measurements	2	b. Representative data from >50% of the sites relevant for the market considered over an adequate period to even out normal fluctuations	2	b. Less than 6 years of difference to our reference year (2010)	2	b. Average data from larger area in which the area under study is included	2	b. NOT USED	2	b. >20	2
c. Non-verified data partly based on qualified estimates	3	c. Representative data from only some sites (<<50%) relevant for the market considered OR >50% of sites but from shorter periods	3	c. Less than 10 years of difference to our reference year (2010)	3	c. Data from smaller area than area under study, or from similar area	3	c. Data on related processes or materials but same technology, OR Data from processes and materials under study but from different technology	3	c. > 10, aggregated figure in env. Report	3
d. Qualified estimate (e.g. by industrial expert); data derived from theoretical information (stoichiometry, enthalpy, etc.)	4	d. Representative data from only one site relevant for the market considered OR some sites but from shorter periods	4	d. Less than 15 years of difference to our reference year (2010)	4	d. NOT USED	4	d. Data on related processes or materials but different technology, OR data on laboratory scale processes and same technology	4	d. >=3	4
e. Non-qualified estimate	5	e. Representativeness unknown or data from a small number of sites AND from shorter periods	5	e. Age of data unknown or more than 15 years of difference to our reference year (2010)	5	e. Data from unknown OR distinctly different area (north america instead of middle east, OECD-Europe instead of Russia)	5	e. Data on related processes or materials but on laboratory scale of different technology	5	e. unknown	5

5.7 Allocation procedures

A number of processes within the system boundary are associated with having multiple inputs and/or outputs. For delivering the functional unit, a procedure for partitioning impacts associated with these processes is required.

ISO 14044:2006 (International Organization for Standardization, 2006), contains a hierarchal procedure for partitioning:

Step 1: *Wherever possible, allocation should be avoided by:*

(1) dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or

(2) expanding the product system to include the additional functions related to the co-products, taking into account the requirements of 4.2.3.3.

> ***Step 2.*** *Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.*
>
> ***Step 3.*** *Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.*

In accordance to ISO 14044:2006, where possible, allocation has been avoided by using systems expansion.

In this study, the systems which have been subject to the ISO 14044:2006 hierarchy are multi-input, multi-output and recycling processes. Allocation for multi-input processes is based upon the physical composition of the inputs, with emissions from related stoichiometric reactions. Multi-input processes, such as waste treatment in landfill, will be avoided by increasing detail. Specific emissions have been modelled for specific material types that are being disposed. The impacts of transport tasks have been allocated based on the mass of the materials being transported and the distance travelled, with the exception of the waste collection systems which are modelled differently. Waste collection impacts are allocated to materials by a model which addresses a range of fuel consumption drivers (refer to Appendix B – Inventory Report).

5.8 Impact Assessment Method

The impact assessment method used in this study is intended to provide sufficient information to assess the environmental impact of recycling in Victoria. The method selected is a mid-point method (refer Appendix A – Life Cycle Assessment and Recycling) in order to retain a backward comparability to prior Australian recycling studies, and to avoid the complexity, subjectivity and lack of transparency associated with end-point methods.

The indicators selected, and the rationale for inclusion of each, are described in Table 13 which comprises the characterisation method. It is acknowledged that even the nine indicators considered only represent a fraction of possible environmental impacts that could be caused by the systems studied. This is a limitation of the study.

The impact assessment method considers global warming, eutrophication, photochemical oxidation, minerals depletion, fossil fuels depletion, land use, water use, solid waste and cumulative energy demand, as shown in Table 13. Global warming, eutrophication, photochemical oxidation, minerals depletion, fossil fuels depletion could all be considered indicators of environmental impact, however the remaining indicators are more correctly considered pre-cursor indicators that may or may not indicate environmental impact. For example, cumulative energy demand tells us what quantum of primary energy is being used by a system, it does not tell us if that that energy has come from fossil or renewable sources. Therefore, the exact nature of the environmental impact is unknown.

The indicators chosen (Table 13) were selected to assess a range of issues that recycling would be likely to affect. They were also chosen to maintain consistency and comparability with the previous LCA study (Grant et al., 2001a), and due to known inventory constraints. Human toxicity and ecotoxicity were excluded as their inclusion would have involved significant additional inventory development.

Some environmental indicators, such as photochemical oxidation and eutrophication tend to cause locally observable environmental impacts under certain conditions. Photochemical oxidation tends to cause smog where transport activities are concentrated in urban areas, whereas impacts are unlikely to be observed if emissions occur in sparsely populated areas, such as at sea or in rural areas. Eutrophication impacts tend to be most pronounced when emissions are to waterways, or through atmospheric transmission to waterways. As the LCA technique involved does not automatically consider these factors, interpretation of these indicators, in particular, needs to consider the likely type and location of the emission.

Detailed impact assessment factors for substances assessed are shown in Appendix D – Impact Assessment Method (Factors).

Table 13 Characterisation method.

Indicator	Description	Unit	Rationale for inclusion
Indicators of environmental impact			
Global warming	Climate change effects resulting from the emission of carbon dioxide (CO_2), methane or other global warming gases into the atmosphere – this indicator is represented in CO_2 equivalents. Factors applied to convert emissions of greenhouse gas emissions into CO_2 equivalents emissions are taken from the IPCC Fourth Assessment Report (2007). The values used are based on a 100 year time horizon.	kg CO_2 eq	Global warming is an issue of national and international importance. Key factors: Carbon dioxide: 1 Methane: 25 Dinitrogen monoxide: 298
Photochemical oxidation	Measurement of the increased potential of photochemical smog events due to the chemical reaction between sunlight and specific gases released into the atmosphere. These gases include nitrogen oxides (NOx), volatile organic compounds (VOCs), peroxyacyl nitrates (PANs), aldehydes and ozone. This indicator is of importance in areas where photochemical smog is likely to be a problem, such as in urban transport environments.	kg NMVOC	Waste treatment processes involve the emissions of chemicals to air, many of which could contribute to smog. Smog is an important consideration in metropolitan areas.
Eutrophication	Eutrophication is the release of nutrients (mainly phosphorous and nitrogen) into land and water systems, altering biotopes, and potentially causing oxygen depletion effects such as increased algal growth. Factors applied to convert emissions into PO_4^{3-} equivalents are taken from the CML impact assessment method from 2000 (CML baseline 2000 all impact categories V2.04).	kg PO_4^{3-} eq	Waste treatment processes could contribute to the eutrophication of waterways directly through processes relating to organics processing or their alternatives. Landfill systems could also contribute.
Mineral resource depletion	The additional investment required to extract minerals resources due to depletion of reserves, leaving lower quality reserves behind, which will require more effort to harvest. Factors to convert raw material inputs into $ equivalents are taken from the ReCiPe method (Version 1.07 - July 2012, © PRé Consultants, Radboud University Nijmegen, Leiden University, RIVM, www.lcia-recipe.net).	$	A key benefit of recycling is intended to be the recovery of useful resources that would otherwise be wasted. This indicator will help measure if these resources are indeed recovered.
Fossil fuel depletion	The additional investment required to extract fossil fuel resources to depletion of reserves, leaving lower quality reserves behind, which will require more effort to harvest. Factors to convert raw material inputs into $ equivalents are taken from the ReCiPe method (Version 1.07 - July 2012, © PRé Consultants, Radboud University Nijmegen, Leiden University, RIVM, www.lcia-recipe.net).	$	A key benefit of recycling is intended to be the recovery of useful resources that would otherwise be wasted. This said, it is also true that recycling systems use energy which is typically derived from fossil fuels. This indicator is intended to help understand the total system fuels impact.
Precursors to environmental impact			
Cumulative energy demand	All energy use including fossil, renewable, electrical and feedstock (energy incorporated into materials such as plastic).	MJ (LHV)	It is common to discuss recycling in terms of the energy that we save by undertaking the activity. This indicator is included to allow this to be measured.
Solid waste	Net solid waste generated. Total of all solid waste generated by the processes considered.	kg	Solid waste generation and avoidance is of primary concern to the SV and is included to provide guidance as to the systemic waste impacts of recycling.
Land use	Gross land use for unit processes under consideration. Actual environmental impact is not assessed.	Ha.a	Processes such as composting may avoid the use of significant land resources due to organics supply chains. Paper recycling may also provide such benefits.
Water use	Gross water use. Total of all water used by the processes considered. The use of water in hydropower plant is excluded.	kL H_2O	Although a rudimentary indicator of impact, water use provides direct visibility of system water impacts, particularly relevant to Victoria which has been subject to water scarcity issues in the past. The indicator could serve to measure resource scarcity or environmental impacts

6 Methodology

LCA has been used as the core method for determining the potential environmental impacts of the products considered. LCA has been applied in accordance with ISO 14040:2006. Refer to Appendix A – Life Cycle Assessment and Recycling for a description of the LCA process and how it is used in the study of recycling systems.

In determining the benefits of recycling a comparative model, similar to that used in Grant et al. (2001a), has been employed. The model is based upon the assumption that waste directed to recycling would otherwise end up in landfill. This assumption then governs a definition of recycling benefit which is equal to the impact of the Recycling System, less the avoided impacts of the Alternative System. The resulting definition of recycling benefit is as described in Figure 9.

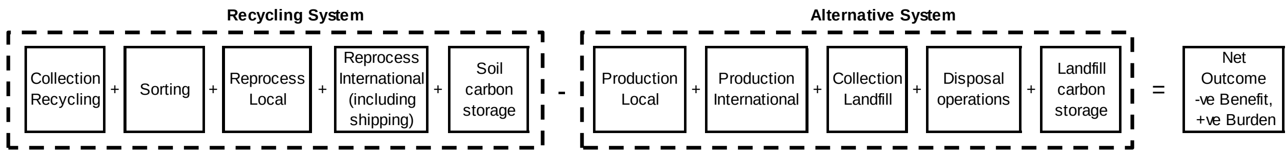


Figure 9 Definition of recycling benefit adapted from Grant et al (2001a).

In determining the impacts of the existing system, a fundamentally attributional approach has been employed that characterises impacts based on the existing systems operation. This method has been complemented by a sub-study which takes a consequential approach which seeks to forecast how systems might react to changes in future. This review primarily considers the assumption that materials recovered by the Recycling System necessarily displace materials produced from virgin resources. This approach undertakes to determine consequential outcomes associated with increased recycling rates based on available market information (utilising techniques described in (Weidema, 2003).

7 Study Limitations

By employing the LCA methodology, the study seeks to quantify potential rather than actual environmental impacts. The approach is therefore useful in understanding the general impacts associated with the functional unit, however is not sufficiently detailed to predict actual environmental impacts at a particular facility.

The assessment method employed addresses nine impact indicators. These indicators provide useful information regarding system impacts, however are incomplete. Many environmental impacts are not addressed by these indicators, such impacts to biodiversity, soil salinity, human toxicity etc. It is therefore important to interpret the study findings as only a partial environmental picture.

The study is not designed to be an economic study of recycling and should not be used in an economic context to model scenarios beyond those directly considered.

Like all studies of its type, it is also limited by the availability and quality of the information used to undertake the study. An assessment of data quality has been undertaken along with sensitivity analysis, where appropriate, to highlight areas where study conclusions need to be tempered.

8 Inventory

Each of the unit processes within the system boundary (Figure 8) were studied in detail and a mix of primary and secondary data were used to develop an inventory of elementary flows. The inventory is based upon the input reference flow of material described by the functional unit (Section 5.2). The core processes considered by the inventory are as follows:

Recycling System processes

Collection – operation of trucks to collect bins and transport waste materials from the kerbside to the MRF, or for garden waste, transport to the organics reprocessor.

Sorting – operation of the MRF, including the disposal of contaminant materials (not required for green and organics). Landfill burdens associated with disposing of contaminants are included in this process.

Local Reprocessing – transport of sorted recyclate from the MRF to a local (within Australia) materials reprocessor. The process stage includes burdens associated with the reprocessing of the recyclate into useful material. For the garden waste, this process stage includes transport from the organics reprocessor to the farm and application of composted materials to soils. Landfill burdens associated with disposing of contaminants (in sorted material from the MRF) are included in this process.

International Reprocessing – includes transport of sorted recyclate from the MRF to an international reprocessor, as well as burdens associated with reprocessing. Landfill burdens associated with disposing of contaminants (in sorted material from the MRF) are included in this process.

Carbon Storage - Soil – refers to the increase in the carbon content of soils to which composted products are applied.

Alternative System processes

Collection Landfill - operation of trucks to collect bins and transport an equivalent quantity of waste materials to that collected in the Recycling System from the kerbside to the landfill.

Disposal Operations – burdens associated with operation of landfill including the emissions from waste deposited within the landfill structure, including an offset for electricity generation from landfill gas. Also includes burdens associated with alternative waste disposal options for green and garden waste (open burning and home composting).

Local Production – includes the burdens associated with extracting and processing raw materials to produce an equivalent quantity of useful material, to that delivered by the Reprocessing Local stage described above. The processes are undertaken within Australia.

For green and garden waste, this also includes the burdens of processes needed to produce synthetic fertiliser and supply water to the soil, in quantities that achieve equivalent benefits to that provided by the quantity of composted product generated by the Recycling System.

International Production – includes the burdens associated with extracting and processing raw materials to produce an equivalent quantity of useful material to that delivered by the Reprocessing International stage described above. If production of the material generated by the Reprocessing International stage can be undertaken in the recyclate reprocessing country (from the Recycling System) then production is assumed to be undertaken in the same country as the reprocessing of the recyclate. However in many cases countries that undertake reprocessing of recyclate streams, don't produce the same material from resources extracted from the environment, for example Malaysia reprocesses steel from recovered scrap but does not produce steel from iron ore. In these cases the Production International stage includes production of equivalent materials within Australia and the transport of those materials to the place where reprocessing occurs. This is done to ensure geographic consistency of processes.

Carbon Storage – Landfill – includes any storage of carbon within the landfill structure for a period of 100 years or more.

The mass flows and key processes associated with the two systems are summarised in Figure 10 for the Recycling System and Figure 11 for the Alternative System. When considering both flow diagrams, recall that both are intended to deliver the same function as described in Section 5.2. The diagrams are intended to provide an overview of material flows, and it is not possible to show all flows. Changes in mass flows apparent in the Recycling System are due mainly to contamination of waste streams and reprocessing losses. The systems shown are described in detail in Appendix B – Inventory Report.

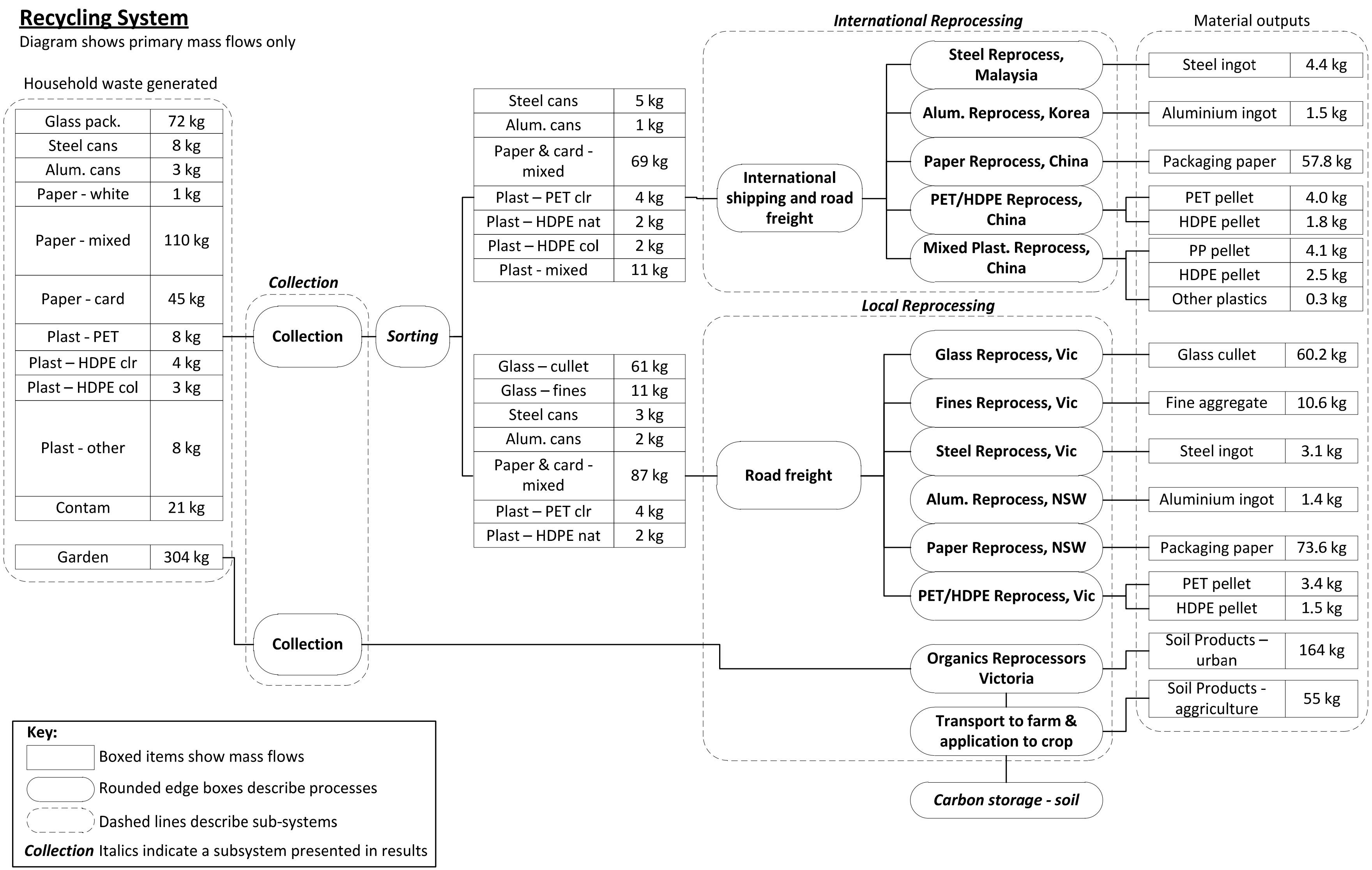


Figure 10 Recycling System processes and mass flows.

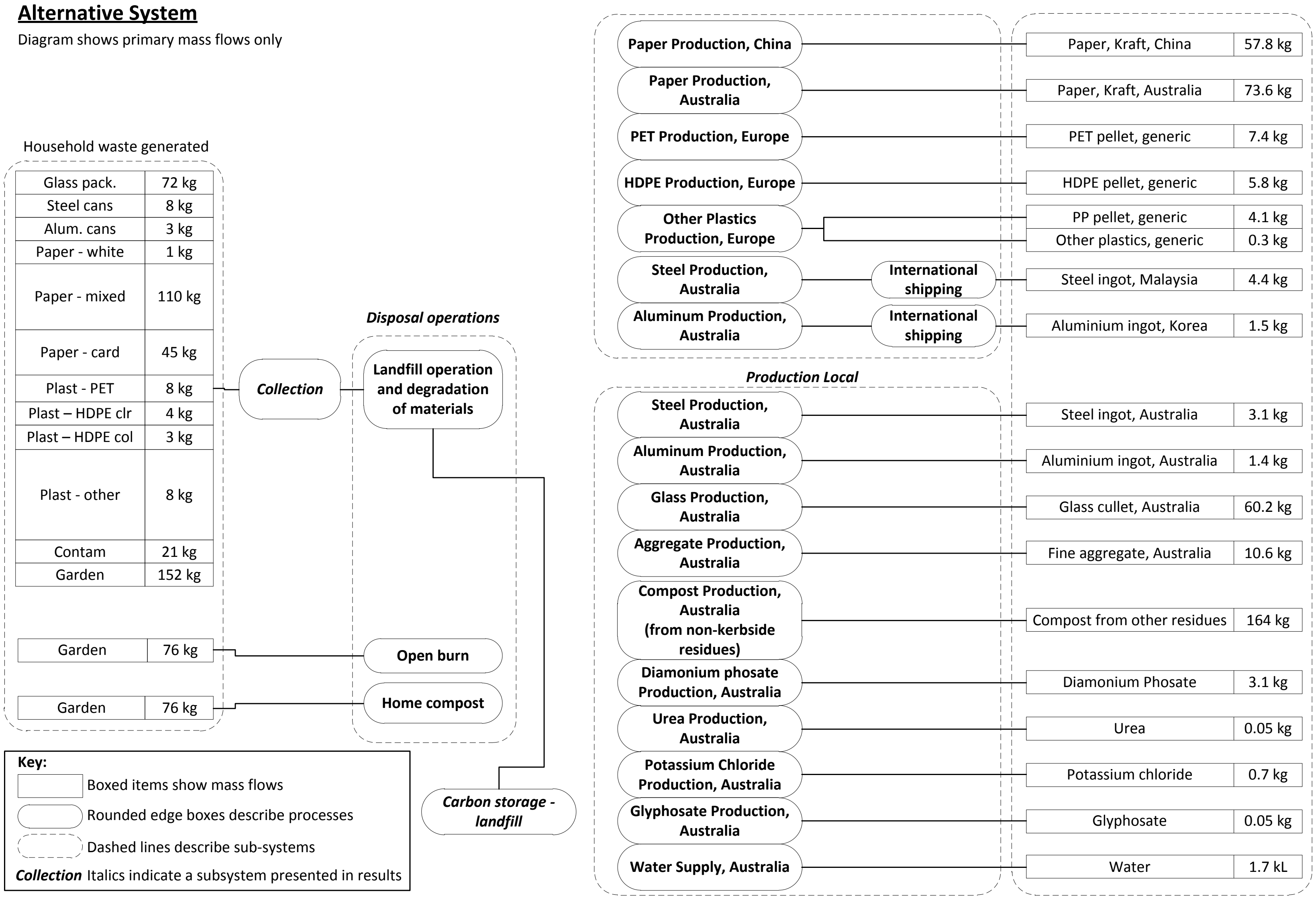


Figure 11 Alternative System processes and mass flows.

8.1 Inventory sub-systems

A further summary of key inventory assumptions is provided in Table 14. The table seeks to briefly describe the approach to modelling each key system in the Recycling System and the Alternative System. Further details for each system are provided in this section and Appendix B – Inventory Report.

Table 14 Summary of inventory assumptions.

Inventory sub-system	Recycling System	Alternative System
Collection	Fuel use for collection 12.3 l/t overall. Allocated to materials based on their in-truck specific volume.	Fuel use for collection 18.3 l/t overall. Allocated to materials based on their in-truck specific volume.
Landfill	Very little landfill considered (only that relating to contamination of recycling streams and reprocessing system wastes). Where considered assumptions as per the Alternative system.	Landfill model developed that considers facility construction and operation; greenhouse gas emissions due to material degradation and that water born emissions due to leachate. Key greenhouse gas assumptions include: Timeframe: 100 years; Methane capture rate: 57%; Methane combustion for energy: 92% of capture; Carbon storage: Carbon stored in landfill according to material specific factors
Sorting	Sorting was estimated to require 30 kWh of electricity per tonne of waste sorted (including glass colour sorting). 1.2 litres LPG gas was estimated for forklift operation. Sorting yields were estimated from U.K. data for facilities targeting similar materials (WRAP, 2009).	No sorting incorporated.
Treatment of garden and green waste	Assumes that all garden and green waste is processed using windrow composting. Once processed, 50% of composted products are utilised in agriculture applications and 50% of products are used in urban amenity applications. Carbon is assumed to be stored in soil under the agriculture applications, and not stored under urban applications. It is recognised that significant uncertainty exists in this area.	50% of garden and green waste is assumed to be treated in landfill, 25% is open burned and 25% is home composted. Additional benefits provided by compost in agriculture are assumed to be provided by synthetic feritilsers, herbicides and by additional water application. Quantities of these materials have been estimated using Recycled Organics Unit (2007).
Treatment of waste paper	Waste paper collected is assumed to be reprocessed into packaging paper, both within Australia (56%) and internationally (China, 44%). Reprocessing within Australia is assumed to be undertaken in a manner similar to that operated at Amcor's Botany paper plant. The inventory is based upon published data for the Botany plant, complemented by European data. For the China inventory, this process is adjusted to incorporate the use of coal for heat in place of natural gas.	Waste paper is assumed to be treated in landfill. Packaging paper production (equivalent to that produced by the Recycling System) is assumed to be via the Kraft process, similar to that employed by Visy at Tumut for packaging paper production. The inventory is based upon published data for the Tumut facility. The inventory is modified for paper production in China, to incorporate coal as the primary heat source, in place of gas. Quantities of materials produced through each inventory are equivalent to those produced by the Recycling System. Carbon stocks in forests and forests products are assumed to remain constant across the life cycle.
Treatment of waste glass	85% of waste glass collected at the kerbside is assumed to be reprocessed into glass packaging and the balance into aggregate substitute products (sands). All glass packaging is assumed to be reprocessed locally in Melbourne. The process inventory adopted is based upon a survey of German glass producers, which correlates well to key data elements published by the local industry (such as greenhouse gasses per tonne).	Waste glass is assumed to be processed in landfill. Packaging glass production is assumed to be produced locally using the same inventory as for the Recycling System. The inventory is adjusted to remove recycled cullet and increase raw materials and energy, in accordance with published ratios. Aggregate products are assumed to be provided by sand, which is mined locally. A sand mining operation from Queensland is used as the basis for the inventory.
Treatment of waste aluminium cans	48% of waste aluminium cans are assumed to be reprocessed at Yennora in NSW, and 52% are assumed to be reprocessed in South Korea. The reprocessing inventory is a European inventory, utilising similar technology to Yennora, and that correlates well with data fragments published for the Yennora facility. The Korea inventory is similar to Australia, however energy sources (electricity and natural gas) have been adjusted to suit Korean conditions.	Waste aluminium cans are assumed to be disposed of to landfill. Aluminium is assumed to be produced at the same quantity as the Recycling System, using a process inventory based upon Australian producer information, which is adjusted for recent improvements in perflourocarbon emissions. As no primary aluminium production occurs in South Korea, it is assumed that a quantity of aluminium is shipped from Australia to Korea to achieve functional equivalence to the Recycling System.
Treatment of waste steel cans	41% of steel cans recovered are assumed to be reprocessed locally whin Victoria in Electro Arc Furnaces (EAFs). 59% of steel cans are assumed to be shipped to Malaysia where it is assumed they undergo a de-tinning process prior to EAF melting to produce steel products. The EAF reprocessing inventory is based upon a study of Australian steel makers (Energetics, 2012). For Malaysia the Australian inventory is adjusted to suit local energy supplies and to incorporate a de-tinning process.	Waste steel cans are assumed to be processed in landfill. Steel quantities, as produced by the Recycling System, are assumed to be produced by the Blast Furnace – Basic Oxygen Steelmaking (BF-BOS) process. The inventory is based upon a published inventory of Australian steelmaking (Energetics, 2012). All steel is assumed to be produced in Australia, with a portion shipped to Malaysia to achieve functional equivalence to the Recycling system (steel is not generally produced from virgin resources in Malaysia).
Treatment of waste plastics	Homogeneous waste plastic streams (PET and HDPE) are assumed to be processed locally (46%) and internationally (China, 54%). Reprocessing is assumed to involve a cleaning and repelletisation process, similar to that modelled by (Franklin Associates., 2010) for U.S. processors. Mixed streams (including coloured HDPE) are assumed to be reprocessed entirely in China. Reprocessing is assumed to be largely manual (which are excluded from the LCA), with included burdens similar to those for homogeneous HDPE. It is acknowledged that reprocessing for these streams is highly uncertain.	Waste plastics are assumed to be treated in landfill. Unlike the other inventories above, plastics production is assumed to be produced through a generic inventory (utilising virgin feedstocks) for each plastic type produced by the Recycling System. These inventories are from the Ecoinvent database and are based upon data produced by Plastics Europe. They are not adjusted for regional energy supplies, and are used as is. Although the regional appropriateness of the datasets is questionable, their overall data quality is believed to be higher than if regional data sets were used, which have varying data qualities.

8.1.1 Collection

Fuel consumption for collection was estimated using a computer model. The model developed was based upon the approach adopted by Grant et al. (2001) who utilised the AWRCM (CRC Waste Management and Pollution Control, 1997) to estimate collection times. The AWRCM algorithm attempts to estimate the total time required to undertake waste collection then applies a standard fuel consumption rate per hour of vehicle operation.

Outcomes from the model were then compared to a sample of councils whose actual fuel use was known. Overall the model was found to be a rough guide to actual fuel use that appeared to over-estimate consumption in most cases (Figure 12). Fuel consumption uncertainty was therefore highlighted as an area requiring sensitivity analysis.

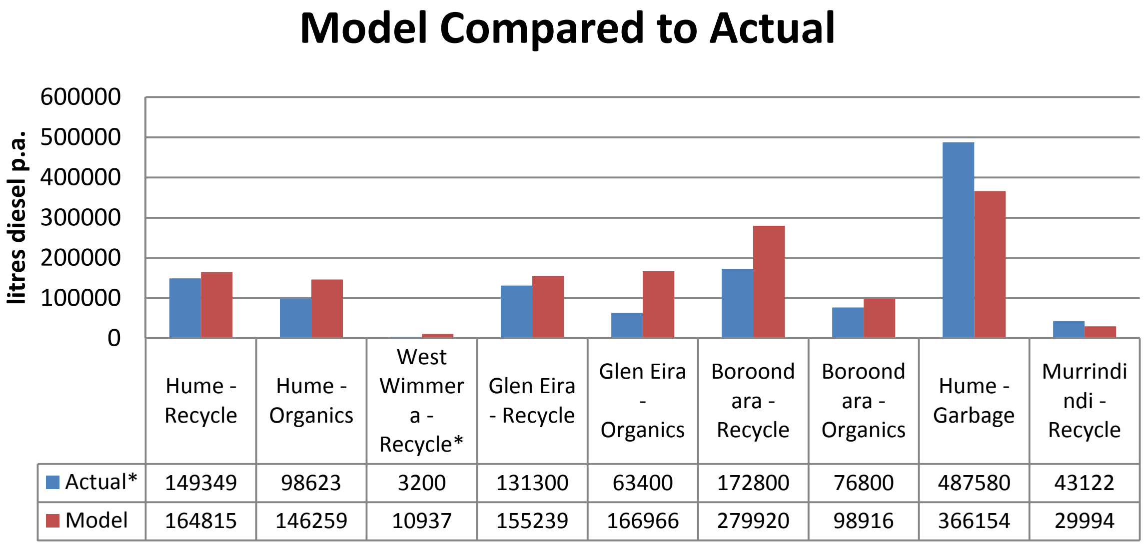


Figure 12 Fuel consumption model compared to actual.

Results from the fuel consumption model for specific materials are shown in Table 15. Fuel use varies from material to material because overall truck usage is allocated to each material based on its in-truck compacted volume. Denser materials therefore attract less fuel consumption per tonne collected. Differences between the Recycling System and the Alternative System are due to a combination of differences in distances travelled (landfill versus MRF) and the frequency of collection (weekly versus fortnightly).

Table 15 Fuel consumption per material (allocation based upon in-truck compacted volume).

	Recycling System l/t	Alternative System l/t
Paper products	11.9	17.1
Plastic containers	40.2	57.5
Glass bottles	7.2	10.3
Cans	18.3	26.2
Contaminants	8.7	12.4
Garden and green	11.6	17.9
Overal System	**12.3**	**18.3**

Having estimated fuel consumption for each local government authority in Victoria using regionally specific distances to landfill, MRFs and organic reprocessors, fuel consumption was converted into a vehicle emission by applying a combustion inventory from Ecoinvent.

8.1.2 Landfill

Landfill, unlike most other processes, does not involve a balance of incoming and outgoing material because much of the material that enters a landfill facility is retained by the facility, at least in the short term (less than 100 years). Although a balance of incoming and outgoing flow is likely in the long term, such estimates are highly uncertain. For this reason, it has been decided to consider the elementary flows associated with landfill over a 100 year time frame.

The landfill operation considered includes activities associated with processing once it is received at the facility gate, as well as downstream processes such as waste water treatment and upstream processes such as the generation of electricity and refining of fossil fuels needed by site machinery. The generation of electricity from landfill gas is also considered.

In addition, it is assumed that all material entering the landfill facility is interred in the ground. This assumption is based upon the inspection of a large facility in Melbourne, in which refuse trucks carrying waste move directly to the face of the landfill cell, where loads are quickly emptied and refuse bulldozed and compacted. The process observed was relatively intense, with little to no time for sorting of waste deposited.

Processes associated with construction of the landfill are also considered.

Excluded from the study are minor infrastructure components, as well as collection systems which bring the waste to the landfill (this is covered elsewhere). Wastes that are not relevant to the study goals are also excluded, as are elementary flows that do not impact the selected impact assessment methods.

8.1.2.1 Construction and remediation

Sanitary landfills are constructed by excavating a pit of varying depth (20 meters is typical), which is lined with clay, HDPE liner and crushed aggregate. Embedded in the pit are drainage systems which allow waste leachate to be collected and prevent it entering local groundwater.

Once complete the landfill 'cell' is progressively filled with waste materials which are periodically covered. As the cell is filled, key infrastructure, such as gas collection pipework is added, and drainage (if necessary). Once full, the cell is capped with an HDPE liner and covered with soil. In most cases land is remediated in some fashion. Gas generated by the decay of waste within the cell is captured and either flared or burned to generate electricity.

Estimation of the elementary flows associated with construction and remediation is achieved by considering the flows associated with constructing the landfill and remediating it at the end of its life. These flows are then divided by the volume of waste contained within the cell, giving an amortised environmental flow per unit of waste deposited.

The estimate adopted for this study is based on the inventory present in the EcoInvent database, developed in (Doka, 2009) .

8.1.2.2 Landfill operation

Once in place, waste is placed into the landfill and progressively covered and compacted. This process is typically undertaken by diesel powered machines such as loaders and bulldozers. Further energy is also required to operate leachate collection systems, typically involving pumps powered by electricity.

Table 16 Landfill operating energy requirements quoted in the literature.

	Doka (2009)	(Manfredi et al., 2009) (Engineered Landfill)	AUPLCI	(Pickin, 2010) (Wollert Landfill)
Geography	Switzerland	Europe	Australia	Australia
Diesel (l/t)	1.3	1-3	1.0	1.4
Electricity (kWh/t)	0.00135 (excludes leachate pumps)	8-12	0.8	0.047

Estimates of diesel fuel use when operating landfill are fairly consistent, as shown by Table 16, however electricity usage varies considerably. As Doka excludes leachate/treatment pumps (required in many Victorian landfills) this electricity figure is likely to be lower than would be experienced locally. Manfredi, by contrast, does not fully explain estimates for electricity use so it is difficult to understand why they appear so much higher than the other estimates shown. The AUPLCI estimate is reportedly based on a communication with a local (New South Wales) landfill operator, and Pickin's estimate is based on the Wollert landfill experience. Overall, the Pickin study appears most applicable to the Victorian situation so is adopted for landfill operations described in this inventory.

8.1.2.3 Emissions due to material degradation within the landfill

Materials that are deposited into landfill degrade over time causing a range of emissions to the environment. Degradation typically results in: a) emissions to the air as gasses generated within the landfill make their way to the atmosphere (often via a collection system), and b) emissions to water associated with leachate generated (again, usually via a collection system). These two broad classes of emissions are addressed in the following report sections.

8.1.2.3.1 Emissions from landfill to atmosphere

Perhaps the most studied of emissions from landfills are greenhouse gasses. Importantly, ongoing attention in this area has driven the development of accepted methods for quantifying emissions for various material classes deposited within landfill. Based on IPCC guidelines (IPCC, 2006), Australia's National Greenhouse Gas Inventory (DCCEE, 2010) provides an accepted method for estimating greenhouse gas emissions from landfill, of which methane is a particular focus because of its high global warming potential.

In this study, the First Order Decay (FOD) model described by IPCC (2006) and employed in DCCEE (2010) is used to estimate emissions. The key parameters employed in the model are described in Table 18, all of which have been derived from DCCEE (2010). The period of analysis employed is 100 years, therefore emissions are considered up to this point. Emissions due to degradation beyond 100 years are not considered. Model parameters are described in Table 17.

Table 17 Methane generation model parameters.

Parameter	Description
CH_4emitted	Methane emitted from landfill (kg)
L_O	Methane generated by landfill (kg)
R	Methane recovered (kg)
OX	Proportion of methane generated, and not recovered, that is oxidised through the landfill cap.
DDOCm	Mass of decomposable DOC deposited in landfill.
F	Fraction of CH_4 in landfill gas (volume fraction).
W	Mass of waste deposited in landfill.
DOC	Degradable organic carbon fraction. The fraction of degradable organic carbon within the waste.
DOC_f	Fraction of DOC that can decompose.
MCF	Methane correction factor. Acknowledges possibility that in some cases waste degradation will not generate methane.

Table 18 Material specific methane generation and carbon storage assumptions.

Material	DOC	Dry matter (%)(2)	DOC source	k	k source	DOC_f	*Remaining organic C kg/dry kg*	DOC_f and remaining C source
Paper (white)	0.4	90	DCCEE(2010) table 8.10 Paper	0.04	DCCEE (2010) table 8.11 Paper and Textiles (Victoria)	0.88	*0.05*	DCCEE (2010) table 8.12 Office paper
Paper (mixed)	0.4	90	DCCEE(2010) table 8.10 Paper	0.04	DCCEE (2010) table 8.11 Paper and Textiles (Victoria)	0.49	*0.24 (1)*	DCCEE (2010) table 8.14 Paper and paper board. Remaining C estimated. Refer note 1.
Paper (newsprint)	0.4	90	DCCEE(2010) table 8.10 Paper	0.04	DCCEE (2010) table 8.11 Paper and Textiles (Victoria)	0.15	*0.42*	DCCEE (2010) table 8.12 New sprint
Paper (magazines)	0.4	90	DCCEE(2010) table 8.10 Paper	0.04	DCCEE (2010) table 8.11 Paper and Textiles (Victoria)	0.21	*0.27*	DCCEE (2010) table 8.12 Coated paper
Paper (LPB)	0.4	90	DCCEE(2010) table 8.10 Paper	0.04	DCCEE (2010) table 8.11 Paper and Textiles (Victoria)	0.21	*0.27*	DCCEE (2010) table 8.12 Coated paper
Paper (cardboard)	0.4	90	DCCEE(2010) table 8.10 Paper	0.04	DCCEE (2010) table 8.11 Paper and Textiles (Victoria)	0.45	*0.26*	DCCEE (2010) table 8.12 Old currugated containers
Organics (garden waste)	0.2	40	DCCEE (2010) table 8.10 garden and Green	0.05	DCCEE (2010) table 8.11 Garden and Green (Victoria)	0.47	*0.24*	DCCEE (2010) table 8.12 Grass
Organics (food waste)	0.15	40	DCCEE (2010) table 8.10 Food	0.06	DCCEE (2010) table 8.11 Food (Victoria)	0.84	*0.08*	DCCEE (2010) table 8.12 Food

Note 1: Carbon remaining for mixed paper has been estimated. Calculated by taking w eighted average of remaing C, w here w eighting as based upon Table 8.13 DCCEE.
Note 2: Dry matter from IPCC(2006) table 2.4

Non-material specific parameters are described in Table 19, along with a number of parameters associated with the calculation of methane recovery. A key variable when estimating emissions is the determination of the mass of methane recovered by the landfill (R_t shown in Table 19, the recovery rate during the collection period, equates to a recovery fraction, R_f, over the 100 year period considered of 56%). The determination of R undertaken in (DCCEE, 2010) is based upon the reporting of carbon emissions by landfill operators under the National Greenhouse and Energy Reporting Scheme (NGERS). The most recent value for R_f reported[7] in (DCCEE, 2010) equates to the recovery of approximately 26% of methane generated in Australian landfill.

In this study an alternative approach to the determination of methane recovery has been adopted due to the limitations of the DCCEE approach, chief amongst these is the retrospective nature of the

[7] R_f is used to represent the proportion of methane recovered relative to the total amount of methane generated, as distinct from R which represents the total mass of methane recovered.

estimate. Under its obligations to report Australia's current emissions from landfill, the fraction of methane captured nationally must incorporate a range of landfill sites that are no longer reflective of contemporary landfill practice. As this study aims to understand landfill impacts prospectively, this approach was considered unrealistic.

As discussed in Appendix B – Inventory Report, 82% of waste collected from the kerbside is deposited in 10 large landfill sites across Victoria, 9 of which are known to be pursuing landfill gas projects involving methane collection and combustion. It is therefore more likely that landfill sites in Victoria accepting kerbside waste will achieve higher recovery rates than the 26% reported by DCCEE. In Pickin (1996), estimates for the Wollert Landfill in Victoria ranged from between 60% and 88% for R_f.

In Pickin's approach, landfill gas was assumed to be collected for a period of 40 years (energy generation for 30 years, followed by 10 years gas flaring), during which time 70% of methane generated would be collected. After this time, collection operations were assumed to cease and the remaining methane generated in the landfill is assumed to be emitted to atmosphere (less the proportion of methane oxidised in the landfill cap). This approach appears reasonable, given likely obligations of landfill operators to extend the operation and management of landfill gas beyond the closure of the landfill site (The Victorian EPA mentions a minimum 30 year period in its best practice guidelines (EPA Victoria, 2010)).

In this study an estimate of methane recovered has been derived in a similar fashion to that adopted by Pickin, for each material considered. Assumptions regarding collection and flaring lifetimes are shown in Table 19, as well as an estimate of methane gas collected and not oxidised. This factor reflects the reality that a portion of landfill gas collected will be vented to atmosphere over the life of the collection system (during maintenance, accidental leakage, etc.). Over the life of the landfill the collected fraction (R_f) is equivalent to 56%.

Table 19 General methane generation, emission and recovery assumptions.

Factor	Value	Source	Note
Methane Corection Factor (MCF)	1	DCCEE (2010)	
Delay constant (M)	13	DCCEE (2010)	6 month delay
Fraction of decomposition to result in methane (F)	0.5	DCCEE (2010)	
Oxidation factor (OF)	0.1	DCCEE (2010)	
Methane recovery fraction Rt	70%	Study assumption based on Picken (2010)	During collection period
Last year of elec. generation	30	Study assumption based on Picken (2010)	year
Years of flaring after generation ceases	10	Study assumption based on Picken (2010)	year
Methane recovered but not oxidised	1.5%	Study assumption based on Picken (2010)	

The results of the emissions analysis are summarised in Table 20 for each material. In addition to methane emissions, carbon storage is also shown. Carbon stored within the landfill is calculated using the factors shown in Table 18, which are in turn based on the work of Morton Barlaz, quoted by DCCEE (2010). The factors assume that a portion of the organic carbon deposited in the landfill will not degrade and will remain within the landfill for an extended period.

In addition, Table 20 describes a calculated equivalent methane capture rate (R_f). This factor is comparable to the 26% capture rate reported by DCCEE (2010) and the 60% and 88% capture rates reported by Pickin (1996).

Table 20 Calculated methane emissions, methane for generation and carbon storage.

	Calculated Outcomes: 1000 kg waste deposited in landfill for a 100 year time frame						
Material	**Methane generated (kg)**	**Methane emission (kg)**	**Methane burned for energy (kg)**	**Methane flared (kg)**	**Methane oxidised in cap (kg)**	**Carbon stored (kg)**	**Equivalent Rf (2)**
Paper (white)	230	91	113	16	10	20	56%
Paper (mixed)	128	51	63	9	6	93	56%
Paper (newsprint)	39	16	19	3	2	165	56%
Paper (magazines)	55	22	27	4	2	106	56%
Paper (LPB)	55	22	27	4	2	106	56%
Paper (cardboard)	118	47	58	8	5	102	56%
Organics (garden waste)	62	22	34	4	2	48	60%
Organics (food waste)	84	28	48	4	3	12	63%

Note 2: Average methane recovery rate for a 100 year period.

8.1.2.3.2 Emissions from landfill to water

In addition to gaseous emissions, many sanitary landfills emit substances to water in the form of leachate, which is collected. Once collected the leachate is typically treated on-site using aeration ponds before being released into the sewer. Treatment may also involve adding chemicals to adjust effluent flow composition such that it lies within discharge limits (trade waste limits). Once discharged to the sewer the leachate travels to municipal waste water treatment plants before being discharged to the ocean.

In this study, the EcoInvent/Doka method has been used to develop an estimate of leachate emissions from landfill which is directly related waste fractions deposited in the landfill. A schematic of the approach is described in Figure 13.

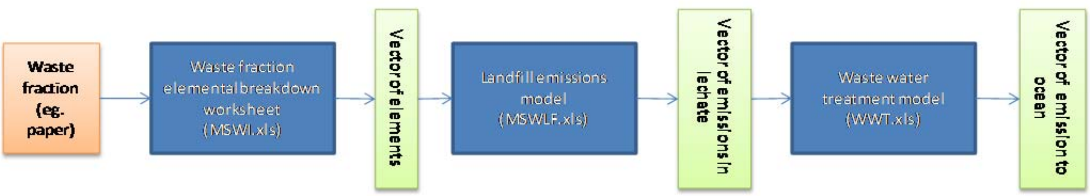


Figure 13 Leachate model (employing transfer models developed by Doka 2009).

Utilising the model described in Figure 13, an inventory of emissions to water associated with waste deposition in landfill was derived for assessed substances (those assessed by the study impact assessment method) in a range of waste fractions over a 100 year period.

8.1.2.4 Storage of carbon in landfill

In addition to emissions to the environment, landfills also store materials within their structures. For many plant based materials, this means that carbon from the environment is stored within the landfill for an extended period of time. Given that the carbon in plant derived materials, such as paper, and garden waste is considered to be from biogenic sources, the storage of this carbon in landfill has a beneficial impact upon global warming.

This study assumes that a portion of organic carbon, present in materials deposited in the landfill, will remain in the landfill for the long term. This assumption is consistent with other studies and is necessary to maintain an approximate carbon mass balance for the landfill system. Carbon that is stored in the landfill system is considered to have been derived from biogenic sources, so represents a beneficial global warming outcome (it reduces global warming).

The method used to estimate carbon stored in landfill is based on the work of Morton Barlaz, as quoted by DCCEE (2010). The calculation of carbon stored is undertaken within the framework of the FOD model for methane emissions such that carbon storage is acknowledged at a consistent rate to methane emissions. As is the case for methane emissions, a portion of the organic carbon entering the landfill is neither emitted nor stored at the end of the 100 year timeframe considered.

The results of carbon storage calculations for each material considered are shown in Table 20.

8.1.2.5 Landfill inventory developed

Utilising the information above, an inventory for landfill was developed that reflects the different behaviour of materials within the landfill. The result is a series of unit processes that describe the elementary flows associated with the landfill waste treatment process for each material considered.

The inventory developed is primarily utilised in the Alternative System as the main means of waste treatment, however it is also utilised in the Recycling System wherever waste is disposed of to landfill (for example, during material reprocessing).

8.1.3 Sorting – Materials Recovery Facility

The impact of MRF operation was surveyed however most participants were unwilling to disclose the information publicly. Instead a model was developed based on the disclosed layout of a MRF in Melbourne and the results compared to international studies. Overall the MRF was estimated to use 30 kWh electricity per tonne of waste processed (including glass sort by colour) and approximately 1.2 litres LPG gas. The upstream and on-site impacts of this energy use were then allocated to materials processed within the facility according to what processes the materials passed through. Materials passing through all processes attracted larger allocations than materials that only pass through a single process.

Waste material sent to landfill (contamination) from the MRF was as reported by Sustainability Victoria (2011a). Contamination embedded in 'sorted' material streams leaving the MRF was estimated from a U.K. study (WRAP, 2009) based upon a survey of MRF's targeting similar materials.

Table 21 MRF inputs to outputs.

MRF Input				MRF Output			
Input material	Per Functional unit		Extraction factor (2)	Extraction amount per functional unit	Extracted material	Extracted material contamination (1)	
Unit	kg/FU			kg/FU		%	kg/FU
			85%	28	Glass - Flint (clear)	1.50%	0.4
Glass (clear)	33		85%	14	Glass - Amber	1.50%	0.2
Glass (green)	17		85%	19	Glass - Green	1.50%	0.3
Glass (brown)	22		Residual	11	Glass - Fines	1.50%	0.2
Steel cans	8		100%	8	Steel	6.20%	0.5
Aluminium cans	3		100%	3	Aluminium	2.50%	0.1
Paper (white)	1		100%	156	Mixed paper and cardboard	15.80%	24.6
Paper (mixed)	110		100%				
Paper (newsprint)							
Paper (magazines)							
Paper (LPB)	2		100%				
Paper (cardboard)	43		100%				
Plastic (PET)	8		100%	8	PET - clear	7.50%	0.6
Plastic (HDPE - clear)	4		100%	4	HDPE - natural	18.20%	0.7
Plastic (HDPE - coloured)	3		100%	11	Mixed plastic	18.20%	2.0
Plastic (PVC)	0		100%				
Plastic (PP)	8		100%				
Plastic (PS)							
Plastics (mixed)							
Contamination	21		100%	21	Landfill	NA	NA
Total	***283***			***283***			***30***

Notes:

1. Extracted material contamination rates reported in WRAP (2009).

2. Extraction factor applied to glass to reflect reality that glass colours are not fully recovered. Part of the stream ends up as fines (15%).

The model described in Table 21 allows input material fractions to be traced to outputs that will then make their way to reprocessing systems.

Destinations for materials leaving MRFs was requested from operators, however the data was not provided. Instead an estimate of international versus local was developed using national reprocessing estimates from Allen and A'Vard (2013).

8.1.4 Treatment of garden and green waste

Organic waste collection in Victoria includes one local government collecting food waste at the kerbside (Nillumbik). The bulk of local governments do not collect food waste, so for this reason organics processing focuses upon garden organics processed through the open windrow process.

The processes required to convert green and garden waste collected from kerbside bins are considered as part of the Recycling System, as are processes that perform a similar function under the Alternative System.

An inventory of the windrow composting process was developed from one facility for which records were available however, three operators were consulted. In addition, the work of Recycled Organics Unit (2007) for a NSW application was also utilised, along with other international studies.

Although some uncertainty exists regarding windrow composting inputs and outputs, greater uncertainty exists as to the function of the product produced. Studies, such as Recycled Organics Unit (2007) focus on assessing the function of compost in specific farm applications, however in Victoria, it is estimated that 75% or more of compost produced is likely to be used in non-farm applications. These non-farm applications relate mainly to urban soil products produced for commercial or consumer markets, for which little research exists.

Significant uncertainty exists across most elements of the garden and green waste treatment inventory. The greatest uncertainty exists in three areas: First, the actual application is uncertain as market application data for Victoria is still developing and is incomplete; second, the benefits derived from applications are uncertain, particularly urban amenity applications, and; finally, the exact nature of waste treatment in the absence of recycling is uncertain – landfill is not the only alternative option for this type waste.

To address these uncertainties a range of scenarios were developed in the inventory, and a 'Balanced Estimate' developed as a base case. All the scenarios employ a mixture of agriculture and urban amenity applications at different ratios (Table 22). For the base case (the 'Balanced Estimate'), it is assumed that 25% of compost produced is used in agriculture or agriculture-like applications. The remaining 75% of compost produced is assumed to be used in urban amenity applications which avoid the production of compost from other residual sources, but are assumed to provide no additional benefits.

The use of 25% of compost products in agriculture or agriculture-like applications has been selected based on the 15% agriculture market utilisation estimated national statistics from Campbell and Shepherd (2010). It is expected that agricultural applications will achieve the full benefit and that many other applications will achieve part of the agriculture benefit, hence the increase from 15% to 25%. The balance of the composted product from the kerbside is assumed to be used in urban amenity applications.

Alternative waste disposal options for garden and green waste are also varied scenario to scenario. Under the 'Balanced Estimate' it is assumed that 50% of garden and green waste is treated in landfill, 25% is home composted and 25% is open burned.

Table 22 Scenarios considered for green and garden waste treatment under the Recycling System and the Alternative System.

Scenario	Extremely Conservative	Mildly Conservative	Balanced Estimate (Base case)	Mildly Optimistic	Extremely Optimistic
Recycling System					
Compost applied in agriculture	0 kg 0% of total	33 kg 15% of total	55 kg 25% of total	110 kg 50% of total	219 kg 100% of total
Compost applied in urban soil applications	219 kg 100% of total	186 kg 85% of total	164 kg 75% of total	109 kg 50% of total	0 kg 0% of total
Alternative System					
Benefit producing mechanisms					
Combination of synthetic fertilisers, herbicides and water N=Nitrogen, P=Phosphorous, K=Potassium, glyph.=glyphosate	0	0.5 kg N 0.5 kg P 0.2 kg K 0 l glyph	0.6 kg N 0.6 kg P 0.3 kg K 0.01 l glyph.	1.3 kg N 1.3 kg P 1.2 kg K 0.02 l glyph.	2.5 kg N 2.5 kg P 1.4 kg K 0.03 l glyph.
Compost produced from alternative residues (wastes)	219 kg	186 kg	164 kg	109 kg	0 kg
Waste disposal mechanisms					
Landfill (via kerbside collection)	0 kg	152 kg	152 kg	152kg	304 kg
Open burning	152 kg	76 kg	76 kg	76 kg	0 kg
Home composting	152 kg	76 kg	76 kg	76 kg	0 kg

A full discussion of the treatment of garden and green waste is included in Appendix B – Inventory Report.

8.1.5 Treatment of waste paper

In a national study of post-consumer packaging recycling infrastructure, (Allan and A'Vard, 2013) states that 56% of waste paper collected from residential sources would be recycled in Australia and that 44% would most likely be reprocessed in China.

This waste paper treatment inventory addresses processing waste paper and cardboard into recycled paper products (corrugated board and linerboard). It also considers the production of these products using pulp derived from forests. A single product that utilises waste paper collected from the kerbside is considered: industrial packaging paper. Newsprint production is not addressed as waste paper from the kerbside stream is no longer used in its production (this is a change from the previous study).

Within the Recycling System, packaging paper products are produced from 100% waste paper fibre sources, and within the Alternative System, packaging paper products are produced from 100% forest fibre sources. In reality both products are typically produced from a mix of waste paper and forest fibre, so production inventories have been adjusted to reflect this change.

8.1.5.1 The Recycling System

The inventory developed seeks to represent the reprocessing of waste paper generated in Victoria by tracing two key reprocessing pathways. Dating to 2002/3, the (A3P, 2005) data indicates that industrial and packaging paper manufacturing utilises 87% of waste paper utilised in Australia and newsprint production utilises 10%. Discussions with newsprint producers indicate that waste paper is no longer utilised from kerbside sources so this reprocessing pathway is excluded.

Packaging paper includes corrugated cardboard which is produced at Amcor's Botany facility from 100% waste paper feedstock. Botany is likely to be a large user of Victoria's waste paper as it is relatively close to the state. The process employed is also indicative of other likely reprocessing facilities such as Visy's linerboard plant at Coolaroo. For these reason's the Botany plant is used as the basis for the packaging paper reprocessing inventory (SKM, 2006). This inventory is complemented by data for Wellenstoff production (FEFCO, 2013), which is also produced from 100% waste paper and is commonly used in corrugate production. Transportation is weighted 50% to Botany and 50% to Coolaroo, reflecting the likely Victoria to NSW spilt in reprocessing activity.

The Recycling System inventory includes both the packaging paper inventory described above as well as an equivalent inventory for packaging paper production in China. The inventory is similar to that for Australia however energy sources have been adjusted to reflect a preference for coal in place of natural gas and differing electricity supply systems. A portion of waste paper, in accordance with Allan and A'Vard (2013) is transported to China by container ship and truck for processing in Shandong Province.

The outputs of the Recycling System include packaging paper in Australia and in China. For the Alternative System, inventories were developed for packaging paper products produced from forest fibre.

8.1.5.2 The Alternative System

The packaging paper output of the Recycling System is produced in the Alternative System from fibre sourced from plantation pine forest. The production processes utilised are different, reflecting the different processing needs of fibre sourced from trees.

Packaging paper production is produced in large quantities at Visy's Tumut mill in NSW using the kraft or sulphate pulp process. This production inventory for this facility is based upon data reported by Advitech (2013), and FEFCO data for kraftliner production is used to complete the inventory.

For packaging paper production in China, the paper is assumed to be produced from Chinese forest fibre using an identical process to that used in Australia, with the exception that coal is used as the heat source in place of natural gas.

A comparison of the treatment of one tonne of waste paper under the Recycling System and the Alternative System utilising he inventory described above is shown in Table 33.

8.1.6 Treatment of waste glass

In Victoria, glass is reprocessed using two principle approaches depending upon the quality of the glass recovered. If the glass is sorted by colour and contaminants such as ceramics removed, it can be used in packaging glass production at a number of facilities nationally, one of which is located in Melbourne (Owens Illinois, Spotswood). If the glass is too small to be sorted (sorting capability in Victoria is approximately 6mm (Visy Recycling, 2013)), the glass cannot be used for packaging glass production so must be used in other applications. Applications for glass fines (smaller than 6 mm) include use in asphalt, as abrasives, as backfill when laying pipes, road base and in concrete (APC Environmental Management, 2006). Broadly, these applications could be described as 'sand-substitute'.

Nationally, (Allen Consulting Group., 2007) states that cullet (recycled glass fragments) currently makes up 30% of packaging glass furnace feed, however this could be expanded to 60% if cullet quality is high. Markets for sand-substitute applications are noted to have expanded in recent years as applications have evolved (Allen Consulting Group., 2007).

The inventory for glass reprocessing into packaging consists of a theoretical inventory for glass manufacture using 100% cullet feedstock and a theoretical inventory using 100% mineral feedstocks (0% cullet). Both have been created from an Ecoinvent inventory for glass bottle manufacture in Germany, utilising 69% cullet (Table 23). Although an important study benchmark, the Australian inventory presented in the AUPLCI was found to be inconsistent with local industry data and international LCA's, so was not used as the basis of this report. The energy and mineral feedstocks of the Ecoinvent inventory were subsequently scaled to achieve the theoretical 0%/100% cullet inventories. Although perhaps unlikely to be produced, when used comparatively they allow the benefits of cullet utilisation in the glass batch to be quantified.

Scaling of raw materials was undertaken using the ratio of 1.2 kg feed material (soda ash, sand, dolomite and feldspar) added for every 1 kg of cullet removed from the production mix. In addition, for every 10% of cullet removed (from the baseline of 69%), heat from natural gas was increased by 2.5% (from a baseline of 3.89 MJ/kg glass). The reverse scaling exercise was undertaken for the 100% cullet inventory.

The result is two glass production inventories that may not be viable as extreme cases, but that when netted off against each other in the recycling benefit equation (Figure 9) reflect the likely benefits from recycling for the range of cullet reprocessing rates considered in the study.

In addition to glass packaging reprocessing, glass fines reprocessing was also considered. A very simple inventory was developed for fines which were seen as a substitute for sand extracted from the environment.

Table 23 Ecoinvent and AUPLCI container glass inventories (selected elements shown) for the production of 1 t container glass.

Selected inventory element	Unit	Ecoinvent Germany Brown Glass Bottles 69% cullet	AUPLCI 60% cullet
Year of data		2000	1998
Inputs			
Water	m3	0.214	0
Fuel oil	kg	23.3	0
Diesel	kg	1	0
Natural gas	MJ	2860	727
Electricity*	kWh	159	1539
Cullets	kg	689	598
Silica sand	kg	195	276
Soda ash	kg	61	70
Limestone	kg	40	0
Dolomite	kg	36	0
Calcined lime	kg	0	46.2
Feldspar	kg	37	0.578
Other inputs not shown			
Emissions not shown			
Impact assessment			
Calculated global waming impact	kg CO2e	599	1870
Cumulative energy demand	MJ LHV	10200	23300

* Both inventories take into account the difference in emission profile country to country

A comparison of the treatment of one tonne of waste glass under the Recycling System and the Alternative System utilising he inventory described above is shown in Table 32.

8.1.7 Treatment of waste aluminium cans

In a national study of post-consumer packaging recycling infrastructure, (Allan and A'Vard, 2013) states that 48% of aluminium collected from residential sources would be recycled by Alcoa in Yennora, NSW and that 52% would most likely be reprocessed in Korea. The inventory developed therefore addresses both a local and international reprocessing pathway.

The inventory developed for aluminium reprocessing is based on an Ecoinvent inventory, however is adjusted to draw upon background process inventories appropriate to Australian conditions. The inventory was selected over the KAAL inventory used in the previous study as it is more transparent and accords better with recent reporting of energy and water use for the Yennora facility (Alcoa, 2013). A comparison of the aluminium reprocessing inventories is shown in Table 24.

Table 24 Comparison of Classen (Ecoinvent) and KAAL aggregated inventories (1 t secondary aluminium).

Compartment	Substance	Unit	Modified Classen (Ecoinvent)	KAAL
Air	Ammonia	kg	0.1	0.0
Air	Carbon dioxide, fossil	kg	1,042.8	1,370.0
Air	Dinitrogen monoxide	kg	0.0	0.2
Air	Methane	kg	0.8	1.4
Air	Nitrogen oxides	kg	13.2	9.3
Air	NMVOC, non-methane volatile organic compounds, unspecified origin	kg	0.4	0.2
Air	Sulfur dioxide	kg	2.1	0.0
Air	Sulfur oxides	kg	1.3	2.4
Air	VOC, volatile organic compounds	kg	0.0	0.2
Raw	Biomass	kg	0.7	55.5
Raw	Coal Hard	kg	372.0	340.0
Raw	Coal, brown, 8.2 MJ per kg, in ground	kg	0.0	756.0
Raw	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	kg	0.1	0.0
Raw	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	kg	0.1	0.0
Raw	Copper, in ground	kg	1.1	0.0
Raw	Energy, potential (in hydropower reservoir), converted	MJ	949.5	195.0
Raw	Gas, Natural	MJ	18,760.7	27,291.6
Raw	Iron, 46% in ore, 25% in crude ore, in ground	kg	4.1	0.0
Raw	Occupation	m2a	52.9	0.0
Raw	Oil, crude, 42.8 MJ per kg, in ground	kg	23.2	0.0
Raw	Oil, crude, in ground	kg	40.0	10.1
Raw	Water	kL	18.9	2.1
Raw	Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	kg	77.3	0.0
Waste	Solid Waste	kg	43.0	215.9
Water	Nitrogen	kg	0.0	0.1
Water	Phosphate	kg	0.1	0.0
Water	Phosphorus pentoxide	kg	0.0	0.1

For reprocessing in Korea the Australian inventory was used as a basis and updated to include shipping of aluminium cans to Korea and the specifics of the local electricity and natural gas supply systems. Natural gas is used in Korea however is imported by ship and the electricity supply system has a significant nuclear component of approximately 33% (IEA, 2009). Natural gas is imported from Qatar, Indonesia, Malaysia and Oman (U.S. EIA, 2013).

The production inventory for the Alternative System is based on the AUPLCI inventory, corrected for water use and updated to reflect recent improvements in perflourocarbon emissions (a 96% reduction from 1990 levels). For Korea, aluminium is assumed to be produced in Australia and shipped to Korea. The Alternative System inventory (AUPLCI – corrected) is shown in Table 25 compared to the International Aluminium Institute inventory (IAI, 2007) and AUPLCI (prior to water use correction).

Table 25 Comparison of international and local primary aluminium production inventories (only selected flows shown). Flows for 1 t of primary aluminium production shown.

Selected inventory element	Unit	IAI (2007)	AUPLCI	AUPLCI corrected
Data time frame	yr	2005	1998	1998
Coverage	NA	International average	Australia only	Australia only
Bauxite	kg	5268	5629	5629
Alumina	kg	1923	1950	1950
Anodes	kg	435	476	476
Cathodes	kg	8	7	7
Water	kL	46.6	229	55.9
Electricity for electrolysis	kWh	15289	15083	15083
CF4 emissions	kg	0.13	0.26	0.26
C2F6 emissions	kg	0.013	0.04	0.04

A comparison of the treatment of one tonne of waste aluminium cans under the Recycling System and the Alternative System utilising he inventory described above is shown in Table 32.

8.1.8 Treatment of waste steel cans

In a national study of post-consumer packaging recycling infrastructure, Allan and A'Vard (2013) states that 41% of steel collected from residential sources would be recycled within Australia and that 59% would most likely be reprocessed internationally in Malaysia.

This inventory addresses processing scrap steel cans into steel slab under the Recycling System and the manufacturing of an equivalent quantity of steel slab from mineral resources extracted from the environment under the Alternative System.

In the Recycling System, sorted and bailed steel cans at the Material Recovery Facility (MRF) are likely to be transported to a processor in Melbourne or shipped internationally for processing. The inventory considers transport and processing operations for both processing pathways, through to the production of unalloyed steel slab.

In the Alternative System steel is produced from resources extracted from the environment. This inventory considers the production of steel from iron ore mined in Australia. Production in Malaysia is not considered as steel is not commonly produced from natural resources in that country. When comparing primary and secondary production burdens, steel consumed in Malaysia is assumed to come from Australia.

Both Recycling System and Alternative System inventories are largely based upon the Australian steelmaking inventory reported by Energetics (2012). The inventory was selected because of its relevance and timeliness. Areas where the Energetics (2012) inventory does not provide data have been provided by Ecoinvent for the most part, the consistency of which appears reasonable when the inventories are compared (Table 26).

Table 26 Comparison of EAF steel production data from different sources. Table excludes transport fuels.

		European Steel Industry EcoInvent	Australian Steel Industry Energetics (2012)	Australia AUPLCI	U.S. Steel industry LBL(2010)
Timeframe of data	year	2000	2012	Unknown	late 1990s
Flow	**unit**	**quantity**	**quantity**	**quantity**	**quantity**
Inputs					
Anode (aluminium)	kg	3	0	0	
Electricity	kWh	424	472-529	1050	304-525
Hard coal	kg	14	0	14	
Iron scrap	kg	1105	1010-1020	1000	
Pig iron/flat iron	kg	0	68-75	0	
Coke	kg	0	15-15	0	
Fluxes	kg	0	18-19	0	
Natural gas	MJ	975	400-450	0	232-927 (1)
Oxygen, liquid	kg	51	0	51	
Quicklime	kg	55	0	55	
water	kl	0	0.9-1.0	0	
Refractory	kg	14	0	0	
Outputs					
Air emissions	NA	various	various	0	
EAF Slag	kg	0	150-160	0	
Solid waste and dust	kg	107	13-19	100	
Steel billet	kg	1000	1000	1000	1000
Product		Unalloyed	Alloyed	Unknown	Alloyed

(1) Assumes 'fuel' other than electricity represents natural gas

An important adjustment to Energetics inventory has been made for primary steel production. Typically, steel would be produced from a mix of scrap steel and natural resources, such as iron ore. In the inventory used here, scrap steel feed (180 kg) is removed from the Energetics inventory, and the output of steel slab is reduced by an identical offsetting amount, in order to present a steel product produced completely from resources extracted from the environment. This approximation may lead to a slight understatement of steel production impacts, as it does not remove likely systemic efficiencies that are caused by the use of scrap. A summary of the Energetics BF-BOS inventory is shown in Table 27 compared to the Ecoinvent inventory of the European steel industry.

Table 27 Comparison of Ecoinvent and Energetics BF-BOS steel inventories.

		EcoInvent	Australian Steel Industry Energetics (2012)
Timeframe of data	year	2001 - 2002	2012
Flow	**unit**	**quantity**	**quantity**
Inputs			
Scrap	kg	125	170-190
Iron ore	kg	1632	1510-1670
Metallrgical coal	kg	619	670-740
Fluxes	kg	348	400-440
Water - fresh	kl	10	1.62-1.78
Water - sea	kl	0	39-45
Electricity	kWh	107	103-111
Natural gas	GJ	0.21	1.0-1.1
Diesel	MJ	Transport not shown	19-22
Outputs			
Air emissions	NA	various	various
BF slag	kg	not inventoried	350-380
BOS slag	kg	not inventoried	100-120
Coke byproducts	kg	not inventoried	30
Solid waste	kg	23.4	16-21
	kg		
Product	kg	1000	1000

As mentioned by Allan and A'Vard (2013), 59% of steel recovered from the kerbside is likely to be reprocessed internationally, probably in Malaysia. Reprocessing in Malaysia will be undertaken using the EAF process, similar to that undertaken in Australia, however it is likely to incorporate a de-tinning stage. De-tinning involves the removal of tin from scrap cans prior to processing them in the EAF furnace. This allows valuable tin to be recovered, while at the same time removing tin from the EAF feedstock, which is considered a contaminant.

De-tinning used to be undertaken in Australia, as it is a complimentary process when producing steel tin-plate. When steel tin-plate production ceased in Australia, so too the de-tinning ceased. In Malaysia, steel tinplate is still produced, so de-tinning is a likely reprocessing pathway for scrap cans. The Malaysian de-tinning process has been modelled based on the now closed de-tinning process at Port Kembla.

A comparison of the treatment of one tonne of waste steel cans under the Recycling System and the Alternative System utilising he inventory described above is shown in Table 32.

8.1.9 Treatment of waste PET, HDPE and mixed plastics

Sustainability Victoria (2011a) report that of the 283 kg of kerbside recycling (excluding garden and green waste) collected per household in Victoria in 2009/10, 23 kg were plastics (8%). These plastics were known to contain plastic types as shown in Table 28.

Table 28 Plastics recycled in Victoria in 2009/10 period. Calculated from Figure 23 in (Sustainability Victoria, 2011a). Excludes contamination separated by MRF.

Plastic type	Mass of plastics collected per household in Victoria 2009/10 (kg)
Plastic (PET)	8
Plastic (HDPE - clear)	4
Plastic (HDPE - coloured)	3
Plastic (PVC)	0
Other plastics	8
Total	23

Notably, the 'Other Plastics' category is not broken down further by Sustainability Victoria (2011a). Other data sources, however, provide information at a national level that could be used to estimate the contents of the 'other plastics' component. Hyder Consulting (2011) estimate Australia-wide plastics recycling rates as shown in Table 29.

Table 29 Polymers recycled from post-consumer sources in Australia, 2009/10 period. Values interpolated from figure 20 in (Hyder Consulting, 2011).

Polymer	Australian - Post-consumer recycling by polymer type	Proportion of total
PET	52,000	41%
HDPE	50,000	39%
PVC	2,000	2%
L/LLDPE	3,000	2%
PP	15,000	12%
PS	4,000	3%
EPS	Minimal	0%
ABS/SAN	Minimal	0%
PU	Minimal	0%
Nylon	Minimal	0%
Other	1,500	1%
Total	127,500	100%

Assuming Victorian MRF's have targeted PET and HDPE, it is likely that the 'other plastics' component reported by Sustainability Victoria is largely made up of PP (estimate 5 kg) and 1 kg each of PVC, L/LLDPE and PS, based on the fractions described in Table 29.

Allan and A'Vard (2013) estimates that 55,000 t of plastics from residential sources were recycled locally and that 65,000 t of plastics were recycled internationally in 2010-11, Australia-wide. This equates to a local reprocessing fraction of 46% and an international reprocessing faction of 54%. Of the international fraction, it is believed that 88% was recycled in China (including Hong Kong) (Allan and A'Vard, 2013).

Within Australia, reprocessing pathways were identified for clear PET and natural HDPE from kerbside collected waste, however no pathways could be identified for coloured HDPE and the 'other plastics' category. It is therefore likely that PET and HDPE are reprocessed both locally and internationally, as described by Allan and A'Vard (2013), and that the remaining plastics (coloured HDPE, PP, PVC, L/LLDPE) are exported as mixed bailed plastic.

Within Australia, clear PET and natural HDPE are known to be reprocessed by a number of companies. Allan and A'Vard (2013) list a number of reprocessors for both HDPE and PET in Victoria (Melbourne region) and interstate. Reprocessing pathways vary from company to company, with some reprocessing plastic packaging into pellet and flake forms, suitable for non-food applications, whereas others are able to reprocess to a food grade level.

The reprocessing of PET and HDPE has been studied in detail in the U.S. and a life cycle inventory developed (Franklin Associates., 2010). The inventory addresses the entire process of collecting sorting and reprocessing PET and HDPE, however only reprocessing is addressed here. The inventory of reprocessing of sorted PET and HDPE into pelletised form is shown in Table 30 and Table 31.

Table 30 Inventory flows to produce 1 t of reprocessed PET from sorted postconsumer PET (Franklin Associates., 2010). Quantities adjusted to metric units from original publication.

Inventory element	Unit	Amount
Inputs		
Sorted post consumer PET	kg	1250.0
Sodium hydroxide	kg	23.8
Surfactant	kg	0.8
Defoamer	kg	2.2
Wetting agent	kg	0.9
Electricity*	kWh	940.4
Natural gas	MJ	3378.5
LPG	l	0.3
Propane	l	0.0
Water	l	395.4
Outputs		
Particulates	g	39.0
Volatiles	g	37.0
Solid waste	kg	220.0
Water - BOD	kg	7.3
Water - COD	kg	20.2
Water - TSS	kg	3.0

* Includes pelletisation.

Table 31 Inventory flows to produce 1 t of reprocessed HDPE from sorted postconsumer PET (Franklin Associates., 2010). Quantities adjusted to metric units from original publication.

Inventory element	Unit	Amount
Inputs		
Sorted post consumer HDPE	kg	1079.0
Sodium hydroxide	kg	0.9
Surfactant	kg	4.2
Defoamer	kg	11.6
Wetting agent	kg	5.6
Alkaline cleaner	kg	0.7
Electricity	kWh	490.1
Natural gas	MJ	307.6
LPG	l	0.8
Propane	l	0.3
Diesel	l	0.2
Water	l	445.5
Outputs		
Particulates	g	38.0
Volatiles	g	0.0
Solid waste	kg	79.1
Water - BOD	kg	0.3
Water - COD	kg	0.0
Water - TSS	kg	0.3
Disolved solids	kg	0.0

When considering the inventories developed by Franklin Associates. (2010), it is important to note the differences in contamination rates seen between the two plastics considered. PET has a significantly higher contamination rate of 18.3% versus HDPE which has a contamination rate of 7%. This difference may have little to do with the inherent qualities of the two plastics and may reflect variation in MRF sorting efficiency or other factors.

8.1.9.1 Plastics reprocessing in China

China absorbs 70% of globally traded recovered plastics (WRAP, 2006). Shipping of plastics to China is facilitated by low cost container freight due to trade imbalances between China and many of its trading partners. Determining the exact nature of waste plastic reprocessing in China is difficult, although known uses for recovered plastics include:

- PET - polyester fibre used for stuffing for toys and furniture, textiles.
- PVC - construction applications.
- ABS - electronics and electrical equipment and household appliances.
- PE - packaging and agricultural plastics.
- PC – DVDs
  Source: (WRAP, 2006)

The province of Guangdong, accounts for 60% or waste plastic imports (WRAP, 2006). Moore (2011) describes an example of the process of recycling PET in China as follows:

- Bales opened and placed in bath of hot water
- Washed materials a subjective to a positive sort, whereby PET bottles (green and clear) are removed from the mix leaving contaminants behind
- Colour separated PET bottles are ground into flake and passed through a float/sink tank
- PET sinks and PP floats (bottle caps)
- Both recovered material streams are washed in hot water, surfactants and caustics
- Materials are dried and bagged
  Source: (Moore, 2011)

Reprocessing pathways for mixed plastic bails are particularly difficult to determine, however some research has been completed. Moore (2011) describes the process of recycling mixed bails as follows:

- Postconsumer bails arrive in Hong Kong where they are inspected, placed in containers and shipped into the interior of Mainland China (to warehouse or recycling facility)

Initial sort:

- The first recycling facility pulls PE and PP from the bails and sorts by resin and colour
- Nine categories of colour are sorted
- After colour sort, the PP or PE is ground and put into a float/sink tank
- Olefin plastics (PE and PP) float, whereas the contaminants sink
- Flake is moved to a wash tank, rinsed and spun dry
- Some facilities pelletise the material, whereas others sell the bagged flake

Secondary sort:

- Small pieces, not separated in the first sort are gathered and passed through the float/sink tank
- The recovered material is washed and dried and used for colour neutral applications
- Remaining plastics, non-olefins, are gathered and sent to a second facility for further sorting by colour and a similar grinding and washing process is employed.

8.1.9.2 Plastic production from resources extracted from the environment

Plastics used in Australia come from a range of sources, some local and some international (Hyder Consulting, 2011). The impacts of plastic production would be expected to vary between these sources. A range of life cycle inventories exist for the production of plastics, some of which are compared below when assessed for global warming impact and cumulative energy demand (Figure 14 and Figure 15).

The Ecoinvent dataset shown in Figure 14 and Figure 15 is based upon 'Ecoprofiles' published by Plastics Europe between 2005 and 2007 and refers to plastics production in Europe. The AUPLCI dataset is based upon a mix of sources, and is intended to reflect plastics production in Australia.

The Ecoinvent inventory has been published and documented in detail (Hischier, 2007), and most inventories have been compiled across groups of facilities in a consistent fashion. The AUPLCI datasets, while being more regionally relevant, reflect a mix of data qualities. Documentation regarding the inventories is minimal.

Internationally, no inventories could be found that referred to plastics production in China.

8.1.9.3 Recycling System inventory developed

This inventory addresses the reprocessing of plastics into products and the production of plastics from natural resources (oil, principally).

All plastics reprocessing is modelled using two reprocessing processes, PET and HDPE that are similar to those described by Franklin Associates. (2010). The processes consist of a washing and sorting process followed by a thermal extrusion into pellet form. For other plastics types, the HDPE process is used as a crude approximation.

The inventory adopts the Franklin Associates. (2010) inventory for reprocessing of PET and HDPE and applies this inventory for reprocessing all the plastic types. This approach was adopted as it is relevant for the major plastics flows of PET and HDPE (65% of plastics) and is considered a reasonable proxy for the float/wash processes described in China (WRAP (2006) and Moore (2011)).

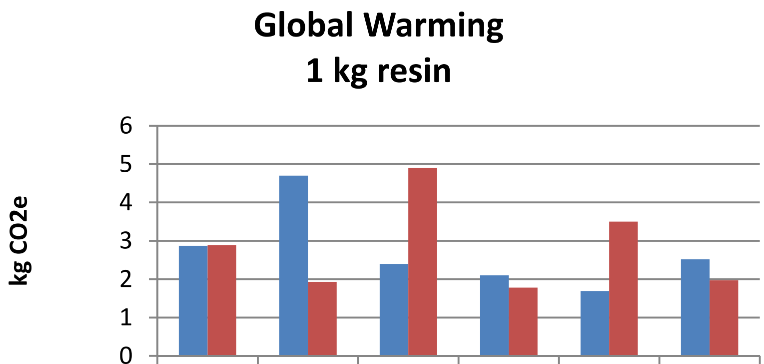
The Franklin inventory is adjusted to utilise electricity supply systems appropriate to Australia and China. It is also adjusted to reflect the contamination rates nominated in this study.

8.1.9.4 Alternative System inventory developed

The Alternative System inventory consists of a production inventory for each of PET, HDPE, LDPE, PP, PS and PVC. Electricity supply and other inputs to the production process are based on European data sets (Ecoinvent).

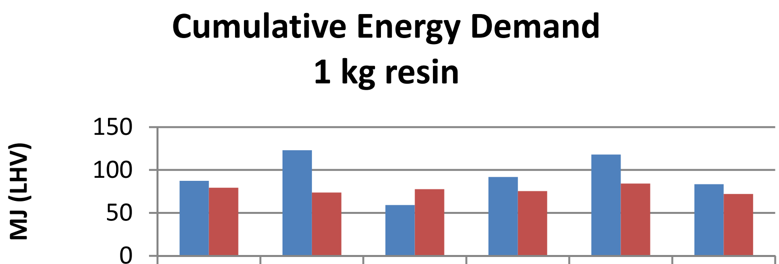
The production of plastics from resources extracted from the environment adopts the Ecoinvent/Plastics Europe inventories. These inventories are utilised as they have been widely published and are thoroughly documented. Unlike other inventories in this study, energy supply systems are not tailored to suit a particular country of production, rather the inventory adopts the electricity supply assumptions in the original inventories (European mix). This may lead to a slightly lower production impact versus regional plastics production, however the advantages of the consistent and well-reviewed data-set are believed to outweigh this shortcoming.

A comparison of the treatment of one tonne of waste plastics under the Recycling System and the Alternative System utilising he inventory described above is shown in Table 34.



	PET	HDPE	PVC	LDPE	PS	PP
AUPLCI	2.87	4.7	2.4	2.1	1.69	2.52
Ecoinvent	2.89	1.93	4.9	1.78	3.5	1.97

Figure 14 Calculated global warming impact for selected resins.



	PET	HDPE	PVC	LDPE	PS	PP
AUPLCI	87.4	123	59.1	91.8	118	83.4
Ecoinvent	79.3	73.7	77.7	75.4	84.2	72

Figure 15 Calculated cumulative energy demand for selected resins.

8.2 Key assumptions for each material

The following tables (Table 32, Table 33 and Table 34) describe key material flows involved in treating one tonne of waste material under the Recycling System and the Alternative System. Each row in the tables shown is intended to represent functional equivalence, such that it is possible to compare the flows associated with each system. The tables are incomplete summaries as it is not possible to show all assumptions in the one diagram.

Where assumptions have been shared between materials, table cells are stretched between material rows. This has been done to clearly indicate areas where material assumptions are common.

The origin of all flows shown in the tables are calculations described in detail in Appendix B – Inventory Report.

Table 32 Key inventory assumptions (Glass, Steel, Aluminium). Flows for 1 t of materials shown

	Recycling System					Alternative System				
Material	**Collection**	**Sorting**	**Reprocess Local**	**Reprocess International**	**Soil carbon storage**	**Production Local**	**Production International**	**Collection**	**Disposal operations**	**Soil carbon storage**
Glass	• Fuel: 7.2 l	• 2.04 kWh electricity • 74 kg Contamination to landfill	• 100% recycled cullet • Produced in Spotswood, Vic • 840 kg glass produced	• None	• None	Glass production (0% cullet) • produced in Spotswood, Vic • 840 kg glass produced Sand mining • Produced in Victoria • 147 kg sand produced	• None	• Fuel: 10.3 l	• 1000 kg landfill • minimal emissions from degradation • unique leachate profile	• None
Steel	• Fuel: 18.3 l	• 0.17 kWh electricity • 74 kg Contamination to landfill	• EAF steel making • processed in Laverton, Vic • 385 kg steel produced	• EAF steel making • processed in Malaysia • Shipped 7677 km • 555 kg steel produced	• None	• BFBOS steel production • produced in Port Kembla, NSW • 350 kg steel produced	• BFBOS steel production • produced in Port Kembla, NSW • 590 kg steel produced • shipped 7677 km to Malaysia	• Fuel: 26.2 l	• 1000 kg landfill • minimal emissions from degradation • unique leachate profile	• None
Aluminium		• 0.12 kWh electricity • 74 kg Contamination to landfill	• Produced in Yennora, NSW • 503 kg aluminium produced	• Produced in Rep. of Korea • Shipped 9349 km • 467 kg aluminium produced	• None	• Produced in Point Henry, Vic • 503 kg aluminium produced	• produced in Point Henry, Vic • 467 kg aluminium produced • shipped 9349 km to Korea		• 1000 kg landfill • minimal emissions from degradation • unique leachate profile	• None

Table 33 Key inventory assumptions (Paper). Flows for 1 t of materials shown.

<table>
<tr><th colspan="2"></th><th colspan="5">Recycling System</th><th colspan="5">Alternative System</th></tr>
<tr><th colspan="2">Material</th><th>Collection</th><th>Sorting</th><th>Reprocess Local</th><th>Reprocess International</th><th>Soil carbon storage</th><th>Production Local</th><th>Production International</th><th>Collection</th><th>Disposal operations</th><th>Soil carbon storage</th></tr>
<tr><td rowspan="3">Paper</td><td>White</td>
<td rowspan="3">• Fuel: 11.9 l</td>
<td rowspan="3">• 3.92 kWh electricity
• 74 kg Contamination to landfill</td>
<td rowspan="3">• Packaging card production (100% rec)
• processed in Botany, NSW
• 370 kg cardboard produced</td>
<td rowspan="3">• Packaging card production (100% rec)
• processed in China
• Shipped 9773 km
• 472 kg cardboard produced</td>
<td rowspan="3">• Minimal (only that associated with reprocessing waste to landfill)</td>
<td rowspan="3">• packaging card production (Kraft)
• produced in Tumut, NSW
• 370 kg cardboard produced</td>
<td rowspan="3">• packaging card production (Kraft)
• produced in China
• 472 kg cardboard produced</td>
<td rowspan="3">• Fuel: 17.1 l</td>
<td>• 1000 kg landfill
• 230 kg methane generated per tonne deposited
• landfill captures 56% of methane
• 92% of methane captured goes to energy generation</td>
<td>• 200 kg carbon stored</td></tr>
<tr><td>Mixed</td>
<td>• 1000 kg landfill
• 39 kg methane generated per tonne deposited
• Landfill captures 56% of methane
• 92% of methane captured goes to energy generation</td>
<td>• 334 kg carbon stored</td></tr>
<tr><td>Cardboard</td>
<td>• 1000 kg landfill
• 55 kg methane generated per tonne deposited
• Landfill captures 56% of methane
• 92% of methane captured goes to energy generation</td>
<td>• 310 kg carbon stored per tonne deposited</td></tr>
</table>

Table 34 Key inventory assumptions (Plastics & Garden and Green). Flows for 1 t of materials shown.

Material		Recycling System: Collection	Recycling System: Sorting	Recycling System: Reprocess Local	Recycling System: Reprocess International	Recycling System: Soil carbon storage	Alternative System: Production Local	Alternative System: Production International	Alternative System: Collection	Alternative System: Disposal operations	Alternative System: Soil carbon storage
Plastic	PET (clear)	• Fuel: 40.2 l	• 1.51 kWh electricity • 74 kg Contamination to landfill	• Processed in Victoria • 426 kg PET pellet produced	• processed in China (Hong Kong) • Shipped 8908 km • 500 kg PET pellet produced	• None	• generic production profile • Plastics Europe model utilised • 926 kg PET pellet produced		• Fuel: 40.2 l	• 1000 kg landfill • minimal emissions from degradation • unique leachate profile	• None
	HDPE (natural)			• processed in Victoria • 348 kg HDPE pellet produced	• processed in China (Hong Kong) • Shipped 8908 km • 410 kg HDPE pellet produced	• None	• generic production profile • Plastics Europe model utilised • 758 kg HDPE pellet produced			• 1000 kg landfill • minimal emissions from degradation • unique leachate profile	• None
	HDPE (coloured)			• None	• processed in China (Hong Kong) • Shipped 8908 km • 758 kg HDPE pellet produced	• None					• None
	Other			• None	• processed in China (Hong Kong) • Shipped 8908 km • 473 kg PP pellet produced • 95 kg LDPE pellet produced • 95 kg PS pellet produced • 95 kg PVC pellet produced	• None	• generic production profile • Plastics Europe model utilised • 579 kg PP pellet produced • 95 kg LDPE pellet produced • 95 kg PS pellet produced • 95 kg PVC pellet produced			• 1000 kg landfill • minimal emissions from degradation • unique leachate profile	• None
Garden and green		• Fuel: 11.6 l	NA	• 100% Windrow composting • 3.45 l fuel for processing • 722 kg compost produced 25% compost distributed to farm applications • 200 km transport to farm gate • Functions as fertiliser, carbon enhancer, herbicide, water retainer 75% compost to urban amenity applications • Functions as a compost product produced from non-kerbside residues • Minimal transport	• None	• 13 kg carbon stored in soil (farm application only)	25% (181 kg) farm applications • 23 kl water extraction • Synthetic fertilisers providing 8 kg N, 8 kg P, 5 kg K • Herbicide (0.1 l glyphosate) • Carbon storage 51 kg 75% (542 kg) urban amenity • Production of alternative compost assumed to have same impact as windrow composting • No fertiliser, water, herbicide requirements No carbon storage		• Fuel: 9.0 l (50% of mass collected; other disposals do not require collection)	50% Landfill (500 kg) • 500 kg landfill • 31 kg methane generated • Landfill captures 60% of methane • 92% of methane captured goes to energy generation 25% Home compost (250 kg) • No carbon storage • Minimal emissions 25% Open burn (250 kg) • No carbon storage • Smog emissions	• 53 kg carbon stored (landfill related)

8.3 Resulting Elementary flows

A summary of elementary flows is shown in Table 35 for the functional unit. The table shows the exchanges with the environment from the system in summary form. The summary is achieved by only showing those flows that contribute more than 1% of any indicator in the impact assessment method.

Table 35 Table of elementary flows associated with 1 functional unit (cut off 1% or less contribution to an indicator). Net flow shown.

Compartment	Substance	Unit	Amount
Air	Carbon dioxide, fossil	kg	25.854
Air	Dinitrogen monoxide	kg	-0.027
Air	Methane	kg	-11.410
Air	Nitrogen oxides	kg	-0.789
Air	NMVOC, non-methane volatile organic compounds, unspecified origin	kg	-0.136
Air	Sulfur dioxide	kg	0.283
Air	VOC, volatile organic compounds	kg	-0.013
Air	Carbon dioxide	kg	-17.003
Air	Methane, biogenic	kg	-0.606
Air	Carbon monoxide	kg	-2.125
Air	Carbon monoxide, biogenic	kg	-3.896
Raw	Coal, 26.4 MJ per kg, in ground	kg	3.371
Raw	Coal, hard, unspecified, in ground	kg	18.583
Raw	Copper, in ground	kg	0.003
Raw	Gas, natural, 36.6 MJ per m3, in ground	m3	2.056
Raw	Gas, natural, in ground	m3	-11.768
Raw	Occupation, urban, green areas	m2a	2.315
Raw	Oil, crude, 42.8 MJ per kg, in ground	kg	-0.266
Raw	Oil, crude, in ground	kg	-12.506
Raw	Uranium, in ground	kg	0.000
Raw	Water, cooling, unspecified natural origin/m3	m3	-1.003
Raw	Water, unspecified natural origin /kg	kg	-136.042
Raw	Water, unspecified natural origin/m3	m3	-2.965
Raw	Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	kg	0.227
Raw	Bauxite, in ground	kg	-16.640
Raw	Iron ore, in ground	kg	-11.664
Raw	Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	kg	-0.019
Raw	Coal, 18.0 MJ per kg, in ground	kg	-1.738
Raw	Coal, 28.0 MJ per kg, in ground	kg	-5.264
Raw	Coal, 29.3 MJ per kg, in ground	kg	-0.738
Raw	Coal, brown, 10.0 MJ per kg, in ground	kg	40.666
Raw	Coal, brown, in ground	kg	-1.400
Raw	Gas, mine, off-gas, process, coal mining/m3	m3	0.208
Raw	Oil, crude, 42.0 MJ per kg, in ground	kg	-5.036
Raw	Oil, crude, 43.4 MJ per kg, in ground	kg	-2.157
Raw	Occupation, arable, non-irrigated	m2a	19.745
Raw	Occupation, forest, intensive, short-cycle	m2a	-246.033
Raw	Water, salt, ocean	m3	-0.324
Raw	Water, unspecified natural origin/kg	kg	-424.168
Raw	Energy, from biomass	MJ	-1,509.310
Waste	Waste, final, inert	kg	-265.002
Waste	bauxite residue	kg	-8.668
Water	COD, Chemical Oxygen Demand	kg	-0.854
Water	Nitrate	kg	-2.635
Soil	Carbon dioxide, biogenic	kg	-49.947

9 Results

The following section describes the results of the impact assessment for a single functional unit (treatment of one Victorian household's recycling for one year). The tables shown describe the outcome of the impact assessment for each indicator described in the impact assessment method (**Table 13**). To simplify the presentation of the results, an abbreviated description of the indicators has been used, in accordance with the following key:

- GW – Global warming
- EU – Eutrophication
- PO – Photochemical oxidation
- MD – Minerals depletion
- FFD – Fossil fuels depletion
- LU – Land use
- WU – Water use
- SW – Solid waste
- CED – Cumulative energy demand

The fundamental result of the study is shown in Table 36. The table describes the net life cycle impact of recycling in Victoria in terms of the environmental indicators described in **Table 13**. The Net Outcome for each indicator is calculated by applying the definition of recycling benefit described by Figure 9. Results that are positive represent burdens (adverse outcomes) and results that are negative represent benefits (favourable outcomes).

Table 36 Characterisation result, broken down by material collected, for 1 functional unit (rounded to 2 significant figures).

Net Outcome -ve Benefit, +ve Burden	*Mass collected*	**GW**	**EU**	**PO**	**MD**	**FFD**	**LU**	**WU**	**SW**	**CED**
	*kg per year**	kg CO2 eq	kg PO4--- eq	kg NMVOC	$	$	ha.a	kL H2O	kg	MJ LHV
Glass bottles	*72*	-38	-0.026	-0.17	0.0096	-0.39	-0.000021	-0.067	-79	-320
Steel cans	*8*	-14	-0.0028	-0.032	-0.83	-0.14	0.000014	-0.34	-7.1	-120
Alum. Cans	*3*	-50	-0.023	-0.23	-0.06	-0.69	-0.00023	-0.088	-14	-620
Paper - white	*1*	-1.3	-0.0021	-0.0041	0.00025	0.012	-0.00014	-0.011	-0.5	0.68
Paper - mixed	*110*	-50	-0.2	-0.2	0.027	0.97	-0.016	-1.2	-73	-40
Paper - card	*45*	-7.6	-0.072	-0.073	0.011	0.38	-0.0064	-0.5	-31	-21
Plastic - PET	*8*	-9.6	-0.022	-0.021	-0.1	-0.46	-0.0000068	-0.55	-7.9	-440
Plastic - HDPE	*4*	-3.3	-0.00016	-0.019	0.0011	-0.23	0.000014	-0.091	-3.6	-200
Plastic - HDPE (col)	*3*	-2.4	0.0002	-0.012	0.00097	-0.17	0.000011	-0.067	-2.7	-150
Plastic - mixed	*8*	-2.5	0.00034	-0.0097	0.0027	-0.27	0.000028	-0.21	-7.3	-240
Garden and green	*304*	-68	-0.037	-0.44	-0.0015	0.28	0.000066	-1.7	-51	94
Total System	***566***	**-250**	**-0.38**	**-1.2**	**-0.94**	**-0.72**	**-0.022**	**-4.9**	**-280**	**-2100**
Uncertainty										
2.5 percentile	*566*	-340	-0.68	-2.3	-1.1	-1.7	-0.046	-7.3	-280	-3200
97.5 percentile	*566*	-130	-0.19	-0.47	-0.79	1.2	-0.0091	-2.8	-260	4.2

* 21 kg contamination removed at MRF not shown, but included in results.

<u>Positives and negatives</u>

The decision to present results in a manner where positive values represent burdens (adverse outcomes) was taken in order to remain true to the difference equation described in Figure 7 and the convention in LCA reports to represent impacts as positive values. In truth, a problem with comparative studies where differences rather than absolutes are the focus, is that the signing convention needs to be regularly considered by the reader.

<u>Uncertainty</u>

In an effort to transparently address the a mix of data qualities encountered in the study, both within the systems studied directly and the background inventories, a Monte Carlo simulation was undertaken for the study result shown in Table 36. This simulation utilised uncertainty data contained within the background inventories employed and all the study inventories developed. For the developed inventories, the uncertainty information was calculated from the pedigree matrix described in Section 5.6.

The results of these simulations are shown in the lower rows of the table, titled '2.5 percentile' and '97.5 percentile'. These values indicate the lower and upper limits within which 95% of study Net

Outcome values were calculated (1000 runs were undertaken for each Net Outcome value). Larger ranges indicate more uncertain outcomes and smaller ranges indicate less uncertain outcomes.

An important objective of the study was to determine the contribution of materials recovered to the overall system result. While Table 36 does this, in terms of the functional unit and reference flows, it is also useful to understand how individual materials compare on a standard mass basis. Table 37 achieves this end by presenting the study results in terms of a standardised one tonne of material recovered.

Table 37 Characterisation for 1 t of each material collected (rounded to 2 significant figures).

Net Outcome -ve Benefit, +ve Burden	*Mass collected*	**GW**	**EU**	**PO**	**MD**	**FFD**	**LU**	**WU**	**SW**	**CED**
	tonnes	kg CO2 eq	kg PO4--- eq	kg NMVOC	$	$	ha.a	kL H2O	kg	MJ LHV
Glass bottles	*1*	-530	-0.36	-2.3	0.13	-5.5	-0.00029	-0.94	-1100	-4500
Steel cans	*1*	-1700	-0.35	-4	-100	-18	0.0018	-42	-880	-15000
Alum. Cans	*1*	-17000	-7.7	-76	-20	-230	-0.078	-29	-4700	-210000
Paper - white	*1*	-1300	-2.1	-4.1	0.25	12	-0.14	-11	-500	680
Paper - mixed	*1*	-450	-1.8	-1.8	0.24	8.8	-0.14	-11	-660	-360
Paper - card	*1*	-170	-1.6	-1.6	0.24	8.5	-0.14	-11	-680	-470
Plastic - PET	*1*	-1200	-2.8	-2.6	-13	-57	-0.00084	-69	-990	-55000
Plastic - HDPE	*1*	-840	-0.041	-4.7	0.28	-58	0.0035	-23	-910	-51000
Plastic - HDPE (col)	*1*	-790	0.067	-4	0.32	-57	0.0036	-22	-910	-50000
Plastic - mixed	*1*	-320	0.043	-1.2	0.34	-34	0.0036	-26	-910	-29000
Garden and green	*1*	-230	-0.12	-1.5	-0.005	0.93	0.00022	-5.7	-170	310

It is also useful to present results in terms of the key processes that contribute to the study outcomes. Using the key processes described in Section 8 as a framework, Table 38 describes the contributions of processes to the overall result. A more detailed breakdown for all processes and materials is shown in Appendix C – Detailed Results by Material.

Table 38 Characterisation result, broken down by key process, for 1 functional unit (rounded to 2 significant figures).

		Recycling System					Alternative System					**Net Outcome -ve Benefit, +ve Burden**
	Unit	Collection Recycling	Sorting	Reprocess Local	Reprocess International	Soil carbon storage	Production Local	Production International	Collection Landfill	Disposal operations	Landfill carbon storage	
GW	kg CO2 eq	27	22	140	150	-14	-170	-140	-28	-300	63	**-250**
EU	kg PO4--- eq	0.025	0.032	0.16	0.15	0	-0.13	-0.12	-0.026	-0.47	0	**-0.38**
PO	kg NMVOC	0.21	0.089	0.77	0.73	0	-0.91	-0.72	-0.22	-1.1	0	**-1.2**
MD	$	0.0002	0.042	0.084	0.063	0	-0.5	-0.62	-0.00015	-0.0088	0	**-0.94**
FFD	$	0.54	0.18	1.7	1.6	0	-2.4	-2.4	-0.54	0.6	0	**-0.72**
LU	ha.a	0.00	0.00	0.00	0.00	0.00	-0.01	-0.02	0.00	0.00	0.00	**-0.022**
WU	kL H2O	0.041	0.035	0.3	1.8	0	-3.4	-3.6	-0.031	0.029	0	**-4.9**
SW	kg	1.1	18	56	15	0	-12	-6.2	-0.82	-350	0	**-280**
CED	MJ LHV	450	180	1500	1700	0	-2600	-2800	-450	13	0	**-2100**

10 Discussion

The results shown in Table 36 show that in terms of all indicators considered, the Recycling System generates a preferable outcome versus the Alternative System. The Alternative System, one where nearly all waste is interred in landfill, is inferior with respect to the indicators considered.

10.1 Directional conclusions

Uncertainty ranges shown in Table 36 are favourable for most of the indicators considered. This outcome makes it possible to conclude that the Recycling System is preferable to the Alternative System, even when data uncertainty is taken into account. The uncertainty ranges also indicate the limitations of the study when it comes to exact findings, and comparison to other studies.

Two indicators where conclusions change under the uncertainty analysis are fossil fuels depletion and cumulative energy demand. Fossil fuel depletion in this study is hard to assess because it is significantly influenced by transportation fuel use, which itself is relatively uncertain. A review of transportation data quality indicates that significant uncertainty exists in processes from waste collection through to shipment of material for international reprocessing. Although best available information is used to estimate transportation distances, other factors such as vehicle utilisation and fuel efficiency make transport impacts difficult to estimate. In recognition of this, the pedigree matrix used to assess data quality allocates a higher basic uncertainty to transport data points versus other process data (Frischknecht and Jungbluth, 2004).

Cumulative energy demand outcomes also change directionally within the range, however this is largely due to a skewed simulation outcome. Figure 16 highlights the skewed nature of the distribution, indicating that only a small fraction of runs resulted in unfavourable outcomes.

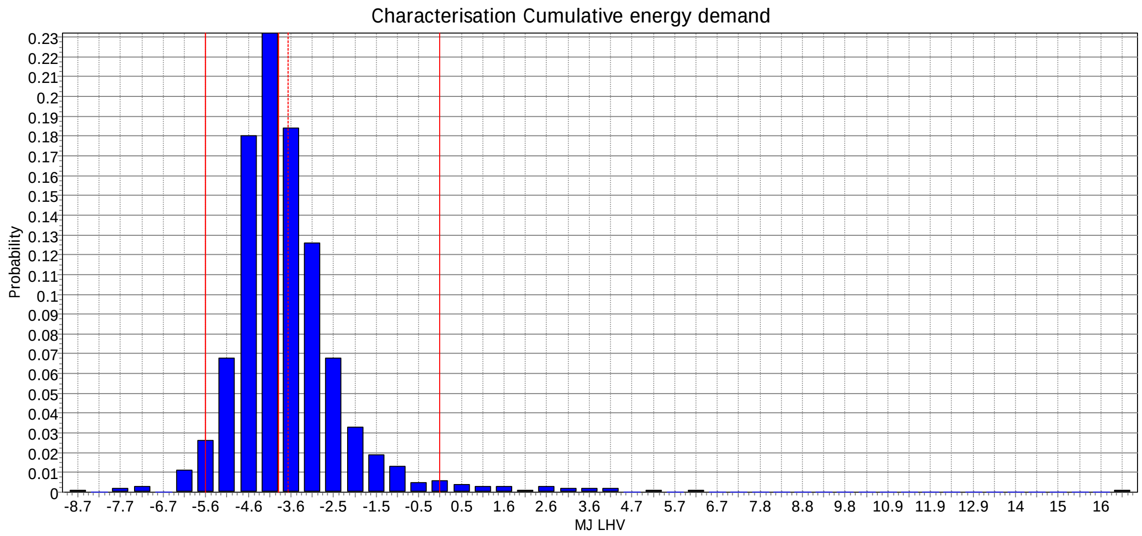


Figure 16 Histogram of simulation outcomes for cumulative energy demand.

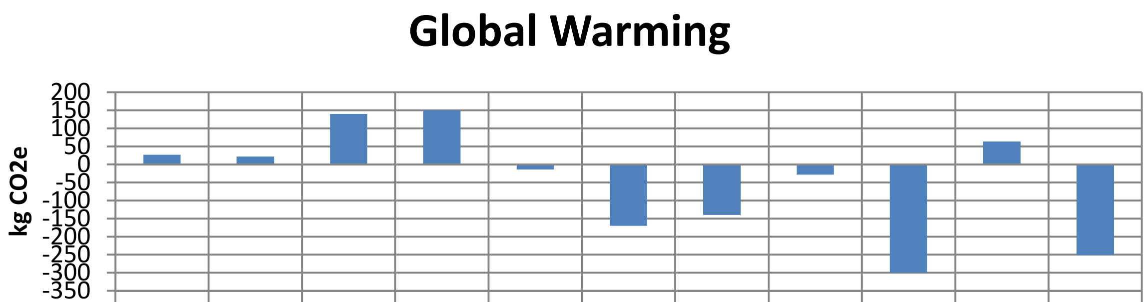
An exact cause for the simulation outcome shown in Figure 16 is hard to pin down as it is the cumulative result of many random events. Areas within the study where cumulative energy demand is likely to be sensitive to data uncertainty relate to coal, particularly quantities and qualities of coal used in China to generate a unit of heat output. Energy in biomass, used in paper production is also uncertain.

Overall, situations where study directional conclusions alter under the uncertainty analysis were very few, suggesting conclusions are directionally robust.

10.2 Global warming

Avoided waste disposal (landfill predominantly) emissions are the largest beneficial contributor to the net global warming benefit of 250 kg CO2e (Figure 17) associated with the Recycling System. Disposal emissions are avoided from garden and green waste (111 kg CO2e), mixed paper (124 kg CO2e) and cardboard (47 kg CO2e). These emissions account for the bulk of the avoided landfill impact. Reprocessing of paper accounts for 65% of the combined local and international reprocessing burden, and garden and green waste accounts for 13% (from Table 57).

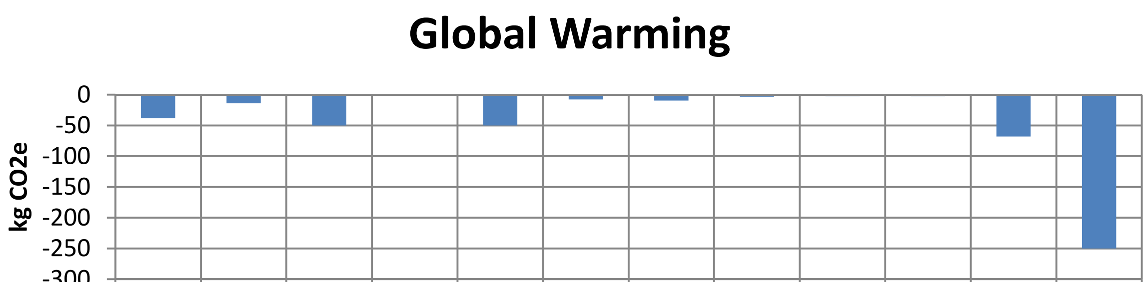
Moderate reprocessing burdens (39 kg CO2e) yet large avoided landfill emissions (111 kg CO2e) and avoided production emissions (12 kg CO2e) make garden and green waste recycling the largest contributor to the overall outcome (Figure 18).



	Collection Recycling	Sorting	Reprocess Local	Reprocess International	Soil carbon storage	Production Local	Production International	Collection Landfill	Disposal operations	Landfill carbon storage	Net Outcome (Benefit)/ Burden
GW	27	22	140	150	-14	-170	-140	-28	-300	63	-250

Figure 17 global warming impact by process (1 functional unit).

From a global warming standpoint, aluminium is one of the most beneficial materials to recycle on a unit mass basis. For every tonne recovered 17 t CO2e of greenhouse gas emissions are avoided (Table 37). Although aluminium is recovered in small quantities (3 kg p.a. per household) the material contributes significantly to the global warming benefits of the Recycling System. Other materials, such as glass, paper and garden and green waste are collected in large quantities yet deliver smaller global warming benefits per tonne collected (Table 37). Overall, glass, aluminium, mixed paper and garden and green waste drive 82% of the global warming benefits of the Recycling System.



	Glass bottles	Steel cans	Alum. Cans	Paper - white	Paper - mixed	Paper - card	Plastic - PET	Plastic - HDPE	Plastic - HDPE (col)	Plastic - mixed	Garden and green	Total
GW	-38	-14	-50	-1.3	-50	-7.6	-9.6	-3.3	-2.4	-2.5	-68	-250

Figure 18 Global warming impact by material (1 functional unit).

10.3 Eutrophication

The eutrophication benefit of the Recycling System of 0.38 kg PO4---eq. is largely driven by the avoidance of waste disposal (predominantly to landfill) (Figure 19). Within the landfill, the disposal of paper causes the largest eutrophication impacts due to the emission of nitrates and phosphates to landfill leachate (0.3 kg PO4---eq.). Although, leachate from the landfill passes through a treatment process, a portion of the phosphates and nitrates are emitted to the environment as the paper degrades. As this outcome is based on modelled results (Doka, 2009), it is highly uncertain, so must be interpreted with care.

Eutrophication impacts associated with reprocessing and the avoided impacts associated with production are primarily driven by atmospheric emissions of nitrogen oxides. These nitrogen oxide emissions (NO_x) occur during combustion of fuels in internal combustion engines so are linked to transport in many cases. The connection between environmental eutrophication outcomes and nitrogen oxide emissions in Australia is not straightforward (Grant and Peters, 2008), and may be overestimated by the impact assessment model employed. As the impact of this form of eutrophication is evenly balanced between recyclate reprocessing and avoided production, any overstatement of impact is likely to minimal.

From a materials standpoint, the recycling of paper generates the largest eutropication benefit (Figure 20) followed by garden and green waste.

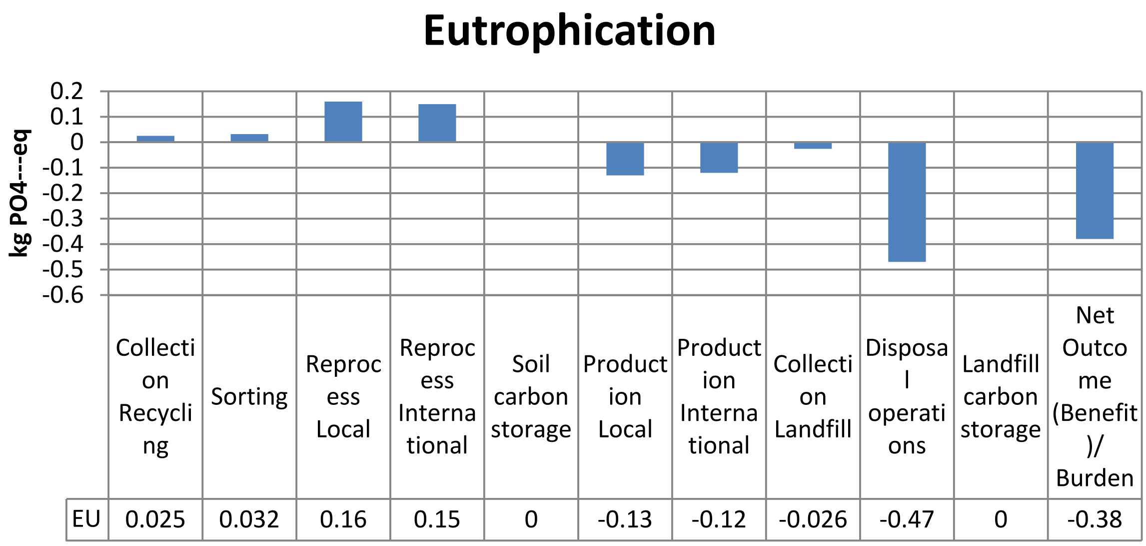
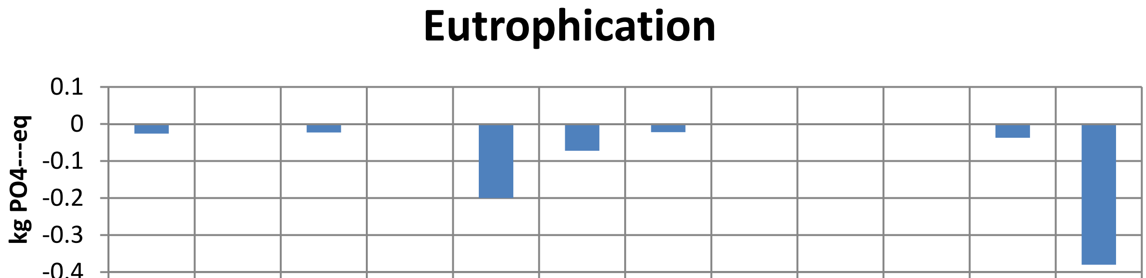


Figure 19 Eutrophication impact by process (1 functional unit).



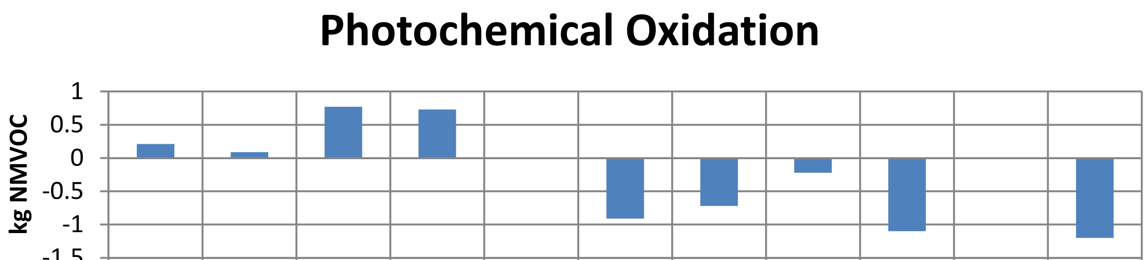
	Glass bottles	Steel cans	Alum. Cans	Paper - white	Paper - mixed	Paper - card	Plastic - PET	Plastic - HDPE	Plastic - HDPE (col)	Plastic - mixed	Garden and green	Total
EU	-0.026	-0.003	-0.023	-0.002	-0.2	-0.072	-0.022	-2E-04	0.0002	0.0003	-0.037	-0.38

Figure 20 Eutrophication impact by material (1 functional unit).

10.4 Photochemical Oxidation

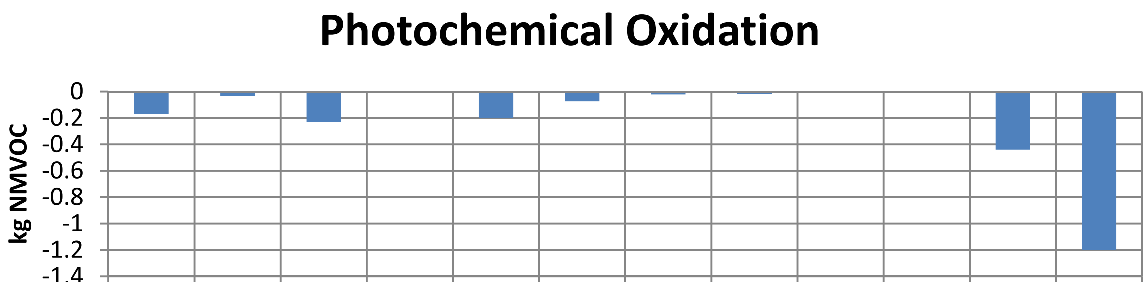
In this study, photochemical oxidation (smog) is mainly caused by the emission of nitrogen oxides, Non Methanic Volatile Organic Compounds (NMVOCs) and carbon monoxide emissions (together approximately 90% of total impact). Photochemical oxidation is caused by material reprocessing processes within the Recycling System and material manufacturing processes under the Alternative System, in roughly even, offsetting quantities (Figure 21). The benefit of recycling is therefore driven by avoided emissions caused by the combustion of landfill gas for electricity generation at the landfill site under the Alternative System.

When individual materials are considered, the greatest photochemical smog benefits are caused by recycling glass, aluminium, paper and garden and green wastes (Figure 22). Glass and aluminium recycling avoid nitrogen oxides emitted during production of these materials from virgin resources. Paper and garden and green waste recycling largely avoids smog causing emissions due to combustion of landfill gas at the landfill, although production emissions too are avoided.



	Collection Recycling	Sorting	Reprocess Local	Reprocess International	Soil carbon storage	Production Local	Production International	Collection Landfill	Disposal operations	Landfill carbon storage	Net Outcome (Benefit)/ Burden
PO	0.21	0.089	0.77	0.73	0	-0.91	-0.72	-0.22	-1.1	0	-1.2

Figure 21 Photochemical oxidation impact by process (1 functional unit).



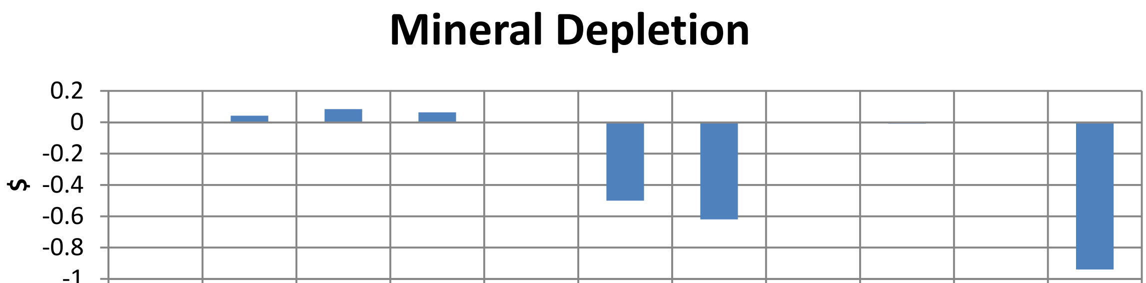
	Glass bottles	Steel cans	Alum. Cans	Paper - white	Paper - mixed	Paper - card	Plastic - PET	Plastic - HDPE	Plastic - HDPE (col)	Plastic - mixed	Garden and green	Total
PO	-0.17	-0.032	-0.23	-0.004	-0.2	-0.073	-0.021	-0.019	-0.012	-0.01	-0.44	-1.2

Figure 22 Photochemical oxidation impact by material (1 functional unit).

10.5 Minerals Depletion

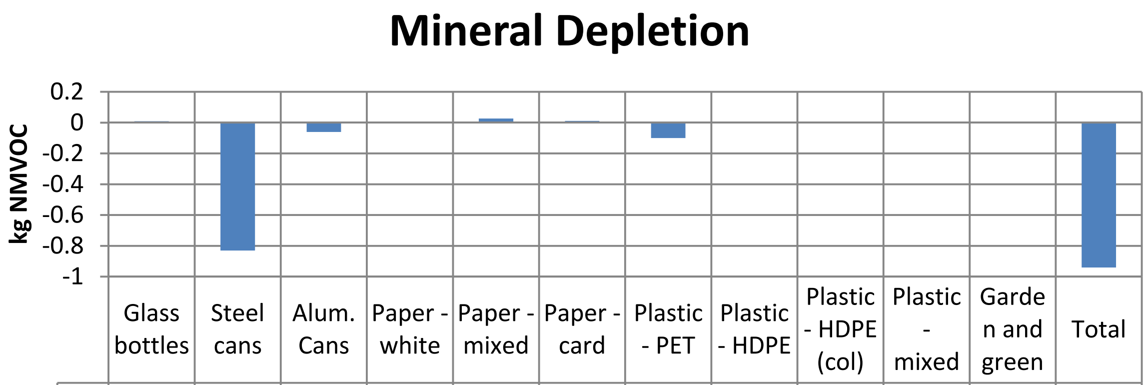
The net minerals depletion outcome of $0.94 is caused by steel recycling (Figure 24). By recycling steel, iron ore does not need to be mined from the earth thus preserving resources for future use. The benefit of avoiding production of steel from iron ore is illustrated in Figure 23.

Notably, aluminium and glass are not seen to contribute to this indicator. This is partially because aluminium is collected in relatively small quantities, but also because both these materials are primarily made from relatively abundant minerals, bauxite and sand respectively. The energy intensity of production for both materials is apparent in other indicators, such as global warming and cumulative energy demand.



	Collection Recycling	Sorting	Reprocess Local	Reprocess International	Soil carbon storage	Production Local	Production International	Collection Landfill	Disposal operations	Landfill carbon storage	Net Outcome (Benefit)/ Burden
MD	0.0002	0.042	0.084	0.063	0	-0.5	-0.62	-2E-04	-0.009	0	-0.94

Figure 23 Minerals depletion impact by process (1 functional unit).



	Glass bottles	Steel cans	Alum. Cans	Paper - white	Paper - mixed	Paper - card	Plastic - PET	Plastic - HDPE	Plastic - HDPE (col)	Plastic - mixed	Garden and green	Total
MD	0.0096	-0.83	-0.06	0.0003	0.027	0.011	-0.1	0.0011	0.001	0.0027	-0.002	-0.94

Figure 24 Minerals depletion impact by material (1 functional unit).

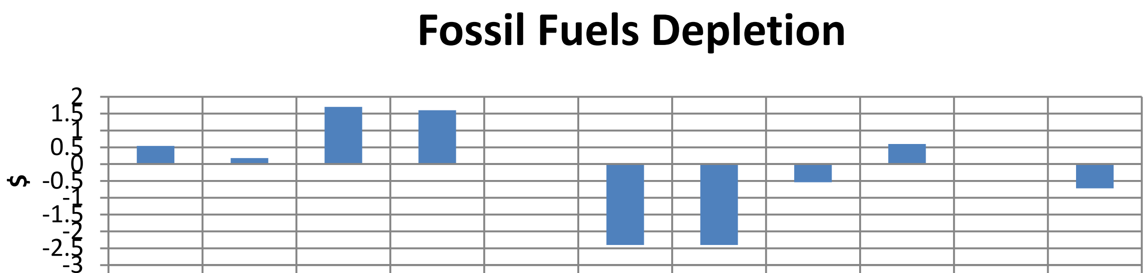
10.6 Fossil Fuels Depletion

The Recycling System's $0.72 net benefit for fossil fuels depletion incorporates a range of offsetting impacts amongst both processes and materials. From a process standpoint, the Recycling System depletes fossil fuels in operation as it requires energy to operate collection, sorting and reprocessing processes, the majority of which is derived from fossil fuels. The overall net benefit is brought about by virtue of the avoided production of materials, which require more fossil fuels to produce from primary resources than they do to reprocess under the Recycling System (Figure 25). An exception to the pattern seen in other indicators is that the avoidance of landfill operation actually has an adverse impact upon fossil fuels depletion as it also avoids the generation of electricity from landfill, which must therefore be supplied from fossil sources under the Recycling System scenario.

Fossil fuels depletion is one of the few indicators where some materials contribute adversely to the Net Outcome. In this indicator the recycling of paper and green and garden waste both deliver worse outcomes than the Alternative System (Figure 26).

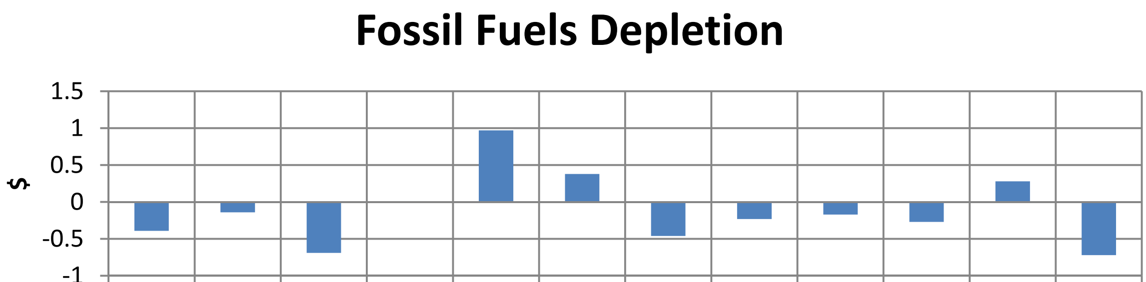
For paper this outcome is partially caused by the avoided electricity generation from landfill, discussed above, but mostly by reprocessing which is more fossil fuel intensive than production from fibre sourced from trees. This is because much of the energy used in kraft paper production from forest sources is supplied by the combustion of forest residues and pulp manufacturing by-products such as black liquor. When paper is reprocessed from kerbside waste, most of the energy used in the process is supplied from fossil sources. The fossil fuels depletion intensity of paper produced from forest sources (locally) is $3.97 per tonne, whereas the local reprocessing intensity is $6.07 per tonne (Table 58).

For garden and green waste, the adverse fossil fuels depletion outcome stems solely from the loss of electricity generation from landfill, which must be supplied from fossil sources under the Recycling System.



	Collection Recycling	Sorting	Reprocess Local	Reprocess International	Soil carbon storage	Production Local	Production International	Collection Landfill	Disposal operations	Landfill carbon storage	Net Outcome (Benefit)/ Burden
FFD	0.54	0.18	1.7	1.6	0	-2.4	-2.4	-0.54	0.6	0	-0.72

Figure 25 Fossil fuels depletion by process (1 functional unit).



	Glass bottles	Steel cans	Alum. Cans	Paper - white	Paper - mixed	Paper - card	Plastic - PET	Plastic - HDPE	Plastic - HDPE (col)	Plastic - mixed	Garden and green	Total
FFD	-0.39	-0.14	-0.69	0.012	0.97	0.38	-0.46	-0.23	-0.17	-0.27	0.28	-0.72

Figure 26 Fossil fuels depletion by material (1 functional unit).

10.7 Land Use

The net land use benefit of 0.02 Ha.a is entirely driven by avoided paper production (Figure 28). By recycling paper the land area required to be occupied by forest plantations necessary to supply pulp-logs for paper production is reduced (Figure 27).

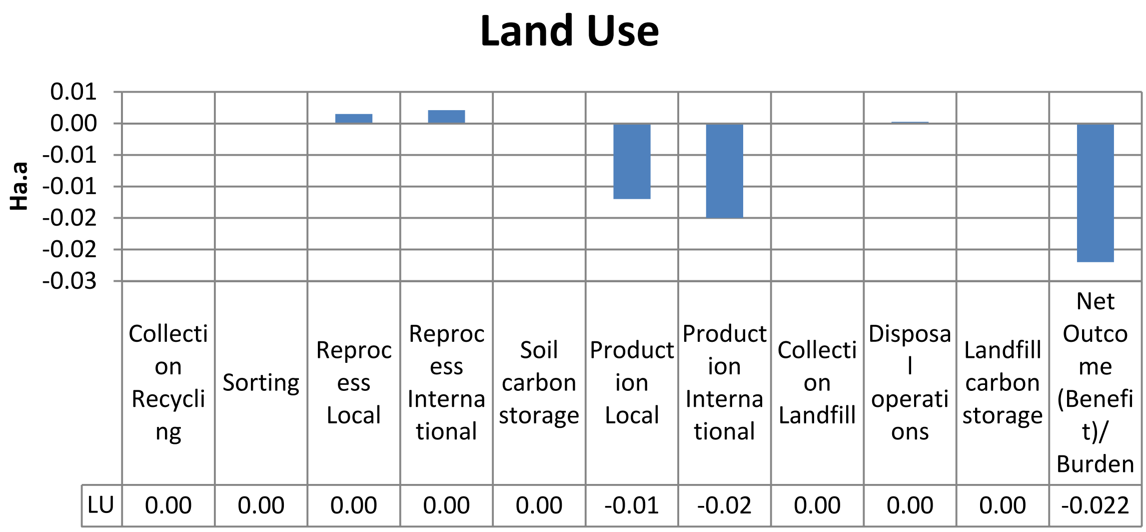


Figure 27 Land use by process (1 functional unit).

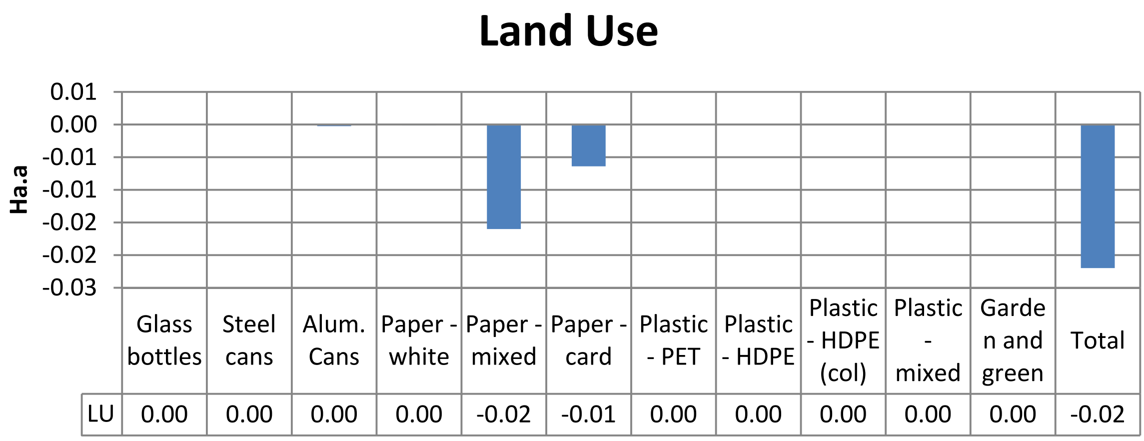
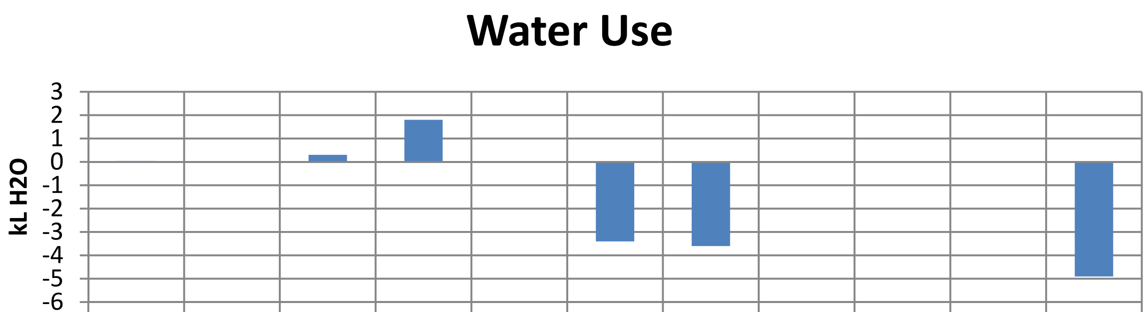


Figure 28 Land use impacts by material (1 functional unit).

10.8 Water Use

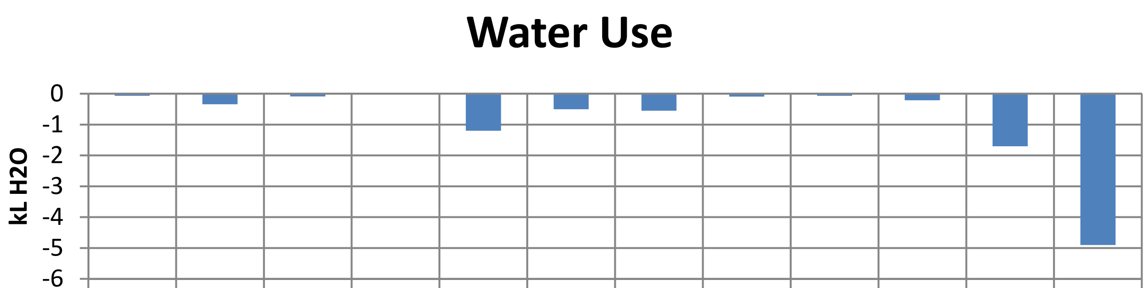
Like land use, the water use benefit of 4.9 kL is caused mostly by one material, garden and green waste (Figure 30). By recycling garden and green waste into compost products and applying those products in agriculture, the water needs of crops are reduced. Although recycling other materials such as aluminium and plastics generate higher water use benefits per tonne (Table 37) the large quantity of garden and green waste (54% of mass recovered) recovered versus these materials (5% of mass recovered) causes garden and green waste to drive the outcome.

Figure 29 Water use by process (1 functional unit).



	Collection Recycling	Sorting	Reprocess Local	Reprocess International	Soil carbon storage	Production Local	Production International	Collection Landfill	Disposal operations	Landfill carbon storage	Net Outcome (Benefit)/ Burden
WU	0.041	0.035	0.3	1.8	0	-3.4	-3.6	-0.031	0.029	0	-4.9

Figure 30 Water use impacts by material (1 functional unit).



	Glass bottles	Steel cans	Alum. Cans	Paper - white	Paper - mixed	Paper - card	Plastic - PET	Plastic - HDPE	Plastic - HDPE (col)	Plastic - mixed	Garden and green	Total
WU	-0.067	-0.34	-0.088	-0.011	-1.2	-0.5	-0.55	-0.091	-0.067	-0.21	-1.7	-4.9

10.9 Solid Waste

The solid waste outcome of 280 kg benefit is almost entirely due to the avoidance of landfill, which is one of the key reasons recycling is undertaken. The reason the avoided mass is not equal to the full 566 kg of recyclate generated is partly because some landfill is generated as the material is collected, sorted and reprocessed. It is also because the landfill indicator excludes the moisture present in the waste (estimated as 10% for papers and 60% for green and garden waste), and any mass lost due to material degradation in the landfill within a 100 year period (for example, the mass of carbon emitted as greenhouse gasses).

Given that the solid waste outcome is caused by landfill avoidance, the indicator is driven by the mass flows of materials recycled (Figure 32).

	Collection Recycling	Sorting	Reprocess Local	Reprocess International	Soil carbon storage	Production Local	Production International	Collection Landfill	Disposal operations	Landfill carbon storage	Net Outcome (Benefit)/ Burden
SW	1.1	18	56	15	0	-12	-6.2	-0.82	-350	0	-280

Figure 31 Solid waste by process (1 functional unit).

	Glass bottles	Steel cans	Alum. Cans	Paper - white	Paper - mixed	Paper - card	Plastic - PET	Plastic - HDPE	Plastic - HDPE (col)	Plastic - mixed	Garden and green	Total
SW	-79	-7.1	-14	-0.5	-73	-31	-7.9	-3.6	-2.7	-7.3	-51	-280

Figure 32 Solid waste impacts by material (1 functional unit).

10.10 Cumulative Energy Demand

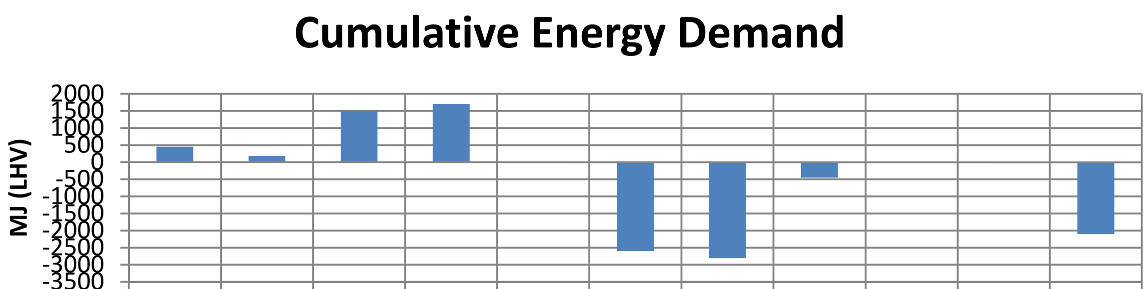
The Recycling System requires energy in order to operate so must avoid a greater amount of energy use in the Alternative System to generate a net benefit. This is indeed the case, as the energy requirements of the Recycling System are less than the Alternative system by 2100 MJ (LHV). The Recycling System benefit is derived from the lower energy requirements of the reprocessing system versus the material production processes of the Alternative System (Figure 33).

Materials being reprocessed that generated the greatest benefits are aluminium, glass and the plastics (Figure 34). The energy intensity of aluminium production from virgin resources versus aluminium scrap reprocessing is emphasised by the significant contribution aluminium makes to the overall Recycling System benefit. Only 3 kg (1% of collected materials) of aluminium is collected yet it contributes 30% of the energy benefit of the Recycling System. There is little difference in the energy required to produce packaging paper (kraft process) from forest resources versus producing it from waste paper, so paper contributes little to the overall energy balance[8].

It must be remembered that CED is not a measure of environmental impact, rather a precursor

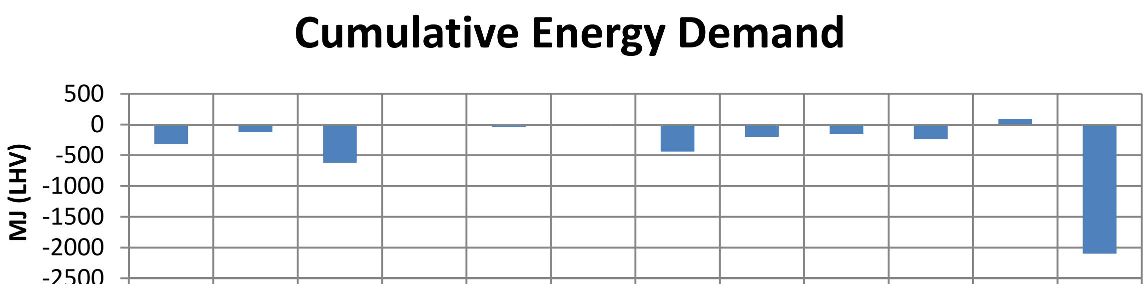
[8] Calculation includes energy derived from biomass used to produce paper in the kraft process (integrated pulp and paper mill).

measure that is useful for assessing system energy efficiency, and for comparing LCA studies as it is commonly calculated. The finding in this study that paper recycling requires more primary energy than disposing of paper to landfill is silent as the impact this might have upon the environment.



	Collection Recycling	Sorting	Reprocess Local	Reprocess International	Soil carbon storage	Production Local	Production International	Collection Landfill	Disposal operations	Landfill carbon storage	Net Outcome (Benefit)/ Burden
CED	450	180	1500	1700	0	-2600	-2800	-450	13	0	-2100

Figure 33 Cumulative energy demand by process (1 functional unit).



	Glass bottles	Steel cans	Alum. Cans	Paper - white	Paper - mixed	Paper - card	Plastic - PET	Plastic - HDPE	Plastic - HDPE (col)	Plastic - mixed	Garden and green	Total
CED	-320	-120	-620	0.68	-40	-21	-440	-200	-150	-240	94	-2100

Figure 34 Cumulative energy demand impacts by material (1 functional unit).

11 Validation

11.1 Comparison to the prior study

Since the prior LCA study of recycling in Victoria (Grant et al., 2001a) many aspects of the recycling system have changed. Notable amongst the changes are the following:

- Move to comingled recycling bins across the state
- Significantly increased collection of garden and green waste
- Increased use of international reprocessors
- Improvements in the management of landfill
- Increased recycling rates overall
- Changes to reprocessing pathways

The mass of material recycled has increased since the prior study as shown in Table 39.

Table 39 Comparison of recycling quantities (values shown in kg per household per year).

	Mass Recycled	
Material	This study	Grant (2001)
Glass bottles	72	61
Steel cans	8	9
Alum. Cans	3	2
Paper - white	156	147
Paper - mixed		
Paper - card		
Plastic - PET	8	6
Plastic - HDPE	7	5
Plastic - HDPE (col)		
Plastic - mixed	8	0
Garden and green	304	Not Assessed
	566	229

A comparison of study results on a mass basis shows that changes beyond the quantities recycled have also occurred. These changes are reviewed and the differences explained in Table 40, Table 41 and Table 42.

Table 40 Global warming impact comparison (1 t of materials recycled). Results shown in kg CO_2e

	GW		
Material	This study	Grant (2001) US EPA Scenario	Reasons for difference
Glass bottles	-527	-347.86	The glass bottle production inventory used is more complete than Grant (2001) and better reflects local furnace technology (gas heat, with electric boost). Production inventory correlates well with published data regarding glass production in the region (Owens Illinois 2010). Possible difference in cullet recovery fraction.
Steel cans	-1,737	-1,100.00	Newer inventory for steel production in Australia (Energetics 2012).
Alum. Cans	-16,614	-14,800.00	Newer data for aluminum production. Incorporates latest industry reporting
Paper - white	-1,347	-930.56	Newsprint (TMP) pulp used as avoided product in Grant. ONP no longer utilised in TMP production.
Paper - mixed	-451		
Paper - card	-170		
Plastic - PET	-1,206	-954.55	Data source for plastics reporcessing updated. Production inventories based on Plastics Europe ecoprofiles.
Plastic - HDPE	-837	-600.00	Data source for plastics reporcessing updated. Production inventories based on Plastics Europe ecoprofiles.
Plastic - HDPE (col)	-789		Data source for plastics reporcessing updated. Production inventories based on Plastics Europe ecoprofiles.
Plastic - mixed	-317	NA	NA
Garden and green	-225	NA	NA

Table 41 Cumulative energy demand comparison(1 t of materials recycled). Results shown in MJ (LHV).

	CED		
Material	This study	Grant (2001) US EPA Scenario	Reasons for difference
Glass bottles	-4,509	-3,776	The glass bottle production inventory used is more complete than Grant (2001) and better reflects local furnace technology (gas heat, with electric boost). Production inventory correlates well with published data regarding glass production in the region (Owens Illinois 2010). Possible difference in cullet recovery fraction.
Steel cans	-14,921	-28,129	Newer inventory for steel production in Australia (Energetics 2012).
Alum. Cans	-207,339	-177,867	Newer data for aluminum production. Incorporates latest industry reporting
Paper - white	681	-2,444	Newsprint (TMP) pulp used as avoided product in Grant. ONP no longer utilised in TMP production.
Paper - mixed	-363		
Paper - card	-468		
Plastic - PET	-55,256	-49,182	Minor change.
Plastic - HDPE	-50,951	-49,730	Minor change.
Plastic - HDPE (col)	-50,201		Minor change.
Plastic - mixed	-29,497	NA	NA
Garden and green	309	NA	NA

Table 42 Water use comparison (1 t of materials recycled). Results shown in kL.

	WU		
Material	This study	Grant (2001) US EPA Scenario	Reasons for difference
Glass bottles	-1	-2.04	Minor change
Steel cans	-42	-0.88	More complete inventory from Energetics
Alum. Cans	-29	-1,716.67	Error in Grant inventory. Water use Bauxite mining.
Paper - white	-11	-22.48	Visy paper production at Tumut increased efficiency from Grant. ONP not used
Paper - mixed	-11		
Paper - card	-11		
Plastic - PET	-69	52.82	Plastics reprocessing known to be less water intensive than presented in Grant (2001)
Plastic - HDPE	-23	76.90	Data source for plastics reporcessing updated. Production inventories based on Plastics Europe ecoprofiles.
Plastic - HDPE (col)	-22		
Plastic - mixed	-26	NA	NA
Garden and green	-6	NA	NA

11.2 Sensitivity analysis

A number of areas of uncertainty were identified throughout the study. Although uncertainty in general has been addressed through the use of the Pedigree Matrix and Monte Carlo Analysis (Section 5.6), it is useful to test areas of known uncertainty in order to identify areas where conclusions might be difficult or potentially misleading.

Within the study the following areas involved significant uncertainty:

a) Fuel consumption used for collection
b) The impact of international transport and reprocessing
c) Garden and green waste assumptions
d) Glass cullet recovery rates
e) Methane capture from landfill
f) Carbon storage is soil

Each of these areas is assessed in isolation in the following sections. In each section the variable considered uncertain is altered within a reasonable range and the impacts noted at a material level, where relevant, and at a system-wide level, where relevant. Areas where conclusions are altered or where results significantly change are noted and discussed.

11.2.1 Collection system fuel consumption

In this study, fuel consumption for waste collection was modelled across the state and average fuel consumption levels were determined. It is acknowledged that fuel used for collection represents a source of considerable uncertainty and is likely to vary between localities, especially between urban and rural locations. Acknowledging that fuel used for collection could vary, the following study analyses the change in study results under different fuel use scenarios (Table 43).

Table 43 Sensitivity to changes in collection fuel use. Results shown to two decimal places.

		Collection fuel consumption			
Indicator	Unit	50% Decrease	Baseline	50% Increase	100% Increase
GW	kg CO2 eq	-245.52	-246.66	-247.85	-249.03
EU	kg PO4--- eq	-0.38	-0.38	-0.39	-0.39
PO	kg NMVOC	-1.20	-1.21	-1.22	-1.23
MD	$	-0.94	-0.94	-0.94	-0.94
FFD	$	-0.70	-0.72	-0.74	-0.76
LU	ha.a	-0.02	-0.02	-0.02	-0.02
WU	kL H2O	-4.87	-4.87	-4.87	-4.87
SW	kg	-275.46	-275.46	-275.46	-275.46
CED	MJ LHV	-2048.25	-2064.77	-2082.12	-2099.26
Percentage change from baseline					
GW	% of baseline	100%	100%	100%	101%
EU	% of baseline	100%	100%	100%	101%
PO	% of baseline	99%	100%	101%	102%
MD	% of baseline	100%	100%	100%	100%
FFD	% of baseline	97%	100%	103%	106%
LU	% of baseline	100%	100%	100%	100%
WU	% of baseline	100%	100%	100%	100%
SW	% of baseline	100%	100%	100%	100%
CED	% of baseline	99%	100%	101%	102%

The study shows that the overall recycling result is not sensitive to changes in collection fuel use. A doubling of fuel used for collection changes the most sensitive indicator (fossil fuel depletion) by only 6%. This finding is mostly due to fact that collection of waste is required under the Recycling System and the Alternative System, therefore increasing the fuel used has an impact on both sides of the equation leading to a minimal net change.

11.2.2 International reprocessing

A key finding of the study has been that the use of international reprocessing facilities does not negate the benefit of recycling. A possible future scenario is that international reprocessing will increase so it would be interesting to understand the effect this might have.

The following study increases the amount of steel, aluminium, paper and card, PET and HDPE recycling internationally from the existing levels of about 50% of total recovery (Table 44).

Table 44 Sensitivity to changes in reprocessing location. Results shown to two decimal places.

		Reprocessing of Steel, Aluminium, Paper/Card, PET, HDPE		
Indicator	Unit	Baseline (50% approx)	75% International	100% International
GW	kg CO2 eq	-246.66	-235.90	-221.73
EU	kg PO4--- eq	-0.38	-0.37	-0.36
PO	kg NMVOC	-1.21	-1.17	-1.13
MD	$	-0.94	-0.94	-0.93
FFD	$	-0.72	-0.68	-0.64
LU	ha.a	-0.02	-0.02	-0.02
WU	kL H2O	-4.87	-4.86	-4.85
SW	kg	-275.46	-275.39	-275.28
CED	MJ LHV	-2064.77	-1993.87	-1900.48
Percentage of baseline				
GW	% of baseline	100%	96%	90%
EU	% of baseline	100%	97%	93%
PO	% of baseline	100%	97%	93%
MD	% of baseline	100%	99%	99%
FFD	% of baseline	100%	96%	90%
LU	% of baseline	100%	100%	99%
WU	% of baseline	100%	100%	99%
SW	% of baseline	100%	100%	100%
CED	% of baseline	100%	97%	92%

Table 44 indicates that the benefits of recycling reduce as international recycling rates are increased. This is primarily due to the added burden of transport associated with the international reprocessing. It is also notable that at a substantially increased international recycling situation, global warming impacts are reduced by only 10%. If this increase were to occur due to an increase in recycling rates, then the added benefit of recycling more material would more than offset the international shipping impact incurred.

The relative importance of international transport varies depending on the benefits derived from recycling the material concerned. From a global warming perspective, transport is of lessor importance for high intensity materials like metals, but becomes significant for materials which generate smaller benefits, such as mixed plastics. The global warming impacts of sea freight transport from Victoria to the Asian countries considered in this study is approximately 100 kg CO2e per t shipped. If international freight is required to recycle an incremental tonne of steel, this transport burden will reduce benefits versus a local reprocessor by about 6%. However, for mixed paper reprocessing the decision to reprocess internationally might reduce global warming benefits by up to 23%.

11.2.3 Garden and green waste assumptions

Quantifying the benefits of collecting and reprocessing garden and green waste involves making a broad range of assumptions. As discussed in Section 8.1.4, the uncertainty surrounding the benefits of processing green and garden waste has been addressed by applying a scenario titled the 'Balanced Estimate'. This scenario forms the baseline assumption set that is used in the results presented in this study. Other scenarios (Extremely Conservative, Mildly conservative, Mildly Optimistic and Extremely Optimistic) were also considered (each is described in full in Appendix B – Inventory Report). The impact of these assumptions on the benefits of garden and green waste recycling can be tested by varying the assumptions (using the scenarios defined) and assessing the result.

Table 45 describes the benefit of recycling one tonne of garden and green waste under each scenario described.

Table 45 Sensitivity of the benefits of garden and green waste reprocessing to assumptions. Results shown to two decimal places.

		Result to reprocess 1 tonne Garden and Green Waste				
		Scenario				
Indicator	Unit	Extremely conservative	Mildly conservative	Balanced estimate (base case)	Mildly optimistic	Extremely optimistic
GW	kg CO2 eq	-21.35	-62.58	-68.46	-83.17	-144.98
EU	kg PO4--- eq	0.01	-0.04	-0.04	-0.04	-0.09
PO	kg NMVOC	-0.23	-0.42	-0.44	-0.49	-0.75
MD	$	0.00	0.00	0.00	0.00	0.00
FFD	$	0.26	0.30	0.28	0.23	0.20
LU	ha.a	0.00	0.00	0.00	0.00	0.00
WU	kL H2O	0.00	-1.04	-1.74	-3.49	-6.98
SW	kg	0.58	-50.22	-50.53	-51.30	-103.19
CED	MJ LHV	219.90	111.85	93.97	49.25	-121.40
Result as a percentage of baseline result						
GW	% of baseline	31%	91%	100%	121%	212%
EU	% of baseline	-33%	96%	100%	111%	254%
PO	% of baseline	52%	96%	100%	111%	171%
MD	% of baseline	-7%	89%	100%	127%	261%
FFD	% of baseline	93%	108%	100%	81%	69%
LU	% of baseline	6%	104%	100%	90%	174%
WU	% of baseline	0%	60%	100%	201%	402%
SW	% of baseline	-1%	99%	100%	102%	204%
CED	% of baseline	234%	119%	100%	52%	-129%

Importantly, the study shows that against most indicators, even the Extremely Conservative scenario generates a benefit or neutral outcome. Energy indicators such as fossil fuel depletion and cumulative energy demand are adverse for most of the scenarios due to the transport and machinery burdens of compost production.

The global warming indicator varies from 31% of the baseline up to 212% under plausible scenarios. If placed into the context of the entire Recycling System, this variation could reduce the study findings for global warming from 250 kg CO2e to 203 kg CO2e, or increase them to 326 kg CO2e. Interestingly, both these outcomes are well within the uncertainty range of the simulation results shown in Table 36 (130 kg CO2e to 340 kg CO2e). The uncertainty associated with garden and green waste recycling is therefore effectively communicated by the uncertainty ranges stated for the results.

11.2.4 Glass cullet recovery rate

A source of uncertainty when compiling study data involved the amount of glass that could be recovered as cullet for use in glass container manufacture. The study assumes 85% of glass placed in recycling bins is recovered as cullet (based on (Allan and A'Vard, 2013)), however anecdotal information suggested that this may in fact be an optimistic assumption. Glass industry sources suggested that far more glass was last as fines, with some suggesting up to 50% is lost as fines. Without data from MRFs, it is impossible to say exactly how much glass ends up as fines, however it is recognised that the environmental benefit of down-cycling glass bottles into aggregate products is far less than can be achieved by retaining glass in the container packaging supply system. The following sensitivity study tests the impact of variation in the glass cullet recovery assumption (Table 46).

Table 46 Sensitivity to change in glass cullet recovery rate. Results shown to two decimal places.

		Glass cullet recovery			
Indicator	Unit	50% of glass	75% of glass	Baseline (85% glass)	95% of glass
GW	kg CO2 eq	-231.96	-242.46	-246.66	-250.86
EU	kg PO4--- eq	-0.38	-0.38	-0.38	-0.39
PO	kg NMVOC	-1.15	-1.19	-1.21	-1.22
MD	$	-0.94	-0.94	-0.94	-0.94
FFD	$	-0.55	-0.67	-0.72	-0.76
LU	ha.a	-0.02	-0.02	-0.02	-0.02
WU	kL H2O	-4.85	-4.87	-4.87	-4.88
SW	kg	-274.41	-275.16	-275.46	-275.76
CED	MJ LHV	-1932.74	-2027.05	-2064.77	-2102.49
Result as a percentage of the baseline result					
GW	% of baseline	94%	98%	100%	102%
EU	% of baseline	98%	99%	100%	101%
PO	% of baseline	95%	99%	100%	101%
MD	% of baseline	100%	100%	100%	100%
FFD	% of baseline	77%	94%	100%	106%
LU	% of baseline	100%	100%	100%	100%
WU	% of baseline	99%	100%	100%	100%
SW	% of baseline	100%	100%	100%	100%
CED	% of baseline	94%	98%	100%	102%

The results in Table 46 show that reducing the glass recovery assumption to 50% does have an adverse impact upon most indicators, but not by as much as might be expected. The reduction of cullet recovery to 50% reduces system global warming benefits by only 6%.

11.2.5 Methane capture and carbon storage in landfill

A point of uncertainty surrounding landfill is the ability of the engineered landfill cell to capture methane generated by the materials stored within it. The baseline assumption for capture is 56% to 63% of methane generated over the life of the study (100 years) is captured, depending upon the material deposited. In reality the 56% capture rate probably reflects a 'best practice' approach to landfill operation. DCCEE (2010) report a national average landfill gas capture rate of 26% however this includes old and decommissioned landfills.

To assess the importance of this assumption a sensitivity study was undertaken that varies the methane capture rate and assesses the impact upon the system result (Table 47).

Table 47 shows that changing methane capture rates most significantly affects global warming outcomes. Global warming benefits of the Recycling System increase as landfill capture rates reduce because global warming impacts increase as more methane is emitted to atmosphere under the Alternative System. At a 20% capture rate (similar to the DCCEE average above), the benefits of the Recycling System increase by 76%. By the same token, if it were possible to collect 80% of methane from landfill, the benefits of the Recycling System would reduce by 32%.

The results illustrate the impact the competing system, landfill, has on the way recycling is assessed. Improvements in the landfill system reduce the benefits of the Recycling System, and degradation in landfill performance increase the benefits of the Recycling System. Importantly, the range of change seen here does not change the fundamental study conclusions.

Table 47 Sensitivity of study results to changes in the methane capture rate of landfill. Results shown to two decimal places.

		Landfill methane collection efficiency			
Indicator	Unit	20% Collected	40% Collected	56% - Baseline	80% Collected
GW	kg CO2 eq	-435.32	-344.96	-246.66	-167.75
EU	kg PO4--- eq	-0.36	-0.37	-0.38	-0.40
PO	kg NMVOC	-0.97	-1.09	-1.21	-1.33
MD	$	-0.94	-0.94	-0.94	-0.94
FFD	$	-1.02	-0.87	-0.72	-0.56
LU	ha.a	-0.02	-0.02	-0.02	-0.02
WU	kL H2O	-4.92	-4.89	-4.87	-4.85
SW	kg	-276.42	-275.93	-275.46	-274.97
CED	MJ LHV	-2177.34	-2120.03	-2064.77	-2006.30
Results shown as a percentage of the baseline result.					
GW	% of baseline	176%	140%	100%	68%
EU	% of baseline	93%	96%	100%	104%
PO	% of baseline	80%	90%	100%	110%
MD	% of baseline	100%	100%	100%	100%
FFD	% of baseline	143%	121%	100%	78%
LU	% of baseline	101%	100%	100%	100%
WU	% of baseline	101%	100%	100%	100%
SW	% of baseline	100%	100%	100%	100%
CED	% of baseline	105%	103%	100%	97%

11.2.5.1 Carbon storage in landfill and in soil

An assumption used in this study is that biogenic carbon can be stored for a 100 year period in landfill and in soils when compost is applied. The rationale behind this assumption is discussed in Appendix B – Inventory Report. To test what impact disregarding this assumption might have, a sensitivity study was completed that excluded the global warming benefit of carbon storage in soils or landfill. The outcome increased the Global Warming benefit of the Recycling System from 247 kg CO2e (before rounding) under the baseline, to 292 kg CO2e. The result is due to the resulting increase in the impact of landfill waste disposal as the global warming benefits of carbon storage are excluded. The Recycling System is less sensitive to carbon storage in soil.

11.3 Consequential analysis

11.3.1 Introduction

As the outcomes of this study may be used to inform potential waste policy, it is important to consider whether or not the outcomes of this study will be applicable in the future.

As outlined in Appendix A – Life Cycle Assessment and Recycling, life cycle assessments are typically based on attributional modelling, that is, they assume that all future impacts will be the same as existing (or past) impacts. In contrast, consequential modelling seeks to understand how a system will respond with changes to the system(s).

The approach taken to quantify net environmental benefits or burdens in this study adopts a largely attribution approach. To calculate the net environmental benefits (or burdens) of recycling, the impacts associated with avoided materials and landfill systems are subtracted from those associated with waste management and reprocessing (Figure 1).

The inherent assumption in this approach is that the reprocessing of material recovered from the recycling stream materials always offsets the need to produce material from virgin resources. This report investigates the applicability of this assumption in the Australian market through the following question:

In the future, would recycling a material from the kerbside stream displace virgin material production?

This section investigates this question by assessing market trends for the main material types covered in this life cycle assessment; packaging glass, metals, mixed paper, cardboard, clear PET and HDPE and green organics. However, this section does not attempt to quantify any potential changes in environmental impacts/benefits under different future scenarios.

The market approach taken adopts the assumption that while excess demand (versus supply) for materials exists, additional recycling will be absorbed by hungry producer firms. If demand for materials is marginal of potentially in contraction the reverse may be true whereby excess supply exists and recycling materials may be of limited or negative value (waste). The analysis assumes that in general, markets will prefer materials produced from virgin sources to recycling materials if both are priced the same. This assumption means that recycled materials are more exposed to markets than primary materials. This assumption is justified by price discounts observed for recycled metals, plastics, cullet and pulp.

11.3.2 Market assessment

11.3.2.1 Packaging Glass

The packaging glass sector in Australia is dominated by Owens-Illinois (O-I), accounting for 46.0% of the glass product (flat glass and packaging glass) sector. In 2002, O-I operated container glass facilities in Adelaide, Brisbane, Melbourne in Sydney. The Melbourne and Adelaide facilities were temporarily closed in 2011 and 2012, respectively. Key financial indicators for O-I in Australia are reported in Table 48.

Table 48 Owen-Illinois (Australia) Pty. Ltd. – financial performance (Kelly, 2013).

Year	Revenue ($ million)	% change	Earnings before interest and tax ($ million)	Employees
2008	1,164.1	N/C	207.2	3,663
2009	1,159.4	-0.6	188.6	3,690
2010	947.2	-18.3	129.3	5,800
2011	869.6	-8.2	-827.7	N/C
2012 (estimate)	850.0	-2.3	N/C	N/C
2013 (estimate)	830.0	-2.4	N/C	N/C

Reductions in revenue have been attributed to reduction in demand for bottles stemming from increased demand for bulk wine shipments for bottling elsewhere.

Amcor Ltd. is a significant company in the packaging glass sector, representing approximately 6% of the glass product (flat glass and packaging sector). They operate one plant in Gawler, South Australia, with multiple furnaces. Similar to O-I, Amcor have reported a reduction in demand for wine bottles for the export market. Reductions in demand in this market have been compensated by improved demand from the beer packaging market. Glass sector performance indicators for Amcor are reported in Table 49.

Table 49 Amcor Ltd. – sector performance (Kelly, 2013).

Year	Revenue ($ million)	% change
2007-08	134	N/C
2008-09	135	0.7
2009-10	131	-3.0
2010-11	139	6.1
2011-12	140	0.7
2012-13	142	1.4

The demand for packaging glass has reduced in recent years, stemming from (Kelly, 2013):

- Reduced demand for beer
- Decrease in bottled-wine exports
- Increase in beer and wine imports
- Substitution from competing packaging materials for fruit and vegetable products (e.g. PET)

Overall, the combined glass sector (flat glass and packaging) is in decline. However, growth is expected to occur, but limited to approximately 1.5% per annum, over five years to 2017-18 (Kelly, 2013).

11.3.2.2 Aluminium

Aluminium recovered from recycled aluminium cans (commonly referred to in the literature as reprocessed used beverage cans, UBC), contributes to the total supply of aluminium, however because of ideal alloying, the recovered aluminium typically is used to produce new aluminium cans; thus it can be considered a closed-loop recycling process (Green, 2007). As documented in other reports of this study, the aluminium recovered from the kerbside is reprocessed domestically in Australia and is exported for reprocessing internationally.

The Australian Packaging Covenant (APC, formerly The National Packaging Covenant, NPC) have published consumption figures for aluminium cans, Table 50.

Table 50 Aluminium can consumption in Australia. All data from the Australian Packaging Covenant (APC, 2012, APC, 2013, NPC, 2011)

Year	Consumption (t)	% change
2009-10	51,600	-
2010-11	57,196	10.8
2011-12	52,900	-7.5

Data on projected aluminium can consumption, with SRU Pty Ltd group estimating that for 2014-15, demand for aluminium cans will be 62,000 t (Allen and A'Vard, 2013); a 17% increase from the 2011-12 consumption figure of 52,900 t. The justification for the SRU estimate was not provided and is therefore uncertain.

The majority (67%) of the exported aluminium is reprocessed in South Korea. No publically available statistics were available on historical or projected aluminium can consumption for South Korea. Although no formal trends could be forecast, recent investment in can recycling and production infrastructure in South Korea (RecyclingToday, 2012) suggests growing demand for aluminium cans.

Primary (smelted) aluminium is not currently produced in South Korea (Shi, 2013); it relies entirely on imported aluminium. The largest imports of aluminium into South Korea is sourced from Australia, accounting for 23.4% (by mass) of imports in 2011 (UN comtrade, 2013).

11.3.2.3 Steel

Steel recovered from steel cans is typically reprocessed in electric-arc furnaces (EAFs), where scrap steel is “charged” with virgin iron or steel. The steel produced from EAFs are used for a variety of applications, including structural steel, sheet and piping products. The alternative process to produce steel is via the blast furnace basic oxygen steelmaking process (BF-BOS).

In Australia, the steel can (for food and beverage) sector accounts for 65.2% of revenue for the metal drum, can and bin industry. Revenue outlook for the metal drum, can and bin industry is low and contracting, Table 51 (Sivasailam, 2012). Similarly, for the broader iron and steel manufacturing sector in Australia, revenue is expected to contract after 2014-15, Table 52 (Willanto, 2012).

Table 51 Projected revenue for metal drum, can and bin industry in Australia (Sivasailam, 2012).

Year	Projected Revenue ($ million)	% change
2013-14	1,155.3	-3.2
2014-15	1,127.6	-2.4
2015-16	1,107.3	-1.8
2016-17	1,098.5	-0.8
2017-18	1,085.2	-1.2
2018-19	1,069.0	-1.5

Table 52 Iron smelting and steel manufacturing in Australia (Willanto, 2012).

Year	Projected Revenue ($ million)	% change
2012-13	9,260.3	-
2013-14	9,807.0	5.9
2014-15	10,131.5	3.3
2015-16	9,896.6	-2.3
2016-17	9,730.9	-1.7
2017-18	9,710.1	-0.2

The largest proportion (59%) of the recovered and exported steel from kerbside recycling is reprocessed in Malaysia. In Malaysia, the production of steel has increased from 5.4 million t in 2009, to 5.7 million t in 2010 and 5.9 million t in 2011. This growth in demand is expected to continue (Tse, 2013).

Globally, demand for steel is expected to increase from 1,413 million t in 2012, to 1,454 million t in 2013 and 1,500 million t in 2014, corresponding to increases of 1.2%, 2.9% and 3.2%, respectively (World Steel Association, 2013). This trend is expected to flow through to Asia, with growths of 1.8%, 3.2% and 2.8% for 2012, 2013 and 2014 respectively (World Steel Association, 2013).

Malaysia has limited raw iron and steel production (blast furnace and basic oxygen furnace) capacity and is expected to continue to rely on imported raw materials (including scrap steel) to make up for the short fall in material required to meet steel demand. The majority of raw iron imported is pig iron from India (Table 53 and Table 54).

Table 53 Raw iron sources in Malaysia for 2010-2012 (UN comtrade, 2013).

Commodity type	Total amount imported (tonne and % primary iron)					
	2010		2011		2012	
Pig iron and spiegeleisen in primary forms	3509.8	5%	79651.2	61%	58366.2	44%
Ferrous products from reduction of iron ore, pure	47404.9	69%	36798.9	28%	34918.2	27%
Granules and powders, of pig iron, iron or steel	17150.4	25%	14420.7	11%	37482.7	29%
Iron and non-alloy steel in primary forms, ingots	170.8	0%	245.6	0%	682.6	1%
Total	68235.9	100%	131116.3	100%	131449.8	100%

Table 54 Largest importers of raw iron in Malaysia for 2010-2012 (UN comtrade, 2013).

Commodity type	Largest importer and % share of total commodity import					
	2010		2011		2012	
Pig iron and spiegeleisen in primary forms	South Africa	29.8%	India	39.5%	India	79.6%
Ferrous products from reduction of iron ore, pure iron	India	99.0%	India	98.9%	Indonesia	49.1%
Granules and powders, of pig iron, iron or steel	Japan	38.2%	Japan	28.4%	Japan	51.0%
Iron and non-alloy steel in primary forms, ingots	Other Asia	59.2%	Australia	39.5%	Italy	54.9%

11.3.2.4 Mixed paper and cardboard

The paper and cardboard sector in Australia is classified under a number of different categories, including:

- Pulp, paper and paperboard manufacturing
- Solid paperboard container manufacturing
- Corrugated paperboard container manufacturing
- Sanitary paper product manufacturing

In Australia, the total production of paper and paper products has been declining since 2007-08, from 3278 k.t to 3155 k.t in 2010-11 (ABARES, 2012). In contrast, the use of recovered waste paper in Australia over the same period increased from 1728 k.t in 2007-08 to 1778 k.t in 2010.11 (ABARES, 2012). Exports of pulp, paper and paperboard from Australia are expected to increase at annual rate of 15.1% to 2017-18, due to strong demand from Asia (Finch, 2012). In contrast, local demand for Australian pulp, paper and paperboard to 2017-18 is expected to decrease due to higher imports. Overall, the revenue in the Australian pulp, paper and paperboard industry is expected to decline over the next five years (Finch, 2012).

In 2012, China was the world's largest consumer of chemical (kraft or sulphite) pulp. Demand for pulp in China is expected to grow from 2012-2016 (Valois et al., 2012).

11.3.2.5 Clear PET and natural HDPE

Clear PET and natural HDPE from the kerbside stream, are reprocessed into plastic blow moulded products.

In the Australian sector, demand for blow-moulded products is driven by the food, milk, wine and beverage sector, accounting for 79.7% of revenue (Lin, 2012). Recent advancements in reprocessing technology have allowed PET and HDPE to be closed-loop recycled into products for the food and beverage market. The industry outlook for plastic blow moulded products is positive, with annualised growth of 1.3% expected to 2017-18. The total number of blown bottles is expected to continually increase from 7,361.8 million units in 2012-13 to 7,596.8 million units in 2017-18.

The largest export market for clear PET and HDPE recovered in Australia is China. In the future, the demand for PET in Asia is expected to be driven largely by China. The Asia-Pacific region accounted for 5.12 million t of PET in 2010 and this is expected to increase to 11.2 million t in 2020 (FoodProcessing, 2012). Similarly, demand for HDPE in China is expected to grow from 9.2 million t in 2009 to 12.5 million t in 2017 (CNCIC Consulting, 2013).

11.3.2.6 Mixed plastics

The largest market for exported mixed plastics is China. In China, the demand for waste plastics more broadly, is expected to increase from 15 million t in 2007 to 45 million t and 85 million t in 2015 and 2020, respectively (IPTS, 2013).

11.3.2.7 Organics

A key future market for reprocessed organic material is agriculture. The agriculture sector includes the production of fruit and vegetables, grains and sugar cane, meat, dairy and egg products. The annual revenue growth of the sector is expected to be 1.8% annualised over five years to 2017-18, driven by forecast increases in demand for exports (Outlaw, 2013). Agricultural output volumes are also expected to increase (Outlaw, 2013). The modelling approach in the main study assumes that reprocessed organics avoided the production of synthetic nitrogen (N), phosphorous (P) and potassium (K) fertilisers. The growth in demand for food production is coupled with fertiliser production and as such, the demand for fertiliser is expected to increase over the five years to 2017-18, with revenue also expected to increase at an annualised rate of 1.8% over this period (Richardson, 2013). An alternate market for reprocessed organic material is garden supply retailers. The forecast for this market is also positive, with revenue expected to grow at annualised rate of 1.5% to 2017-18 (Fitzpatrick, 2013).

11.3.3 Discussion

11.3.3.1 Packaging Glass

Although the limited growth in the packaging glass sector would likely lead to continual use and increase in demand for cullet, a contraction in the demand for local (Australian) glass could mean that any additional cullet (from the recycling supply chain) would not be used in the production of new glass bottles. Cullet is only used domestically as the economics are not favourable for international reprocessing. As such, if the demand for cullet decreases as a result of reduced domestic packaging glass production, the environmental credit for its use in packaging glass would no longer be applicable. Rather, the fate of cullet may take one or more different pathways, including stock-piling or reprocessing and use as a substitute for sand/aggregate (GHD, 2008). The use of reprocessed glass waste for sand/aggregate can have environmental benefits (Hedayati, 2013), although this is sensitive to transport distances and market dynamics.

It is suggested that the domestic production of packaging glass be monitored. The consequences of any future reductions in production volume (mass) would need to be assessed, but will likely limit the environmental benefits of cullet use in new bottle packaging.

11.3.3.2 Aluminium

The projections by SRU for increased demand of aluminium cans in Australia would mean that any recycled aluminium used for new production would displace virgin production. Therefore, the assessment in this study that recycling aluminium avoids virgin production is considered sound. However, the basis for the SRU demand projection is uncertain. If a decrease in demand for aluminium cans produced in Australia was to occur, then the demand for reprocessed aluminium would reduce. Under these circumstances, virgin aluminium in Australia, sourced from Australia, would no longer be displaced and the demand for scrap aluminium would reduce. Given that aluminium scrap is already exported to South Korea and the projected increased demand for scrap in South Korea, it is considered likely that any additional aluminium scrap available in Australia (in the case of reduced local demand) would be exported to South Korea. Given the projected increased demand for aluminium in South Korea, the reprocessing of scrap aluminium in South Korea would displace the need for virgin production. In South Korea, the majority of virgin aluminium is sourced from Australia. As such, the environmental benefits of recycling aluminium from the kerbside would be similar to those reported in this study.

11.3.3.3 Steel

The forecast for reduced demand for steel produced in Australia means that in the future, any reprocessed scrap steel (recovered from the kerbside) would most likely not displace all virgin production in Australia. Rather, given favourable pricing, it is likely that the recovered scrap steel would be exported for reprocessing elsewhere. The end-destination is uncertain; however it could be assumed (given the current export reprocessing pathway) that this would be Malaysia. The use of scrap steel in electric arc furnaces negates the need to produce steel from raw iron, via the blast furnace basic oxygen steelmaking (BF-BOS) pathway. Given the forecast increase in demand for steel in Malaysia and Asia more broadly, the displacement of steel via the BF-BOS pathway is likely to occur in the future. In Malaysia, the largest raw iron source (for production of steel via the BF-BOS process) was pig iron (from blast furnaces) from India. Thus, in the future, the avoided product for kerbside recycling of steel is likely to be BF-BOS processing in Malaysia, fed by pig-iron produced in India. An assessment on future recycling pathways could be warranted, to better quantify potential environmental benefits.

11.3.3.4 Mixed paper and cardboard

The forecast for reduced demand for Australian produced pulp, due to higher imports, means that in the future, any paper and cardboard recovered for reprocessing from the kerbside will be unlikely to displace all local virgin production. The future end-destination for excess recovered paper and cardboard is unknown. Given the recent trends for exporting recovered paper and cardboard to China, and China's forecast demand for pulp, it might be expected that paper and cardboard from the kerbside would be reprocessed in China, thereby displacing virgin chemical pulp production in China.

In the future, the export of fibre to China may be affected by the "Green Fence" policy, which restricts the importation of contaminated recyclate. The policy may mean that recyclate needs additional processing at MRFs, which increases recyclate production cost (through increased infrastructure and processing costs). Increases in recyclate production cost may mean that the recyclate is no longer economically viable to produce. In this instance, the recyclate could be regarded as a waste (with a value of less than zero). If this was to occur, the applicability of environmental benefits for avoided virgin production and landfill avoidance may not be applicable.

It is recommended that the exports masses of paper and cardboard scrap to all countries be monitored, and the consequences of any export reductions to China be assessed. In addition, it is recommended that data on the contents of exported product (e.g. proportion of single streams and contamination), as well as price data for the single export streams, be collected, reported and monitored.

11.3.3.5 Clear PET and clear HDPE

The forecast increase in demand for clear PET and clear HDPE in Australia, together with new technology to allow closed-loop recycling of these materials, means that in the future, recycling of clear PET and clear HDPE are expected to displace the need for PET and HDPE from virgin sources. Similarly, given the forecast demand for clear PET and clear HDPE in China, it is expected that any exported clear PET and clear HDPE would displace virgin PET and HDPE in China.

An aspect which may affect the viability of exporting PET and HDPE (and indeed other plastics) is China's new "Green Fence" policy. This policy may mean that scrap needs additional processing at the MRFs prior to export. The additional processing would likely result in an increase in processing costs, which may affect the economic viability of producing recyclate streams. If the clear PET and clear HDPE plastic recyclate is no longer economical to produce, then it could be reclassified as waste. If the recyclate is reclassified as waste, then displacement of virgin production will not occur, meaning that any environmental benefits associated with avoided virgin production will not be realised. The consequences of avoided landfill benefits are unknown, as it is not known what the effect a reduction in economic viability (of production of recyclate) would have on the fate of the recyclate (e.g. being sent to landfill or stock-piled). If the recyclate is classified as a waste stream, then benefits of landfill avoidance may not be applicable.

It is recommended that the export masses of clear PET and clear HDPE scrap to all countries be monitored, and the consequences of any export reductions to China be assessed. In addition, it is recommended that data on the contents of exported product (e.g. proportion of single streams and contamination), as well as price data for the single export streams be collected, reported and monitored. Such reporting would provide data to inform a clearer understanding of the make-up and quality of exports, as well as informing the economic viability of production of the clear PET and clear HDPE streams.

11.3.3.6 Mixed plastics

The forecast increase in demand for mixed plastic in Chian means that, the displacement of virgin production, by exported and reprocessed mixed plastics from Australia, will most likely continue. As discussed previously, policy changes in China may mean that additional processing in Australia is required to meet new requirements for mixed plastic waste entering China (for further reprocessing). Like for the clear PET and clear HDPE streams, additional processing requirements may result in mixed plastics being not economical to produce, meaning that any environmental benefits associated with avoided virgin production will not be realised. In addition, benefits for landfill avoidance may not necessarily apply. Similarly for the clear PET and clear HDPE streams, it is recommended that data be collected on price, exports mass (to all countries) and make-up of single streams be reported, so as to inform understanding of the economic viability of the system, which in-turn, affect the environmental impacts/benefits associated with the recycling system.

The identification of the displaced virgin product remains uncertain. WRAP acknowledge that it is “impossible to track specific end market applications for every consignment of recovered plastic sent to China for recycling” (WRAP, 2011). Analysis by WRAP suggest that mixed plastics are sorted and reprocessed in single streams, then used in a variety of applications, including packaging, construction materials (e.g. piping, wood-plastic composites), electronic appliances and everyday consumer goods, such as toothbrushes and coat hangers (WRAP, 2011).

11.3.3.7 Organics

The forecast increase in demand for food production in Australia, coupled with fertiliser production, means that the displacement of synthetic fertilisers will most likely continue in the future.

11.3.4 Conclusions to Consequential Analysis

This section assesses whether or not the findings of the main study apply to future scenarios. Specifically, it explores the applicability of the credit for avoiding virgin production is sound by examining market trends.

> *In the future, would recycling a material from the kerbside stream displace virgin material production?*

Overall, it was considered that, in the short-term future, recycling of material from the kerbside will continue to displace virgin material production. The displacement of virgin production is sensitive to the demand for end-products, as well as the economical viability of producing recyclate. The forecast for the demand of these end-products is uncertain, particularly for glass packaging and aluminium cans. As such, it is recommended that the demand for end-products by monitored. The environmental consequences of any decrease in local demand would need to be assessed.

China’s “Green Fence” policy could force additional infrastructure and processing costs on local MRFs, meaning that in the future, the production of clear PET, clear HDPE, mixed plastics and mixed paper and cardboard recyclate streams for export could become uneconomical. If this occurs, then these streams could be considered waste, meaning that environmental benefits associated with virgin production and landfill avoidance may not apply. It is recommended that the export masses of these streams be monitored, and the consequences of any export reductions to China be assessed. In addition, it is recommended that data on the contents of exported product (e.g. proportion of single streams and contamination), as well as price data for the single export streams, be reported, collected and monitored.

Market forecasts are inherently uncertain and subject to change. The future application of credits for avoided virgin production relies on market projections, and as such, the conclusions in this study are limited by the uncertainty of the market forecasts. Similarly, many commodities examined in this study are traded globally and subject to regional price variations. The regions identified for reprocessing, as well as for displaced virgin production, are best estimates only and do not necessarily reflect future conditions.

12 Conclusion

The study set out to assess the net environmental benefits or burdens of recycling activity in Victoria, by building upon the study "Stage 2 Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria" (Grant et al., 2001a). It has addressed this objective by utilising the life cycle assessment methodology, as defined by ISO14044, to assess the potential environmental benefits/burdens of recycling versus an alternative approach centred around landfill.

The study determined that the existing materials recycled by Victorians generate a net environmental benefit, as shown in Table 36. Each indicator considered achieved a favourable outcome versus the alternative. Underpinning this finding, the uncertainty analysis undertaken also showed that benefits were consistently demonstrated by recycling in 950 out of 1000 Monte Carlo simulations.

Each material recycling system was also assessed individually, with the majority achieving beneficial outcomes in all indicators considered.

A comparison of the study findings to the prior study showed that the environmental benefits of recycling have increased since Grant et al. (2001a). For most materials, the results achieved in this study are comparable to those achieved in Grant et al. (2001a), despite the increase in international material reprocessing.

A series of sensitivity studies were undertaken to address data concerns and points of interest. Of these studies, the review of green and garden waste reprocessing was the most useful, indicating the overall study result is most significantly influenced by assumptions in this area, however directional study conclusions remained unchanged.

Broadly, the conclusion of the sensitivity analysis is that the conclusion that 'recycling generates a benefit versus landfill' across each of the indicators considered is sound and robust. Even significant changes to assumptions in garden and green waste did not lead to an adverse outcome for the system. The uncertainty ranges described at the base of Table 36 serve to indicate the accuracy of the findings.

Finally, a consequential rather than attributional interpretation was undertaken. This study concluded that, overall, recycling of material from the kerbside will continue to displace virgin material production in the immediate future. The displacement of virgin production is sensitive to the demand for end-products. The forecast for the demand of these end-products is uncertain, particularly for glass packaging and aluminium cans. As such, it is recommended that the demand for end-products be monitored. The environmental consequences of any decrease in local demand would need to be assessed. Of these materials, glass is potentially problematic as the export of recovered cullet is not considered economically viable. Implementation of China's 'Green Fence' policy, restricting the import of contaminated recyclate streams, is also seen as a risk, particularly for papers and plastics.

Overall, the study verified that recycling in Victoria continues to generate a net environmental benefit for the state, in terms of the indicators considered.

12.1.1.1 Further work

A key challenge of the study involved determining the exact fate of recyclate streams recovered by MRFs. This data was not provided by MRF operators and was difficult to source in secondary form. Although the analysis undertaken in this study attempted to address data uncertainties using Monte Carlo analysis and sensitivity analysis, broader issues of waste stewardship became apparent as the study was completed. The analysis suggests that the globalisation of the recycling system to incorporate overseas reprocessors does not necessarily have significant environmental consequences, however the lack of transparency of the system leaves significant cause for doubt, especially with respect to issues that go beyond the scope of this LCA study. For this reason it is highly recommended that further work be undertaken to establish reporting mechanisms that transparently describe the fate of materials deposited in kerbside recycling bins in Victoria.

Key areas where improved reporting is required are as follows:

Glass – Cullet versus fines: The environmental benefit from cullet recovery is significantly greater than fines recovery. For this reason it is vital that future reporting distinguish between glass recovered as cullet and glass recovered as fines.

Mixed bails versus segregated streams: Plastic recovery is currently reported by polymer, even though these polymers are often incorporated in a mixed plastic bail when they leave the MRF. As the environmental benefit of plastics recycling is significantly greater for segregated materials (they don't attract a sorting burden) reporting should be limited to exactly what is recovered by the MRF and not disaggregated based on the assumed contents of mixed bails.

Fate analysis: Throughout this study it was often necessary to estimate the fate of reprocessed materials as data was difficult to source. In future, reporting should track recyclate flows to at least the first receiver of the materials. As time progresses this tracking could be increased to determine a fate of the material. Such tracking, although potentially burdensome, is necessary if genuine waste stewardship is to be achieved.

13 Glossary

Alternative System: The system defined by the system boundary to the right of Figure 8.

Aerobic composting: the controlled biological decomposition of organic materials under aerobic conditions (i.e. in the presence of oxygen), accomplished in windrows (see below) or open static piles. Aerobic composting involves the action of thermophilic (heat loving) micro-organisms that thrive under increased temperature conditions. If correctly managed, it results in the destruction of seeds and disease-causing organisms.(B)

Carbon dioxide equivalent (CO2-e): a metric measure used to compare the emissions of various different greenhouse gases based on their global warming potential.(B)

Compost: material resulting from the controlled microbiological transformation of organic materials such as animal manures, bark fines, biosolids, leaf mulch, sawdust and shredded green waste, under aerobic and thermophilic conditions, rendering them safe for use in growing situations. Compost may also be produced through anaerobic processes.(B)

Composting: the aerobic or anaerobic processes that produce compost, with or without mechanical treatment and processing.(B)

Commingled materials: Materials mixed together, such as plastic bottles with glass and metal containers. Commingled recyclable materials require sorting after collection before they can be recycled.(A)

Cullet: glass that is crushed finely for recycling into new glass.(B)

Diversion: the act of diverting a waste away from landfill for another purpose such as re-use or recycling.(B)

Garden organics: Organics derived from garden sources e.g. grass clippings and pruned tree branches.(A)

Global warming potential: a system of multipliers devised to enable comparison among warming effects of different gases. For example, over the next 100 years, a gram of methane in the atmosphere is currently estimated as having 25 times the warming effect of a gram of carbon dioxide; methane's 100-year global warming potential is thus 25.(B)

Green waste: generally refers to biodegradable garden or park waste such as grass clippings or leaves.(B)

Greenhouse gas emissions: releases to the atmosphere of substances that contribute to the enhanced greenhouse effect and climate change. The main greenhouse gases generated by human activity are carbon dioxide (CO2), methane and nitrous oxide. There are also manufactured gases such as chlorofluorocarbons (CFCs), halocarbons and some of their replacements.(B)

HDPE: High density polyethethylene

Kerbside collection: Collection of household recyclable materials (separated or commingled) that are left at the kerbside for collection by local collection services.(A)

Landfill: Sites that are licensed by EPA Victoria for the disposal of materials (both waste and potentially recyclable materials). Also known as tips.(A)

Landfill gas: gas generated by the natural degradation and decomposition of solid waste by anaerobic micro-organisms in landfills. Consists of approximately equal parts methane (the primary component of natural gas) and carbon dioxide, as well as traces of non-methane organic compounds.(B)

LPB: Liquid paper board

Materials Recovery Facility (MRF): a specialised facility that receives, separates and prepares recyclable materials for marketing to end-user manufacturers. May also be referred to as municipal/mixed recycling or recovery facility, and usually involves mechanical sorting and separation of materials. An MRF does not process residual organic waste, or cover sites that are mainly transfer stations.(B)

Municipal solid waste (MSW): waste produced primarily by households and council facilities, including biodegradable material, recyclable materials such as bottles, paper, cardboard and aluminium cans, and a wide range of non‑degradable material including paint, appliances, old furniture and household lighting.(B)

Organic waste: waste materials from plant or animal sources, including garden waste, food waste, paper and cardboard.(B)

PET: Polyethylene terephthalate

PP: Polypropylene

PS: Polystyrene

PVC: Polyvinyl chloride

Recyclate: material able to be processed for recycling in a facility. In this study, used only to refer to materials actually recovered from the MRF, excluding residual wastes.(modified from B)

Recycled: In general the term is used to refer to a material that is the product of reprocessing. Eg. recycled aluminium.

Recycling System: The system defined by the boundary to the left of Figure 8.

Recycling (verb): a resource recovery method involving the collection and processing of waste for use as a raw material in the manufacture of the same or similar non-waste product.(B)

Recycling (noun): as a noun, the term is avoided in this report. It is replaced by 'material recovered for recycling' in most instances.

Recovered material: Material that would have otherwise been disposed of as waste, but has instead been collected and recovered (reclaimed) as a material input, in lieu of a new primary material, for a recycling or manufacturing process.(A)
Recovery rate: The recovery rate is the percentage of materials recovered for reprocessing from the total quantity of waste generated.(A)

Transfer station: a facility which temporarily houses waste prior to its transfer for treatment elsewhere. May involve some sorting, separation and baling, but not extensive processing such as at an MRF or an advanced waste water treatment (AWT) plant.(B)

Waste: any discarded, rejected, unwanted, surplus or abandoned matter; discarded, rejected, unwanted, surplus or abandoned matter intended for recycling, re‑processing, recovery, re-use, or purification by a separate operation from that which produced the matter, or for sale, whether of any value or not.(B)

Windrow composting: the production of compost by piling biodegradable waste in long rows known as windrows.(B)

Reference Key
A - (Sustainability Victoria, 2011b)
B - (DEWHA and EPHC, 2010)

14 References

14.1 Databases

The following life cycle inventory databases were utilised in background processes of the LCA model, constructed using the Sima Pro software package by Pre Consultants:

AUPLCI – Australasian Unit Process Inventory, Published by Life Cycle Strategies, Released Sept 1, 2010

Ecoinvent – Ecoinvent 2.2, published by The Swiss Centre for Life Cycle Inventories, released May 2010

14.2 Literature

A3P 2005. Australian Paper Industry Production Statistics 2003-04.

ABARES 2012. Agricultural Commodity Statistics 2012. Rural commodities - forestry. Australian Bureau of Agricultural and Resource Economics and Sciences. Department of Agriculture, Fisheries and Forestry.

ADVITECH 2013. Environmental Compliance Audit - 2012 - Tumut Facility. Mayfield: Advitech Pty Ltd.

ALCOA 2013. Meeting Minutes: Community Consultation Commitee Meeting: 9th April 2013. *In:* DAHANAYAKA, N. (ed.). Alcoa Rolled Products.

ALLAN, P. & A'VARD, D. 2013. Assessment of Recycling Infrastructure: Current Status and Future Opportunities. Melbourne: SRU Pty Ltd for the National Packaging Covenant.

ALLEN CONSULTING GROUP. 2007. Environmental Resource Efficiency Plans - Regulations 2007 - Regulatory Impact Statement. Melbourne.

ALLEN, P. & A'VARD, D. 2013. Assessment of recycling infrastructure. North Melbourne: Sustainable Resource Use Pty Ltd.

APC 2012. The Australian Packaging Covenant. 2011 Annual Report. Gordon: Australian Packaging Covenant Council.

APC 2013. The Australian Packaging Covenant. 2012 Annual Report. Gordon: Australian Packaging Covenant Council.

APC ENVIRONMENTAL MANAGEMENT 2006. Queensland Used Glass Sourcing Study. Queensland EPA.

BERNSTAD, A. & LA COUR JANSEN, J. 2012. Review of comparative LCAs of food waste management systems - Current status and potential improvements. *Waste Management*.

CAMPBELL, A. & SHEPHERD, N. 2010. Organics Recycling in Australia - Industry Statistics 2010. Sydney: Recycled Organics Unit, University of New South Wales.

CARRE, A., JONES, I., BONTINCK, P.-A. & HAYES, G. D.-M. 2009. Extended Environmental Benefits of Recycling (EEBR) Project. Melbourne: RMIT University.

CNCIC CONSULTING 2013. Demand status and forecast of polyolefins in China. China National Chemical Information Center.

CRC WASTE MANAGEMENT AND POLLUTION CONTROL 1997. Australian Waste and Recycling Cost Model V1.0.

DCCEE 2010. Australian National Greenhouse Accounts - National Inventory Report 2010. Canberra: Dept. Climate Change and Energy Efficiency.

DEWHA & EPHC 2010. National Waste Report 2010. Department of Environment Heritage and the Arts, Environment Protection and Heritage Council.

DOKA, G. 2009. Life Cycle Inventories of Waste Treatment Services - Part II Landfills, Underground Deposits, Landfarming. *Ecoinvent report number 13.* Swiss Centre for Life Cycle Inventories.

EKVALL, T. & TILLMAN, A. M. 1997. Open-loop recycling: Criteria for allocation procedures. *International Journal of Life Cycle Assessment,* 2**,** 155-162.

ENERGETICS 2012. Steel Stewardship Forum - Australian Steel Chain Footprint Project, May 2012. Sydney: Energetics.

EPA VICTORIA 2010. Best Practice Environmental Management - Siting, Design, Operation and Rehabilitation of Landfills. Melbourne.

EUNOMIA RESEARCH & CONSULTING 2002. Economic Analysis of Options for Managing Biodegradable Municipal Waste - Final Report to the European Commission.

EUROPEAN COMMISSION - JOINT RESEARCH CENTRE 2008. Environmental Assessment of Municipal Waste Management Scenarios: Part II – Detailed Life Cycle Assessments. Luxembourg: European Commission - Joint Research Centre, Institute for Environment and Sustainability.

FEFCO 2013. European Database for Corrugated Board Life Cycle Studies - 2012. Brussels: Cepi Container Board.

FINCH, C. 2012. IBISWorld Industry Report C1510. Pulp, Paper and Paperboard Manufacturing in Australia. IBISWorld Pty Ltd.

FITZPATRICK, N. 2013. IBISWorld Industry Report G4232. Garden Supplies Retailing in Australia. IBISWorld Pty Ltd.

FOODPROCESSING. 2012. China will lead PET market by 2020, says GBI Research. Available: www.foodprocessing.com.au/news/53428-China-will-lead-PET-market-by-2-2-says-GBI-Research [Accessed 23/05/2013].

FRANKLIN ASSOCIATES. 2009. Life Cycle Inventory of Three Single-Serving Softdrink Containers. Prairie Village, Kansas: Completed for the PET Resin Association.

FRANKLIN ASSOCIATES. 2010. Life Cycle Inventory of 100% Post-Consumer HDPE and PET Recycled Resin From Post-Consumer Containers and Packaging. Prairie Village, Kansas: The Plastics Division of the American Chemistry Council and others.

FRISCHKNECHT, R. & JUNGBLUTH, N. 2004. Ecoinvent Report No. 1 - Overview and Methodology. Dübendorf: Swiss Centre for Life Cycle Inventories.

GHD 2008. The use of Crushed Glass as both an Aggregate Substitute in Road Base and in Asphalt in Australia. Business Case. *Packaging Stewardship Forum, Australian Food and Grocery Council.*

GLASS PACKAGING INSTITUTE 2010. Environmental Overview Complete Life Cycle Assessment of North American Container Glass. Glass Packaging Institute.

GRANT, T. & JAMES, K. 2005. Life Cycle Impact Data for Resource Recovery from Commercial and Industrial and Construction and Demolition Waste in Victoria Melbourne: Centre for Design, RMIT University.

GRANT, T., JAMES, K., DIMOVA, C., SONNEVELD, K., TABOR, A. & LUNDIE, S. 1999. Stage 1 of the National Project on Life Cycle Assessment of Waste Management Systems for Domestic Paper and Packaging.

GRANT, T., JAMES, K., LUNDIE, S. & SONNEVELD, K. 2001a. Stage 2 Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria. Melbourne: EcoRecycle Victoria.

GRANT, T., JAMES, K., LUNDIE, S., SONNEVELD, K. & BEAVIS, P. 2001b. Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in New South Wales. Melbourne.

GRANT, T., JAMES, K. & PARTL, H. 2003a. Life Cycle Assessment of Waste and Resource Recovery Options (including energy from waste) - Final Report for EcoRecycle Victoria. Melbourne, Victoria: Centre for Design at RMIT University (www.cfd.rmit.edu.au).

GRANT, T., JAMES, K. L. & PARTL, H. 2003b. Life Cycle Assessment of Waste and Resource Recovery Options (including energy from waste). Melbourne: EcoRecycle Victoria.

GRANT, T. & PETERS, G. 2008. Best Practice Guide to Life Cycle Assessment in Australia. Australian Life Cycle Assessment Society.

GREEN, J. A. S. 2007. Recycling of Aluminium. *In:* GREEN, J. A. S. (ed.) *Aluminum Recycling and Processing for Energy Conservation and Sustainability.* ASM International.

GUINÉE, J. B. 2002. *Handbook on Life Cycle Assessment : Operational Guide to the ISO Standards*, Kluwer Academic Publishers.

HEDAYATI, M. 2013. Life cycle assessment of recycled sand. ISO 14040:2006 compliant LCA prepared for Alex Fraser Pty. Ltd. Melbourne: Centre for Design, RMIT University.

HERMANN, B. G., DEBEER, L., DE WILDE, B., BLOK, K. & PATEL, M. K. 2011. To compost or not to compost: Carbon and energy footprints of biodegradable materials' waste treatment. *Polymer Degradation and Stability,* 96**,** 1159-1171.

HISCHIER, R. 2007. Life Cycle Inventories of Packaging and Graphical Papers - Part II Plastics. Dübendorf: Swiss Centre for Life Cycle Inventories.

HYDER CONSULTING 2008. Australian Beverage Packaging Consumption, Recovery and Recycling Quantification Study. Melbourne: Report for Packaging Stewardship Forum of the Australian Food and Grocery Council.

HYDER CONSULTING 2009. Waste and Recycling in Australia - Ammended Report. Canberra: Department of Environment, Heritage, Water and the Arts.

HYDER CONSULTING 2011. 2010 National Plastics Recycling Survey - July 2009 to June 2010 survey period. Melbourne: Plastics and Chemicals Industries Association.
IAI 2007. Life Cycle Assessment of Aluminium: Inventory Data for the Primary Aluminium Industry - 2005 Update. International Aluminium Institute.
IEA. 2009. *Statistics by Country/Region* [Online]. International Energy Agency. Available: http://www.iea.org/stats/index.asp [Accessed Feb 10 2013].
INTERNATIONAL ORGANIZATION FOR STANDARDIZATION 2006. ISO 14044: Environmental Management - Life Cycle Assessment - Requirements and guidelinges. Geneva: International Organization for Standardization.
IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. *In:* EGGLESTON, S., BUENIDA, L., MIWA, K., NGARA, T. & TANABE, K. (eds.).
IPTS 2013. End-of-waste criteria for waste plastic for conversion. Technical proposals. Final Draft Report.: JRC European Commission. Institute for Prospective Technological Studies.
JAMES, K., GRANT, T. & SONNEVELD, K. 2002. Stakeholder involvement in australian paper and packaging waste management LCA study. *The International Journal of Life Cycle Assessment,* 7**,** 151-157.
JOLLIET, O., MÜLLER-WENK, R., BARE, J., BRENT, A., GOEDKOOP, M., HEIJUNGS, R., ITSUBO, N., PEÑA, C., PENNINGTON, D., POTTING, J., REBITZER, G., STEWART, M., HAES, H. & WEIDEMA, B. 2004. The LCIA midpoint-damage framework of the UNEP/SETAC life cycle initiative. *The International Journal of Life Cycle Assessment,* 9**,** 394-404.
KELLY, A. 2013. IBISWorld Industry Report C2010. Glass and Glass Product Manufacturing in Australia. IBISWorld Pty Ltd.
LIN, R. 2012. IBISWorld Industry Report C1912a. Plastic Blow Moulded Product Manufacturing in Australia. IBISWorld Pty Ltd.
MANFREDI, S., TONINI, D., CHRISTENSEN, T. H. & SCHARFF, H. 2009. Landfilling of waste: accounting of greenhouse gases and global warming contributions. *Waste Management & Research,* 27**,** 825-836.
MICHAUD, J.-C., FARRANT, L., JAN, O., KJÆR, B. & BAKAS, I. 2010. Environmental benefits of recycling – 2010 update.
MOORE, P. 2011. Film, PET and Mixed Plastic Recycling in China - An Account of Patty Moore's Visits to Several Plastic Recycling Facilities in China. California: Moore Recycling Associates Inc.
MORRIS, J., SCOTT MATTHEWS, H. & MORAWSKI, C. 2012. Review and meta-analysis of 82 studies on end-of-life management methods for source separated organics. *Waste Management*.
NPC 2011. The National Packaging Covenant. 2010 Annual Report. Gordon: Australian Packaging Covenant Council.
NSW DEPARTMENT OF ENVIRONMENT AND CONSERVATION 2007. Life Cycle Inventory and Life Cycle Assessment for Windrow Composting Systems. Sydney: NSW Department of Environment and Conservation.
OUTLAW, K. 2013. IBISWorld Industry Report X0005. Agribusiness in Australia. IBISWorld Pty Ltd.
PICKIN, J. 1996. *Paper and the Greenhouse Effect.* RMIT.
PICKIN, J. 2010. Hanson Landfill Services / City of Whittlesea - Comparative Greenhouse Gas Life Cycle Assessment of Wollert Landfill. Melbourne: Hyder Consulting.
RECYCLED ORGANICS UNIT 2007. Life Cycle Inventory and Life Cycle Assessment for Windrow Composting Systems. Second ed.: Report prepared for NSW Department of Environment and Conservation (Sustainability Programs Division).
RECYCLINGTODAY. 2012. Novelis Opens UBC Recycling Plant in South Korea. Available: http://www.recyclingtoday.com/novelis-ubc-recycling-south-korea.aspx [Accessed 23/05/2013].
RICHARDSON, A. 2013. IBISWorld Industry Report C1831. Fertiliser Manufacturing in Australia. IBISWorld Pty Ltd.
SHI, L. 2013. The Mineral Industry of the Republic of Korea. *In:* SURVEY, U. S. G. (ed.) *2011 Minerals Yearbook. Republic of Korea (Advance Release).* U.S. Department of the Interior.
SIVASAILAM, N. 2012. IBISWorld Industry Report C2239. Metal Drum, Can and Bin Manufacturing in Australia. IBISWorld Pty Ltd.
SKM 2006. New Botany Paper Mill Project B9 - ENVIRONMENTAL ASSESSMENT REPORT St Leonards.
STICHLING, J. & NGUYEN-NGOC, D. 2009. Life Cycle Inventory and Impact Analysis for Beverage Cans. PE International.

SUSTAINABILITY VICTORIA 2011a. Victorian Local Government Annual Survey 2009-2010. Melbourne.
SUSTAINABILITY VICTORIA 2011b. Victorian Recycling Industries Annual Survey 2009-10.
SUSTAINABILITY VICTORIA 2012. Sustainability Victoria Strategic Plan 2012-15. Melbourne.
SUSTAINABILITY VICTORIA. 10/10/2012 2012b. *RE: LCA of MSW - Update.* Type to CLUNE, S.
T.EKVALL. Attributional and consequential LCI modelling (presentation). InLCA/LCM 2003, 2003 Seattle, Washington. American Center for Life Cycle Assessment.
TSE, P.-K. 2013. The Mineral Industry of Malaysia. *In:* SURVEY, U. S. G. (ed.) *2011 Minerals Yearbook. Malaysia (Advance Release).* U.S. Department of the Interior.
U.S. EIA 2013. Country Report - South Korea. U.S. Energy Information Administration.
UN COMTRADE 2013. United Nations Commodity Trade Statistics Database. *In:* DIVISION, U. N. S. (ed.). New York.
VALOIS, M., AKIM, E., LOMBARD, B. & PARIK, T. 2012. Forest Products Annual Market Review 2011-2012. Chapter 8. Paper, parperboard and woodpulp markets, 2011-2012. New York and Geneva: United Nations.
VISY RECYCLING. 2013. *Australia's most sophisticated glass recycling plant* [Online]. Visy Recycling. Available: http://test.visy.com.au/recycling/?id=182 [Accessed 3 June 2013].
WEIDEMA, B. 1997. *Guidelines for Critical Review of Product LCA* [Online]. 2.-0 LCA Consultants. Available: http://www.lca-net.com/publications/critical_review/ [Accessed 9/10/2012 2012].
WEIDEMA, B. 2003. *Environmental Project No. 863 - Market Information in Life Cycle Assessment,* Denmark, Danish Environmental Protection Agency.
WEIDEMA, B. P. & WESNÆS, M. S. 1996. Data quality management for life cycle inventories—an example of using data quality indicators. *Journal of Cleaner Production,* 4**,** 167-174.
WILLANTO, R. 2012. IBISWorld Industry Report C2110. Iron Smelting and Steel Manufacturing in Australia. IBISWorld Pty Ltd.
WORLD STEEL ASSOCIATION 2013. Short range outlook for apparent steel use, finished steel products (2012-2014). Brussels and Beijing: World Steel Association,.
WRAP 2006. UK Plastics Waste – A review of supplies for recycling, global market demand, future trends and associated risks. Banbury.
WRAP 2009. Final Report - Material quality assessment of municipal MRFs within the UK. Completed by Enviros Consulting.
WRAP 2011. The Chinese markets for recovered paper and plastics – an update. *Market Situation Report – Spring 2011.* Waste & Resources Action Programme.

Appendix A – Life Cycle Assessment and Recycling

1.1. LCA Methodology

The following sections provide a brief description of the LCA methodology. The most important terminology is explained, as well as how to interpret outcomes of the assessment.

LCA is the process of evaluating the potential effects that a product, process or service has on the environment over the entire period of its life cycle. Figure 5-1 illustrates the life cycle system concept of natural resources and energy entering the system with products, waste and emissions leaving the system.

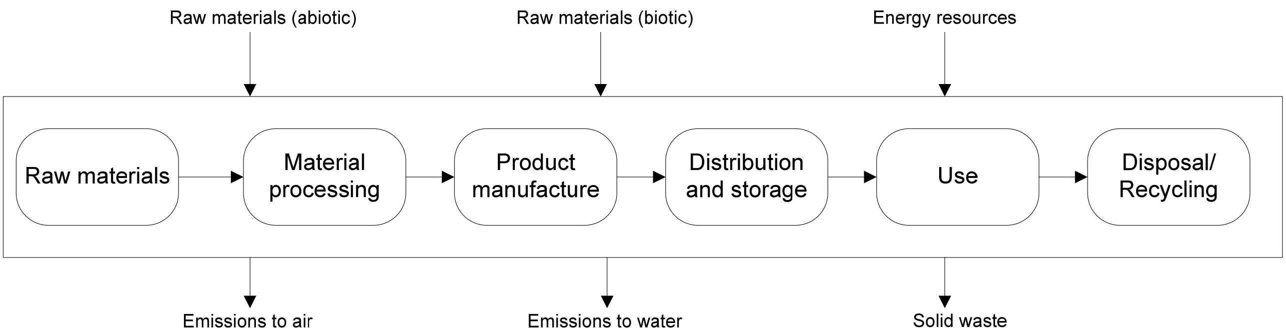


Figure 0-1 Life cycle system concept the figure

The International Standards Organization (ISO) defines LCA as:

"[A] Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its lifecycle" (ISO 14040:2006 pp.2).

The technical framework for LCA consists of four components, each having a very important role in the assessment. They are interrelated throughout the entire assessment and in accordance with the current terminology of the International Standards Organisation (ISO). The components are goal and scope definition, inventory analysis, impact assessment and interpretation as illustrated in Figure 3-2.

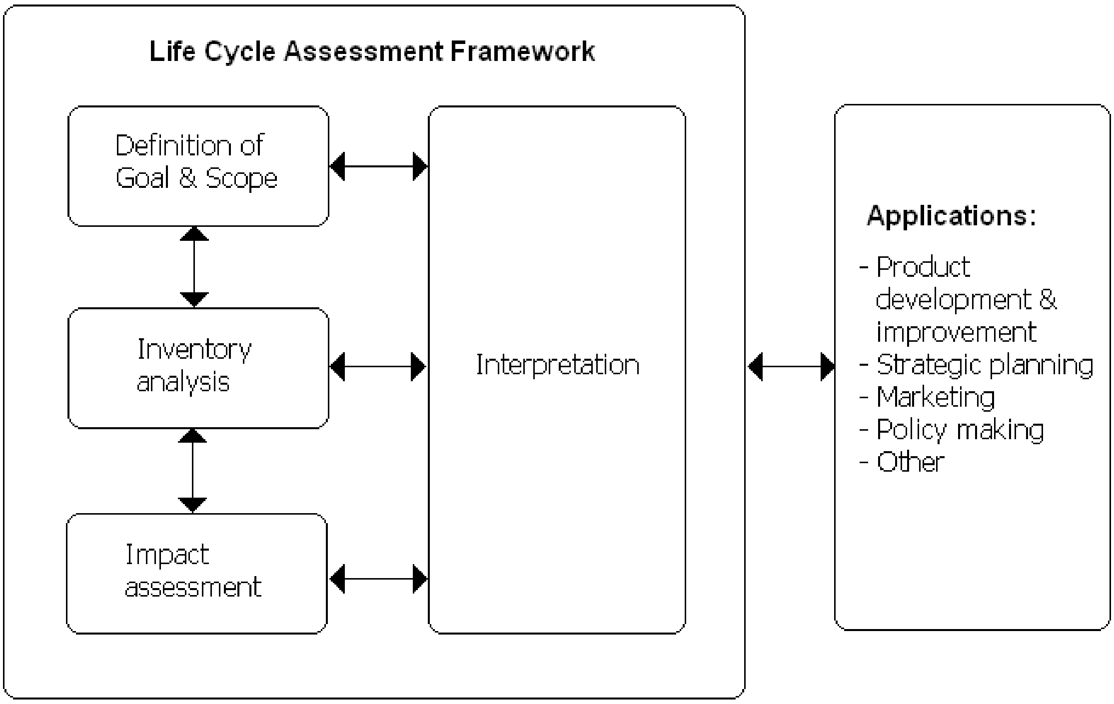


Figure 0-2: The Framework for LCA from the International Standard (ISO 14040:2006(E) pp.8)

1.2. Goal and scope definition

At the commencement of an LCA, the goal and scope of the study needs to be clearly defined. The goal should state unambiguously the intended application/purpose of the study, the audience for which the results are intended, the product or function that is to be studied, and the scope of the study. When defining the scope, consideration of the reference unit, system boundaries and data quality requirements are some of the issues to be covered.

1.3. Inventory analysis

Inventory analysis is concerned with the collection, analysis and validation of data that quantifies the appropriate inputs and outputs of a product system. The inventory can include process flow charts, details of raw material inputs, environmental emissions and energy inputs associated with the product under study. These process inputs and outputs are typically reported in inventory tables.

1.4. Impact assessment

Impact assessment identifies the link between the product's life cycle and the potential environmental impacts associated with it. The impact assessment stage consists of three phases that are intended to evaluate the significance of the potential environmental effects associated with the product system:

- The first phase is the characterisation of the results, assigning the elemental flows to impact categories, and calculating their contribution to that impact.
- The second phase is the comparison of the impact results to total national impact levels and is called normalisation.
- The third phase is the weighting of these normalised results together to enable the calculation of a single indicator result. In this study, only the first two phases are undertaken.

1.5. Interpretation

Interpretation is a systematic evaluation of the outcomes of the life cycle inventory analysis and/or impact assessment, in relation to the goal and scope. This interpretation result into conclusions of the environmental profile of the product or system under investigation, and recommendations on how to improve the environmental profile.

2. The application of LCA to studies of recycling

> In ISO 14040 (see below) LCA is defined as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle". Thus, LCA is a tool for the analysis of the environmental burden of products at all stages in their life cycle – from the extraction of resources, through the production of materials, product parts and the product itself, and the use of the product to the management after it is discarded, either by reuse, recycling or final disposal (in effect, therefore, 'from the cradle to the grave').
>
> (Guinée, 2002)

The above quote from (Guinée, 2002), illustrates the power of LCA to analyse the impacts of the recycling system. The multifaceted nature of the recycling system means that any assessment approach must look across multiple processes and consider impacts that occur at different points in a product life cycle. For these and other reasons, the LCA method is considered a good tool for assessing the impact of recycling in a holistic and objective manner. (Guinée, 2002) refers specifically to the assessment of waste management options as an appropriate use of LCA (p.7.).

Although an appropriate tool for assessing the environmental impacts of recycling, LCA is not without its limitations. Of these, the allocation protocol (to deal with process which have multiple inputs and/or multiple outputs) used within an LCA can be a source of subjectivity, therefore clear rules are presented in the ISO standard that govern how allocation should be applied. Within ISO14044:2006 (section 4.3.4.3), recycling is addressed directly under the topic of allocation. In summary, the standard requires that allocation be avoided where possible, and that "Changes in the inherent properties of materials shall be taken into account" (ISO14044:2006), and that clear explanation of the system boundary between "original and subsequent" product system be provided.

2.1. Allocation and partitioning

Typically, partitioning problems pervade the study of products rather than systems, where impacts have to be allocated to a particular product in isolation from subsequent products (such as when a glass bottle is recycled at the end of its life). For example, the model used in Grant et al (2001a) addressed the impacts needed to reprocess the recyclate to a material equivalent to virgin material. In affect the approach used in Grant et al (2001a) is a 'closed loop' model of reprocessing. This approach may be valid, however alternative approaches exist that will need to be considered.

Ekvall and Tillman (1997), provide a basis for making the allocation decision that helps navigate the allocation procedure selection, with the essential conclusion being "use a logical approach, consistent with the study goal" when dealing with allocation in open-loop recycling (SETAC 1993)" (Ekvall and Tillman, 1997). They argue that more than one approach is valid and it is the consistency with the goals of the study that should determine selection. In this study, allocation procedures will be argued within this context.

2.2. Consequential versus attributional perspectives

In addition to, and stemming from, the allocation challenge, the perspective from which the LCA is compiled is important. LCA's are typically compiled from a largely attributional standpoint, from which the existing impacts of the system are allocated to the unit processes that make up the system. This is in contrast to the consequential approach which seeks to understand how a system will respond to a change in system operation. The attributional perspective is typified by a retrospective viewpoint and assumed that all future impacts will be the same as the past, whereas the consequential perspective is considered a prospective view, where future impacts will be different to the past.

The conceptual difference between attributional and consequential LCA, as outlined by Weidema (2003), is provided in Figure 3. The two circles represent the total global environmental exchanges. In the left circle, attributional LCA seeks to cut out the piece with dotted lines that belongs to a specific human activity, e.g. car driving. In the right circle, consequential LCA seeks to capture the change in environmental exchanges that occur as a consequence of adding or removing a specific human activity (e.g. the additional amount of road needed for one additional car).

The consequential LCI methodology described in Weidema's (2003) paper aims to describe how the environmentally relevant physical flows to and from the technological system will change in response to possible changes in the life cycle. We distinguish it from attributional LCI methodology, which aims at describing the environmentally relevant physical flows to and from a life cycle and its subsystems. A consequential LCI methodology is designed to generate information on the consequences of actions (Weidema, 2003).

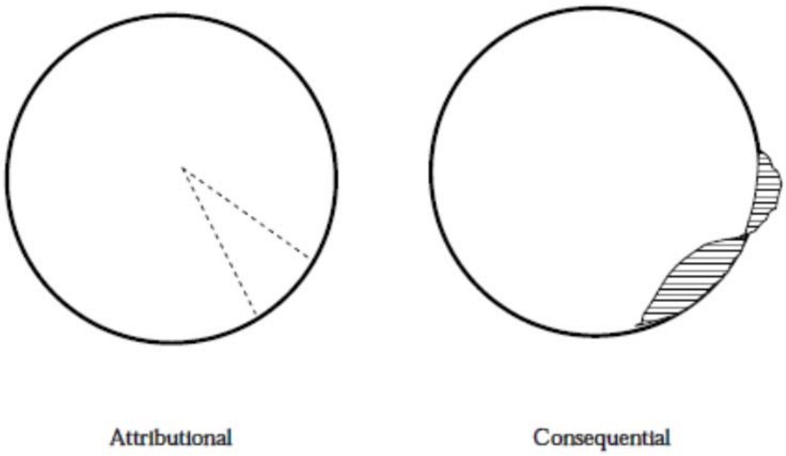


Figure 3 Consequential versus attributional perspectives. The circles represent the total global environmental exchanges. In the left circle, attributional LCA seeks to cut out the piece with dotted lines that belongs to a specific human activity, e.g. car driving. In the right circle, consequential LCA seeks to capture the change in environmental exchanges that occur as a consequence of adding or removing a specific human activity."(Weidema, 2003)

The difference between the consequential and attributional approach is particularly relevant to the assessment of recycling systems, especially where growth in recycling is the desired outcome. The attributional approach assumes that an increase in recycling will result in environmental impacts that are linearly related to the impacts of the current recycling system. The consequential approach does not assume a linear 'scaling' of the existing system, but rather explores shifts of behaviour within the system.

Both approaches have their limitations which (T.Ekvall, 2003) summarises:

- Attributional LCA:
  - Describes systems only
  - Systems are subjective (allocation, geographical boundaries etc.)
- Consequential LCA:
  - Describes consequences only
  - Entails great uncertainty and instability"

The selection of approach will impact the study outcome so methods such as that described by Ekvall and Tillman (1997), will need to be employed. In this study, it is likely that attributional approaches will be used to characterise the impacts of the existing recycling system, and consequential approaches used to determine the impact of policies that seek to increase recycling rates.

2.3. Characterising environmental impacts

In characterising the environmental impacts of recycling, ISO14044:2006 provides guidance, as do prior studies such as Grant et al (2001a) and LCA review studies such as Michaud et al (2010).

"The LCIA phase shall be carefully planned to achieve the goal and scope of the study. The LCIA phase shall be coordinated with other phases of the LCA to take into account the following possible omissions and sources of uncertainty:

a) Whether the quality of the LCI data and results is sufficient to conduct the LCIA in accordance with the study goal and scope definition;

b) Whether the system boundary and data cut-off decisions have been sufficiently reviewed to ensure the availability of LCI results necessary to calculate indicator results for the LCIA;

c) Whether the environmental relevance of the LCIA results is decreased due to the LCI functional unit calculation, system wide averaging, aggregation and allocation" (ISO14044:2006)

Locally derived documents also provide guidance as to how to apply methods in a way appropriate to the Australian situation (Grant and Peters, 2008).

A survey[9] of LCA's that consider waste treatment systems, Table 55, indicates a variety of impact assessment methods are employed in studies that consider waste treatment and recycling The indicators listed are categorised as either indicators of environmental impact (I) or precursors to environmental impact (P). The difference between these two groups is that indicators directly measure environmental impact (such as Global Warming), whereas precursors measure activities that typically lead to subsequent environmental impact, such as Solid Waste. The Solid Waste indicator is considered a precursor because it measures a quantity of waste disposed of to landfill, yet does not describe what the environmental impact of this might be. Precursors leave readers to infer the environmental outcomes from an indicator (such as leachate generation, land occupation or global warming).

Table 55 Indicators used to characterise environmental impacts.

Indicators (definitions for indicators to be used in this study are provided in Section 5.8)	Indicator of Impact (I) or precursor to impact (P)	(Grant et al., 2001a)	(Grant et al., 2003a)	(European Commission - Joint Research Centre, 2008)	(Carre et al., 2009)	Michaud et al. (2010)
Photochemical oxidation	I	✓	✓			
Cumulative energy demand	P	✓			✓	✓
Water use	I	✓			✓	✓
Solid waste	P	✓			✓	
Global warming	I	✓	✓		✓	✓
Human toxicity	I		✓			
Ecotoxicity	I		✓			
Resource depletion	I		✓			✓
Eutrophication	I		✓			
End-point indicator*	n/a			✓*		

* An end-point indicator compiles and weights the results of a range of mid-point indicators (such as global warming, water use, photochemical oxidation etc.) to assess a total 'damage' outcome. The end-point indicator used in the study here required the assessment of 22 mid-point indicators. The end point method used was a combination of EDIP 2003 and IMPACT 2002+.

Other studies (not shown in the table) tend to address one indicator (commonly global warming), with fewer addressing a range of indicators. Those LCA studies which address a range of indicators can be split into two categories, the first being those that employ 'mid-point' assessment methods, and the second being those that employ 'end-point' assessment methods (a definition of each is presented below). Mid-point approaches tended to be the most common of the multi-indicator approaches considered.

---

[9] Michaud et al. (2010) provides an excellent overview of LCA studies that address waste treatment.

Mid-point methods

"Classical impact assessment methods (e.g. The Dutch Handbook: Guine et al. 2002, EDIP: Hauschild and Wenzel 1998 and further adaptations, TRACI: Bare et al. 2003) that stop quantitative modelling before the end of the impact pathways and link LCI results to so-defined midpoint categories, e.g. ozone depletion or acidification. However, depletion of the ozone layer, as expressed by a corresponding midpoint category indicator such as ozone depletion potential, is an environmental concern in itself, but the larger concern is usually the subsequent damages to humans, animals and plants." (Jolliet et al., 2004)

End-point methods

"Damage oriented methods (e.g. Ecoindicator 99: Goedkoop and Spriensma 2000, EPS: Steen 1999) which aim at LCA outcomes that are more easily interpretable for further weighting, by modelling the cause-effect chain up to the environmental damages, the damages to human health, to the natural environment and to natural resources. These may be expressed for example in additional cases of human health impairment or species endangerment, enabling to reduce the number of considered endpoints in making different midpoints comparable. They can, however, lead to high uncertainties."(Jolliet et al., 2004)

Overall, the literature provides a range of valid options when it comes to impact assessment.

2.4. More recent recycling LCA's

Numerous local (Australian) LCA based studies have been completed since Grant et al (2001a), including:

- Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in New South Wales (Grant et al., 2001b)
- Life Cycle Assessment of Waste and Resource Recovery Options (including energy from waste) - Final Report for EcoRecycle Victoria (Grant et al., 2003a)
- Life Cycle Impact Data for Resource Recovery from Commercial and Industrial and Construction and Demolition Waste in Victoria (Grant and James, 2005)
- Extended Environmental Benefits of Recycling (EEBR) Project (Carre et al., 2009)

These reports share a common methodology, stemming from Grant et al (2001a). Although a common method has been applied, data have been progressively updated to incorporate the various local aspects of the recycling systems considered and underpinning infrastructure elements (such as electricity generation).

More broadly, many LCA studies have been completed looking at individual packaging and product systems which incorporate recycling processes (Franklin Associates., 2009, Franklin Associates., 2010, Hyder Consulting, 2008, Stichling and Nguyen-Ngoc, 2009, Glass Packaging Institute, 2010). These reports study of the impacts of various packaging systems, and although recycling is not the primary focus, its impacts are important and discussion of recycling represents a significant proportion of reporting. They also provide useful sources of information regarding the reprocessing of materials, however much of this is associated with international systems.

In addition to synthetic material reprocessing studies, are studies that consider the treatment of organic waste. Organic waste treatment systems have been assessed in a range of studies locally and internationally (Eunomia Research & Consulting, 2002, NSW Department of Environment and Conservation, 2007, Hermann et al., 2011, Morris et al., 2012, Bernstad and la Cour Jansen, 2012).

A review of LCAs undertaken globally has been completed by Michaud et al (2010). This review covers materials and disposal pathways including recycling, Table 56.

Table 56 Material and technology combinations considered by (Michaud et al., 2010).

	Recycling	Composting	Incineration	Landfill	Anaerobic digestion	Pyrolysis	Gasification
Paper and card	x		x	x			
Plastics	x		x	x		x	
Biopolymers	x	x	x	x	x		
Food and garden waste		x	x	x	x		
Wood	x		x	x			
Textiles	x		x	x			

Rather than undertaking LCA research to determine waste processing impacts, Michaud et al (2010) surveyed and reviewed the outcomes of existing studies. This approach provides an overview of work completed and provides a benchmark against which to compare study results. Importantly, the review only considered environmental impacts in terms of:

- Depletion of natural resources
- Global warming (Climate change) potential
- Cumulative energy demand
- Water consumption

As evidenced by Michaud et al (2010), the indicators above have been of interest in many past LCA studies of waste treatment, and provide comparable benchmarks for future studies, thus they are therefore are worthy of consideration in this study.

Appendix B – Inventory Report

Refer separate report.

Appendix C – Detailed Results by Material

The following tables contain the study results shown by material and by process.

Table 57 describes the study results for each indicator, broken down by both process and material being recycled. This table is intended to provide results in a form that allows the influence of mixture of recovered material on the overall outcome to be considered. Each indicator is shown in terms of the contribution each material stream provides to the outcome.

Colours in Table 57 are used to highlight the processes and materials that drive the indicator outcome. Red toned cells highlight those process/material combinations that adversely impact the environmental outcome, and green toned cells indicate process/material combinations beneficially impact the outcome. White cells indicate minimal contribution to the Net Outcome. To further assist interpretation the Net Outcome column is enhanced by a bar indicating a beneficial (green) or adverse (red) material outcome, and a rank is provided highlighting the materials that contributed most to the outcome when recycled.

Below Table 57, Table 58 provides the same results, however results are scaled to reflect the outcome if 1 t of each material were to be recycled, rather than the mix of material quantities prescribed by the functional unit. This table serves to indicate those materials that provide the biggest benefits when recycled.

Table 57 Characterisation for 1 functional unit, broken down by material.

			Recycling System					Alternative System							95th Percentile	
Item	Indicator	Unit	Collection Recycling	Sorting	Reprocess Local	Reprocess International	Soil carbon storage	Production Local	Production International	Collection Landfill	Disposal operations	Landfill carbon storage	Net Outcome -ve Benefit, +ve Burden	Rank	2.5 Percentile	97.5 Percentile
Glass bottles		kg CO2 eq	2.17	5.96	26.57	0.00	0.00	-62.16	0.00	-2.71	-7.76	0.00	-37.93	4	-48.89	-27.94
Steel cans		kg CO2 eq	0.58	0.59	2.97	4.28	0.00	-8.32	-12.36	-0.77	-0.86	0.00	-13.90	5	-16.08	-12.08
Alum. Cans		kg CO2 eq	0.22	0.29	1.81	1.58	0.00	-27.55	-25.58	-0.29	-0.32	0.00	-49.84	2	-53.40	-47.10
Paper - white		kg CO2 eq	0.05	0.08	0.39	0.82	0.00	-0.28	-0.48	-0.06	-1.93	0.07	-1.35	11	-1.74	-0.52
Paper - mixed		kg CO2 eq	5.29	8.67	42.67	90.30	0.00	-31.19	-53.18	-6.87	-124.32	18.97	-49.65	3	-98.67	18.81
Paper - card	GW	kg CO2 eq	2.16	3.55	17.46	36.94	0.00	-12.76	-21.76	-2.81	-47.26	16.85	-7.63	7	-30.92	26.19
Plastic - PET		kg CO2 eq	1.25	1.04	5.32	6.70	0.00	-9.85	-11.56	-1.68	-0.86	0.00	-9.65	6	-15.36	-4.42
Plastic - HDPE		kg CO2 eq	0.62	0.52	1.32	1.77	0.00	-2.90	-3.41	-0.84	-0.43	0.00	-3.35	8	-4.36	-2.10
Plastic - HDPE (col)		kg CO2 eq	0.47	0.39	0.00	2.46	0.00	0.00	-4.73	-0.63	-0.32	0.00	-2.37	10	-3.24	-1.44
Plastic - mixed		kg CO2 eq	1.25	1.04	0.00	6.57	0.00	0.00	-8.85	-1.68	-0.86	0.00	-2.54	9	-4.90	-0.01
Garden and green		kg CO2 eq	13.44	0.00	38.56	0.00	-14.08	-11.85	0.00	-9.94	-111.36	26.78	-68.46	1	-99.71	-23.10
Glass bottles		kg PO4--- eq	0.00	0.01	0.03	0.00	0.00	-0.05	0.00	0.00	-0.02	0.00	-0.03	4	-0.04	-0.01
Steel cans		kg PO4--- eq	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7	-0.01	0.00
Alum. Cans		kg PO4--- eq	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	-0.02	5	-0.03	-0.02
Paper - white		kg PO4--- eq	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8	0.00	0.00
Paper - mixed		kg PO4--- eq	0.00	0.01	0.04	0.09	0.00	-0.03	-0.06	-0.01	-0.25	0.00	-0.20	1	-0.46	-0.04
Paper - card	EU	kg PO4--- eq	0.00	0.01	0.02	0.04	0.00	-0.01	-0.02	0.00	-0.09	0.00	-0.07	2	-0.19	-0.01
Plastic - PET		kg PO4--- eq	0.00	0.00	0.00	0.01	0.00	-0.01	-0.02	0.00	0.00	0.00	-0.02	6	-0.06	-0.01
Plastic - HDPE		kg PO4--- eq	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9	0.00	0.00
Plastic - HDPE (col)		kg PO4--- eq	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10	0.00	0.00
Plastic - mixed		kg PO4--- eq	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11	0.00	0.00
Garden and green		kg PO4--- eq	0.01	0.00	0.07	0.00	0.00	-0.01	0.00	-0.01	-0.10	0.00	-0.04	3	-0.07	-0.01
Glass bottles		kg NMVOC	0.02	0.02	0.20	0.00	0.00	-0.35	0.00	-0.02	-0.04	0.00	-0.17	4	-0.25	-0.07
Steel cans		kg NMVOC	0.00	0.00	0.01	0.02	0.00	-0.02	-0.04	-0.01	0.00	0.00	-0.03	6	-0.06	-0.01
Alum. Cans		kg NMVOC	0.00	0.00	0.01	0.01	0.00	-0.13	-0.12	0.00	0.00	0.00	-0.23	2	-0.25	-0.21
Paper - white		kg NMVOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	11	-0.01	0.00
Paper - mixed		kg NMVOC	0.04	0.04	0.25	0.44	0.00	-0.22	-0.32	-0.05	-0.37	0.00	-0.20	3	-0.66	0.16
Paper - card	PO	kg NMVOC	0.02	0.01	0.10	0.18	0.00	-0.09	-0.13	-0.02	-0.14	0.00	-0.07	5	-0.25	0.07
Plastic - PET		kg NMVOC	0.01	0.00	0.02	0.03	0.00	-0.03	-0.03	-0.01	0.00	0.00	-0.02	7	-0.04	0.00
Plastic - HDPE		kg NMVOC	0.00	0.00	0.00	0.01	0.00	-0.01	-0.02	-0.01	0.00	0.00	-0.02	8	-0.03	-0.01
Plastic - HDPE (col)		kg NMVOC	0.00	0.00	0.00	0.01	0.00	0.00	-0.02	0.00	0.00	0.00	-0.01	9	-0.02	0.00
Plastic - mixed		kg NMVOC	0.01	0.00	0.00	0.03	0.00	0.00	-0.03	-0.01	0.00	0.00	-0.01	10	-0.03	0.01
Garden and green		kg NMVOC	0.10	0.00	0.16	0.00	0.00	-0.06	0.00	-0.08	-0.56	0.00	-0.44	1	-1.00	-0.10
Glass bottles		$	0.00	0.01	0.05	0.00	0.00	-0.05	0.00	0.00	0.00	0.00	0.01	9	-0.10	0.11
Steel cans		$	0.00	0.00	0.00	0.00	0.00	-0.34	-0.49	0.00	0.00	0.00	-0.83	1	-0.90	-0.75
Alum. Cans		$	0.00	0.00	0.03	0.02	0.00	-0.06	-0.05	0.00	0.00	0.00	-0.06	3	-0.07	-0.05
Paper - white		$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5	0.00	0.00
Paper - mixed		$	0.00	0.02	0.00	0.02	0.00	0.00	-0.01	0.00	0.00	0.00	0.03	11	0.01	0.05
Paper - card	MD	$	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	10	0.00	0.02
Plastic - PET		$	0.00	0.00	0.00	0.00	0.00	-0.05	-0.06	0.00	0.00	0.00	-0.10	2	-0.30	-0.04
Plastic - HDPE		$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7	0.00	0.00
Plastic - HDPE (col)		$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6	0.00	0.00
Plastic - mixed		$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8	0.00	0.00
Garden and green		$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4	-0.01	0.01
Glass bottles		$	0.04	0.05	0.45	0.00	0.00	-0.84	0.00	-0.05	-0.03	0.00	-0.39	3	-0.56	-0.23
Steel cans		$	0.01	0.00	0.04	0.06	0.00	-0.09	-0.14	-0.01	0.00	0.00	-0.14	7	-0.19	-0.11
Alum. Cans		$	0.00	0.00	0.03	0.03	0.00	-0.39	-0.36	-0.01	0.00	0.00	-0.69	1	-0.74	-0.66
Paper - white		$	0.00	0.00	0.01	0.01	0.00	0.00	-0.01	0.00	0.01	0.00	0.01	8	0.01	0.03
Paper - mixed		$	0.10	0.07	0.67	0.93	0.00	-0.44	-0.57	-0.13	0.34	0.00	0.97	11	0.42	2.24
Paper - card	FFD	$	0.04	0.03	0.27	0.38	0.00	-0.18	-0.23	-0.05	0.13	0.00	0.38	10	0.15	0.87
Plastic - PET		$	0.02	0.01	0.07	0.09	0.00	-0.29	-0.34	-0.03	0.00	0.00	-0.46	2	-0.60	-0.33
Plastic - HDPE		$	0.01	0.01	0.02	0.02	0.00	-0.12	-0.15	-0.02	0.00	0.00	-0.23	5	-0.25	-0.21
Plastic - HDPE (col)		$	0.01	0.00	0.00	0.03	0.00	0.00	-0.20	-0.01	0.00	0.00	-0.17	6	-0.19	-0.15
Plastic - mixed		$	0.02	0.01	0.00	0.09	0.00	0.00	-0.36	-0.03	0.00	0.00	-0.27	4	-0.31	-0.23
Garden and green		$	0.26	0.00	0.13	0.00	0.00	-0.09	0.00	-0.19	0.17	0.00	0.28	9	-0.03	0.67
Glass bottles		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5	0.00	0.00
Steel cans		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9	0.00	0.00
Alum. Cans		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3	0.00	0.00
Paper - white		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4	0.00	0.00
Paper - mixed		ha.a	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	-0.02	1	-0.03	-0.01
Paper - card	LU	ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	2	-0.01	0.00
Plastic - PET		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6	0.00	0.00
Plastic - HDPE		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8	0.00	0.00
Plastic - HDPE (col)		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7	0.00	0.00
Plastic - mixed		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10	0.00	0.00
Garden and green		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11	0.00	0.00
Glass bottles		kL H2O	0.00	0.01	0.06	0.00	0.00	-0.13	0.00	0.00	-0.01	0.00	-0.07	9	-0.11	-0.02
Steel cans		kL H2O	0.00	0.00	0.01	0.02	0.00	-0.15	-0.21	0.00	0.00	0.00	-0.34	5	-0.36	-0.31
Alum. Cans		kL H2O	0.00	0.00	0.03	0.03	0.00	-0.08	-0.07	0.00	0.00	0.00	-0.09	8	-0.12	-0.07
Paper - white		kL H2O	0.00	0.00	0.00	0.01	0.00	-0.01	-0.02	0.00	0.00	0.00	-0.01	11	-0.02	0.00
Paper - mixed		kL H2O	0.01	0.01	0.06	1.09	0.00	-0.62	-1.79	-0.01	0.03	0.00	-1.22	2	-2.08	-0.33
Paper - card	WU	kL H2O	0.00	0.01	0.02	0.44	0.00	-0.25	-0.73	0.00	0.01	0.00	-0.50	4	-0.86	-0.07
Plastic - PET		kL H2O	0.00	0.00	0.09	0.11	0.00	-0.35	-0.41	0.00	0.00	0.00	-0.55	3	-0.74	-0.40
Plastic - HDPE		kL H2O	0.00	0.00	0.01	0.01	0.00	-0.05	-0.06	0.00	0.00	0.00	-0.09	7	-0.09	-0.09
Plastic - HDPE (col)		kL H2O	0.00	0.00	0.00	0.01	0.00	0.00	-0.08	0.00	0.00	0.00	-0.07	10	-0.07	-0.06
Plastic - mixed		kL H2O	0.00	0.00	0.00	0.03	0.00	0.00	-0.24	0.00	0.00	0.00	-0.21	6	-0.22	-0.20
Garden and green		kL H2O	0.02	0.00	0.02	0.00	0.00	-1.77	0.00	-0.01	0.00	0.00	-1.74	1	-3.53	-0.69
Glass bottles		kg	0.09	4.89	0.95	0.13	0.00	-2.75	0.00	-0.08	-81.87	0.00	-78.64	1	-79.20	-78.48
Steel cans		kg	0.02	0.54	0.62	0.91	0.00	-0.01	-0.02	-0.02	-9.10	0.00	-7.06	8	-7.07	-6.72
Alum. Cans		kg	0.01	0.20	0.06	0.04	0.00	-5.66	-5.23	-0.01	-3.41	0.00	-13.99	5	-17.91	-14.01
Paper - white		kg	0.00	0.07	0.07	0.07	0.00	-0.02	-0.01	0.00	-0.69	0.00	-0.50	11	-0.51	-0.46
Paper - mixed		kg	0.21	7.46	7.57	8.21	0.00	-1.80	-0.70	-0.20	-93.50	0.00	-72.74	2	-73.70	-71.06
Paper - card	SW	kg	0.09	3.05	3.10	3.36	0.00	-0.74	-0.29	-0.08	-39.01	0.00	-30.52	4	-31.10	-29.97
Plastic - PET		kg	0.05	0.55	0.30	0.36	0.00	0.00	0.00	-0.05	-9.10	0.00	-7.89	6	-7.91	-6.87
Plastic - HDPE		kg	0.02	0.27	0.30	0.35	0.00	0.00	0.00	-0.02	-4.55	0.00	-3.63	9	-3.64	-3.42
Plastic - HDPE (col)		kg	0.02	0.21	0.00	0.49	0.00	0.00	0.00	-0.02	-3.41	0.00	-2.72	10	-2.74	-2.54
Plastic - mixed		kg	0.05	0.55	0.00	1.29	0.00	0.00	0.00	-0.05	-9.10	0.00	-7.25	7	-7.29	-6.89
Garden and green		kg	0.58	0.00	43.42	0.00	0.00	-0.78	0.00	-0.29	-93.46	0.00	-50.53	3	-58.98	-41.04
Glass bottles		MJ LHV	35.16	47.63	377.48	0.47	0.00	-702.06	0.00	-42.79	-40.55	0.00	-324.66	3	-464.40	-183.60
Steel cans		MJ LHV	9.40	4.50	32.19	53.87	0.00	-80.61	-122.12	-12.09	-4.51	0.00	-119.37	7	-160.00	-88.80
Alum. Cans		MJ LHV	3.53	2.48	29.14	27.75	0.00	-351.67	-327.01	-4.53	-1.69	0.00	-622.02	1	-657.00	-588.00
Paper - white		MJ LHV	0.78	0.62	5.14	8.93	0.00	-6.38	-9.22	-0.98	1.79	0.00	0.68	10	-5.59	15.90
Paper - mixed		MJ LHV	85.88	67.81	564.96	982.67	0.00	-701.63	-1,013.94	-108.29	82.65	0.00	-39.88	8	-720.50	1,232.00
Paper - card	CED	MJ LHV	35.13	27.74	231.12	402.00	0.00	-287.03	-414.79	-44.30	29.07	0.00	-21.06	9	-279.00	504.00
Plastic - PET		MJ LHV	20.22	9.49	63.83	81.97	0.00	-269.80	-316.72	-26.52	-4.51	0.00	-442.05	2	-581.60	-331.20
Plastic - HDPE		MJ LHV	10.11	4.74	15.84	22.11	0.00	-110.90	-130.19	-13.26	-2.25	0.00	-203.80	5	-219.20	-187.20
Plastic - HDPE (col)		MJ LHV	7.58	3.56	0.00	30.71	0.00	0.00	-180.82	-9.94	-1.69	0.00	-150.60	6	-163.50	-136.20
Plastic - mixed		MJ LHV	20.22	9.49	0.00	81.89	0.00	0.00	-316.53	-26.52	-4.52	0.00	-235.98	4	-268.80	-198.40
Garden and green		MJ LHV	219.94	0.00	149.05	0.00	0.00	-77.40	0.00	-156.71	-40.91	0.00	93.97	11	-196.99	449.92

Table 58 Characterisation for the recycling of 1 t of each material shown (impact intensity).

			Recycling System					Alternative System								
Item	Indicator	Unit	Collection Recycling	Sorting	Reprocess Local	Reprocess International	Soil carbon storage	Production Local	Production International	Collection Landfill	Disposal operations	Landfill carbon storage	Net Outcome -ve Benefit, +ve Burden	Rank	2.5 Percentile	97.5 Percentile
Glass bottles		kg CO2 eq	30.09	82.83	369.06	0.00	0.00	-863.28	0.00	-37.68	-107.81	0.00	-526.79	7	-679.00	-388.00
Steel cans		kg CO2 eq	72.40	73.90	370.71	534.65	0.00	-1,039.82	-1,545.47	-95.79	-107.81	0.00	-1,737.22	2	-2,010.00	-1,510.00
Alum. Cans		kg CO2 eq	72.40	97.54	602.23	527.43	0.00	-9,182.30	-8,527.47	-95.79	-107.81	0.00	-16,613.77	1	-17,800.00	-15,700.00
Paper - white		kg CO2 eq	48.10	78.79	387.92	820.86	0.00	-283.50	-483.45	-62.42	-1,926.50	73.40	-1,346.79	3	-1,740.00	-515.00
Paper - mixed		kg CO2 eq	48.10	78.79	387.92	820.86	0.00	-283.50	-483.45	-62.42	-1,130.17	172.49	-451.37	8	-897.00	171.00
Paper - card	GW	kg CO2 eq	48.10	78.79	387.92	820.86	0.00	-283.50	-483.45	-62.42	-1,050.28	374.34	-169.63	11	-687.00	582.00
Plastic - PET		kg CO2 eq	155.70	129.88	664.91	837.26	0.00	-1,230.72	-1,444.76	-210.18	-108.10	0.00	-1,206.01	4	-1,920.00	-552.00
Plastic - HDPE		kg CO2 eq	155.70	129.88	329.51	443.54	0.00	-725.82	-852.05	-210.18	-107.81	0.00	-837.23	5	-1,090.00	-526.00
Plastic - HDPE (col)		kg CO2 eq	155.70	129.88	0.00	821.38	0.00	0.00	-1,577.86	-210.18	-107.81	0.00	-788.90	6	-1,080.00	-480.00
Plastic - mixed		kg CO2 eq	155.70	129.88	0.00	821.38	0.00	0.00	-1,105.85	-210.18	-107.93	0.00	-317.00	9	-613.00	-1.08
Garden and green		kg CO2 eq	44.22	0.00	126.83	0.00	-46.33	-38.99	0.00	-32.69	-366.32	88.08	-225.20	10	-328.00	-76.00
Glass bottles		kg PO4--- eq	0.03	0.12	0.41	0.00	0.00	-0.65	0.00	-0.04	-0.24	0.00	-0.36	6	-0.60	-0.13
Steel cans		kg PO4--- eq	0.07	0.12	0.22	0.45	0.00	-0.30	-0.55	-0.09	-0.27	0.00	-0.35	7	-0.93	0.03
Alum. Cans		kg PO4--- eq	0.07	0.13	0.53	0.57	0.00	-4.46	-4.23	-0.09	-0.24	0.00	-7.72	1	-8.46	-7.02
Paper - white		kg PO4--- eq	0.04	0.12	0.34	0.84	0.00	-0.29	-0.55	-0.06	-2.52	0.00	-2.07	3	-4.57	-0.51
Paper - mixed		kg PO4--- eq	0.04	0.12	0.34	0.84	0.00	-0.29	-0.55	-0.06	-2.26	0.00	-1.81	4	-4.15	-0.40
Paper - card	EU	kg PO4--- eq	0.04	0.12	0.34	0.84	0.00	-0.29	-0.55	-0.06	-2.04	0.00	-1.60	5	-4.14	-0.16
Plastic - PET		kg PO4--- eq	0.14	0.13	0.46	0.67	0.00	-1.66	-1.95	-0.20	-0.35	0.00	-2.75	2	-6.92	-0.95
Plastic - HDPE		kg PO4--- eq	0.14	0.13	0.21	0.37	0.00	-0.20	-0.24	-0.20	-0.26	0.00	-0.04	9	-0.35	0.27
Plastic - HDPE (col)		kg PO4--- eq	0.14	0.13	0.00	0.69	0.00	0.00	-0.44	-0.20	-0.26	0.00	0.07	11	-0.26	0.50
Plastic - mixed		kg PO4--- eq	0.14	0.13	0.00	0.69	0.00	0.00	-0.37	-0.20	-0.35	0.00	0.04	10	-0.30	0.43
Garden and green		kg PO4--- eq	0.04	0.00	0.22	0.00	0.00	-0.02	0.00	-0.03	-0.33	0.00	-0.12	8	-0.24	-0.02
Glass bottles		kg NMVOC	0.23	0.33	2.84	0.01	0.00	-4.82	0.00	-0.29	-0.59	0.00	-2.29	7	-3.53	-1.03
Steel cans		kg NMVOC	0.55	0.32	1.29	2.66	0.00	-2.76	-4.73	-0.74	-0.59	0.00	-4.00	5	-7.47	-1.55
Alum. Cans		kg NMVOC	0.55	0.37	4.00	4.10	0.00	-43.17	-40.60	-0.74	-0.59	0.00	-76.08	1	-81.90	-70.50
Paper - white		kg NMVOC	0.36	0.33	2.30	3.97	0.00	-1.99	-2.95	-0.48	-5.58	0.00	-4.05	3	-8.63	0.84
Paper - mixed		kg NMVOC	0.36	0.33	2.30	3.97	0.00	-1.99	-2.95	-0.48	-3.38	0.00	-1.84	8	-6.03	1.41
Paper - card	PO	kg NMVOC	0.36	0.33	2.30	3.97	0.00	-1.99	-2.95	-0.48	-3.16	0.00	-1.62	9	-5.54	1.55
Plastic - PET		kg NMVOC	1.18	0.44	2.18	3.38	0.00	-3.49	-4.10	-1.62	-0.59	0.00	-2.62	6	-5.57	0.29
Plastic - HDPE		kg NMVOC	1.18	0.44	0.97	1.97	0.00	-3.25	-3.81	-1.62	-0.59	0.00	-4.71	2	-6.60	-2.66
Plastic - HDPE (col)		kg NMVOC	1.18	0.44	0.00	3.64	0.00	0.00	-7.06	-1.62	-0.59	0.00	-4.01	4	-6.13	-1.10
Plastic - mixed		kg NMVOC	1.18	0.44	0.00	3.64	0.00	0.00	-4.26	-1.62	-0.59	0.00	-1.21	11	-3.47	1.34
Garden and green		kg NMVOC	0.33	0.00	0.53	0.00	0.00	-0.21	0.00	-0.25	-1.85	0.00	-1.45	10	-3.29	-0.34
Glass bottles		$	0.00	0.16	0.70	0.00	0.00	-0.70	0.00	0.00	-0.03	0.00	0.13	5	-1.33	1.47
Steel cans		$	0.00	0.16	0.49	0.44	0.00	-42.90	-61.78	0.00	-0.03	0.00	-103.62	1	-113.00	-93.90
Alum. Cans		$	0.00	0.16	8.65	8.05	0.00	-19.18	-17.75	0.00	-0.03	0.00	-20.09	2	-22.30	-18.00
Paper - white		$	0.00	0.16	0.01	0.20	0.00	-0.01	-0.09	0.00	-0.02	0.00	0.25	8	0.09	0.52
Paper - mixed		$	0.00	0.16	0.01	0.20	0.00	-0.01	-0.09	0.00	-0.02	0.00	0.24	7	0.09	0.48
Paper - card	MD	$	0.00	0.16	0.01	0.20	0.00	-0.01	-0.09	0.00	-0.02	0.00	0.24	6	0.08	0.50
Plastic - PET		$	0.00	0.16	0.04	0.10	0.00	-6.14	-7.20	0.00	-0.03	0.00	-13.06	3	-38.00	-4.72
Plastic - HDPE		$	0.00	0.16	0.08	0.15	0.00	-0.04	-0.05	0.00	-0.03	0.00	0.28	9	0.13	0.53
Plastic - HDPE (col)		$	0.00	0.16	0.00	0.27	0.00	0.00	-0.09	0.00	-0.03	0.00	0.32	10	0.17	0.59
Plastic - mixed		$	0.00	0.16	0.00	0.27	0.00	0.00	-0.07	0.00	-0.03	0.00	0.34	11	0.17	0.57
Garden and green		$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	-0.01	4	-0.05	0.04
Glass bottles		$	0.59	0.67	6.18	0.01	0.00	-11.70	0.00	-0.72	-0.48	0.00	-5.46	7	-7.72	-3.13
Steel cans		$	1.41	0.56	4.55	7.70	0.00	-11.86	-17.88	-1.82	-0.48	0.00	-17.82	6	-23.80	-13.40
Alum. Cans		$	1.41	0.86	10.33	9.29	0.00	-130.16	-121.01	-1.82	-0.48	0.00	-231.58	1	-245.00	-220.00
Paper - white		$	0.94	0.62	6.07	8.43	0.00	-3.97	-5.21	-1.19	5.95	0.00	11.64	11	6.54	27.30
Paper - mixed		$	0.94	0.62	6.07	8.43	0.00	-3.97	-5.21	-1.19	3.11	0.00	8.79	10	3.83	20.40
Paper - card	FFD	$	0.94	0.62	6.07	8.43	0.00	-3.97	-5.21	-1.19	2.82	0.00	8.51	9	3.29	19.40
Plastic - PET		$	3.03	1.27	9.14	11.68	0.00	-35.73	-41.94	-3.99	-0.48	0.00	-57.02	3	-75.00	-41.50
Plastic - HDPE		$	3.03	1.27	4.09	5.75	0.00	-30.94	-36.32	-3.99	-0.48	0.00	-57.59	2	-62.30	-52.60
Plastic - HDPE (col)		$	3.03	1.27	0.00	10.66	0.00	0.00	-67.26	-3.99	-0.48	0.00	-56.78	4	-61.80	-51.10
Plastic - mixed		$	3.03	1.27	0.00	10.66	0.00	0.00	-44.50	-3.99	-0.48	0.00	-34.02	5	-38.90	-28.30
Garden and green		$	0.87	0.00	0.42	0.00	0.00	-0.31	0.00	-0.62	0.57	0.00	0.93	8	-0.09	2.19
Glass bottles		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6	0.00	0.00
Steel cans		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8	0.00	0.00
Alum. Cans		ha.a	0.00	0.00	0.00	0.00	0.00	-0.04	-0.04	0.00	0.00	0.00	-0.08	4	-0.15	-0.04
Paper - white		ha.a	0.00	0.00	0.01	0.01	0.00	-0.07	-0.09	0.00	0.00	0.00	-0.14	3	-0.29	-0.05
Paper - mixed		ha.a	0.00	0.00	0.01	0.01	0.00	-0.07	-0.09	0.00	0.00	0.00	-0.14	2	-0.30	-0.06
Paper - card	LU	ha.a	0.00	0.00	0.01	0.01	0.00	-0.07	-0.09	0.00	0.00	0.00	-0.14	1	-0.29	-0.06
Plastic - PET		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5	-0.01	0.00
Plastic - HDPE		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9	0.00	0.01
Plastic - HDPE (col)		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10	0.00	0.01
Plastic - mixed		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11	0.00	0.01
Garden and green		ha.a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7	0.00	0.00
Glass bottles		kL H2O	0.04	0.13	0.90	0.00	0.00	-1.79	0.00	-0.04	-0.18	0.00	-0.94	11	-1.59	-0.31
Steel cans		kL H2O	0.10	0.12	0.98	2.20	0.00	-18.31	-26.80	-0.10	-0.18	0.00	-42.00	2	-45.40	-38.80
Alum. Cans		kL H2O	0.10	0.16	9.66	9.71	0.00	-25.12	-23.62	-0.10	-0.18	0.00	-29.39	3	-38.40	-22.50
Paper - white		kL H2O	0.07	0.12	0.50	9.87	0.00	-5.64	-16.23	-0.07	0.70	0.00	-10.67	9	-18.20	-0.59
Paper - mixed		kL H2O	0.07	0.12	0.50	9.87	0.00	-5.64	-16.23	-0.07	0.31	0.00	-11.06	8	-18.90	-2.99
Paper - card	WU	kL H2O	0.07	0.12	0.50	9.87	0.00	-5.64	-16.23	-0.07	0.26	0.00	-11.10	7	-19.00	-1.62
Plastic - PET		kL H2O	0.22	0.21	11.83	14.35	0.00	-43.59	-51.17	-0.23	-0.18	0.00	-68.54	1	-92.30	-50.20
Plastic - HDPE		kL H2O	0.22	0.21	1.48	2.20	0.00	-12.23	-14.35	-0.23	-0.18	0.00	-22.87	5	-23.60	-22.00
Plastic - HDPE (col)		kL H2O	0.22	0.21	0.00	4.07	0.00	0.00	-26.58	-0.23	-0.18	0.00	-22.48	6	-23.40	-21.20
Plastic - mixed		kL H2O	0.22	0.21	0.00	4.07	0.00	0.00	-30.45	-0.23	-0.19	0.00	-26.35	4	-27.60	-24.70
Garden and green		kL H2O	0.07	0.00	0.06	0.00	0.00	-5.82	0.00	-0.04	0.01	0.00	-5.71	10	-11.60	-2.27
Glass bottles		kg	1.20	67.91	13.24	1.86	0.00	-38.20	0.00	-1.10	-1,137.15	0.00	-1,092.23	2	-1,100.00	-1,090.00
Steel cans		kg	2.89	67.77	77.05	113.80	0.00	-1.54	-2.22	-2.79	-1,137.15	0.00	-882.20	7	-884.00	-840.00
Alum. Cans		kg	2.89	68.15	19.87	14.51	0.00	-1,887.78	-1,742.57	-2.79	-1,137.15	0.00	-4,664.87	1	-5,970.00	-4,670.00
Paper - white		kg	1.92	67.85	68.84	74.63	0.00	-16.33	-6.35	-1.82	-685.13	0.00	-496.40	10	-509.00	-463.00
Paper - mixed		kg	1.92	67.85	68.84	74.63	0.00	-16.33	-6.35	-1.82	-849.99	0.00	-661.25	9	-670.00	-646.00
Paper - card	SW	kg	1.92	67.85	68.84	74.63	0.00	-16.33	-6.35	-1.82	-866.88	0.00	-678.14	8	-691.00	-666.00
Plastic - PET		kg	6.21	68.66	37.89	44.49	0.00	0.00	0.00	-6.12	-1,137.15	0.00	-986.01	3	-989.00	-859.00
Plastic - HDPE		kg	6.21	68.66	74.42	87.36	0.00	0.00	0.00	-6.12	-1,137.15	0.00	-906.61	4	-911.00	-856.00
Plastic - HDPE (col)		kg	6.21	68.66	0.00	161.78	0.00	0.00	0.00	-6.12	-1,137.15	0.00	-906.61	6	-913.00	-846.00
Plastic - mixed		kg	6.21	68.66	0.00	161.78	0.00	0.00	0.00	-6.12	-1,137.15	0.00	-906.61	5	-911.00	-861.00
Garden and green		kg	1.90	0.00	142.83	0.00	0.00	-2.55	0.00	-0.95	-307.45	0.00	-166.22	11	-194.00	-135.00
Glass bottles		MJ LHV	488.34	661.50	5,242.73	6.53	0.00	-9,750.81	0.00	-594.26	-563.25	0.00	-4,509.23	7	-6,450.00	-2,550.00
Steel cans		MJ LHV	1,175.12	561.94	4,023.59	6,733.96	0.00	-10,075.95	-15,265.55	-1,510.70	-563.25	0.00	-14,920.84	6	-20,000.00	-11,100.00
Alum. Cans		MJ LHV	1,175.12	825.48	9,712.53	9,248.82	0.00	-117,222.47	-109,004.24	-1,510.70	-563.25	0.00	-207,338.72	1	-219,000.00	-196,000.00
Paper - white		MJ LHV	780.76	616.45	5,136.05	8,933.39	0.00	-6,378.49	-9,217.59	-984.46	1,794.89	0.00	680.98	11	-5,590.00	15,900.00
Paper - mixed		MJ LHV	780.76	616.45	5,136.05	8,933.39	0.00	-6,378.49	-9,217.59	-984.46	751.34	0.00	-362.56	9	-6,550.00	11,200.00
Paper - card	CED	MJ LHV	780.76	616.45	5,136.05	8,933.39	0.00	-6,378.49	-9,217.59	-984.46	645.92	0.00	-467.98	8	-6,200.00	11,200.00
Plastic - PET		MJ LHV	2,527.21	1,186.02	7,978.66	10,245.95	0.00	-33,725.20	-39,590.45	-3,314.95	-563.28	0.00	-55,256.02	2	-72,700.00	-41,400.00
Plastic - HDPE		MJ LHV	2,527.21	1,186.02	3,958.95	5,527.41	0.00	-27,725.17	-32,546.94	-3,314.95	-563.31	0.00	-50,950.78	3	-54,800.00	-46,800.00
Plastic - HDPE (col)		MJ LHV	2,527.21	1,186.02	0.00	10,235.95	0.00	0.00	-60,272.12	-3,314.95	-563.31	0.00	-50,201.19	4	-54,500.00	-45,400.00
Plastic - mixed		MJ LHV	2,527.21	1,186.02	0.00	10,235.95	0.00	0.00	-39,565.95	-3,314.95	-565.35	0.00	-29,497.07	5	-33,600.00	-24,800.00
Garden and green		MJ LHV	723.48	0.00	490.28	0.00	0.00	-254.59	0.00	-515.50	-134.56	0.00	309.10	10	-648.00	1,480.00

Appendix D – Impact Assessment Method (Factors)

Global Warming zero flow			
Compartment	Substance	Factor	Unit
Air	1-Propanol, 3,3,3-trifluoro-2,2-bis(trifluoromethyl)-, HFE-7100	297	kg CO2 eq / kg
Air	Butane, 1,1,1,3,3-pentafluoro-, HFC-365mfc	794	kg CO2 eq / kg
Air	Butane, perfluoro-	8860	kg CO2 eq / kg
Air	Butane, perfluorocyclo-, PFC-318	10300	kg CO2 eq / kg
Air	Carbon dioxide	1	kg CO2 eq / kg
Air	Carbon dioxide, biogenic	0	kg CO2 eq / kg
Soil	Carbon dioxide, biogenic	-1	kg CO2 eq / kg
Air	Carbon dioxide, fossil	1	kg CO2 eq / kg
Raw	Carbon dioxide, in air	0	kg CO2 eq / kg
Air	Carbon dioxide, land transformation	1	kg CO2 eq / kg
Air	Chloroform	31	kg CO2 eq / kg
Air	Dimethyl ether	1	kg CO2 eq / kg
Air	Dinitrogen monoxide	298	kg CO2 eq / kg
Air	Ethane, 1-chloro-1,1-difluoro-, HCFC-142b	2310	kg CO2 eq / kg
Air	Ethane, 1-chloro-2,2,2-trifluoro-(difluoromethoxy)-, HCFE-235da2	350	kg CO2 eq / kg
Air	Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b	725	kg CO2 eq / kg
Air	Ethane, 1,1-difluoro-, HFC-152a	124	kg CO2 eq / kg
Air	Ethane, 1,1,1-trichloro-, HCFC-140	146	kg CO2 eq / kg
Air	Ethane, 1,1,1-trifluoro-, HFC-143a	4470	kg CO2 eq / kg
Air	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	1430	kg CO2 eq / kg
Air	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	6130	kg CO2 eq / kg
Air	Ethane, 1,2-dibromotetrafluoro-, Halon 2402	1640	kg CO2 eq / kg
Air	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	10000	kg CO2 eq / kg
Air	Ethane, 1,2-difluoro-, HFC-152	53	kg CO2 eq / kg
Air	Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	609	kg CO2 eq / kg
Air	Ethane, 2,2-dichloro-1,1,1-trifluoro-, HCFC-123	77	kg CO2 eq / kg
Air	Ethane, chloropentafluoro-, CFC-115	7370	kg CO2 eq / kg
Air	Ethane, fluoro-, HFC-161	12	kg CO2 eq / kg
Air	Ethane, hexafluoro-, HFC-116	12200	kg CO2 eq / kg
Air	Ethane, pentafluoro-, HFC-125	3500	kg CO2 eq / kg
Air	Ether, 1,1,1-trifluoromethyl methyl-, HFE-143a	756	kg CO2 eq / kg
Air	Ether, 1,1,2,2-Tetrafluoroethyl 2,2,2-trifluoroethyl-, HFE-347mcc3	575	kg CO2 eq / kg
Air	Ether, 1,1,2,2-Tetrafluoroethyl 2,2,2-trifluoroethyl-, HFE-347mcf2	374	kg CO2 eq / kg
Air	Ether, 1,1,2,2-Tetrafluoroethyl methyl-, HFE-254cb2	359	kg CO2 eq / kg
Air	Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356mec3	101	kg CO2 eq / kg
Air	Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcc3	110	kg CO2 eq / kg
Air	Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcf2	265	kg CO2 eq / kg
Air	Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcf3	502	kg CO2 eq / kg
Air	Ether, 1,2,2-trifluoroethyl trifluoromethyl-, HFE-236ea2	989	kg CO2 eq / kg
Air	Ether, 1,2,2-trifluoroethyl trifluoromethyl-, HFE-236fa	487	kg CO2 eq / kg
Air	Ether, 2,2,3,3,3-Pentafluoropropyl methyl-, HFE-365mcf3	11	kg CO2 eq / kg
Air	Ether, di(difluoromethyl), HFE-134	6320	kg CO2 eq / kg
Air	Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245cb2	708	kg CO2 eq / kg
Air	Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245fa1	286	kg CO2 eq / kg
Air	Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245fa2	659	kg CO2 eq / kg
Air	Ether, ethyl 1,1,2,2-tetrafluoroethyl-, HFE-374pc2	557	kg CO2 eq / kg
Air	Ether, nonafluorobutane ethyl-, HFE569sf2 (HFE-7200)	59	kg CO2 eq / kg
Air	Ether, pentafluoromethyl-, HFE-125	14900	kg CO2 eq / kg
Air	Hexane, perfluoro-	9300	kg CO2 eq / kg
Air	HFE-227EA	1540	kg CO2 eq / kg
Air	HFE-236ca12 (HG-10)	2800	kg CO2 eq / kg
Air	HFE-263fb2	11	kg CO2 eq / kg
Air	HFE-329mcc2	919	kg CO2 eq / kg
Air	HFE-338mcf2	552	kg CO2 eq / kg
Air	HFE-338pcc13 (HG-01)	1500	kg CO2 eq / kg
Air	HFE-347pcf2	580	kg CO2 eq / kg
Air	HFE-43-10pccc124 (H-Galden1040x)	1870	kg CO2 eq / kg
Air	Methane	25	kg CO2 eq / kg
Air	Methane, biogenic	22.25	kg CO2 eq / kg
Air	Methane, bromo-, Halon 1001	5	kg CO2 eq / kg
Air	Methane, bromochlorodifluoro-, Halon 1211	1890	kg CO2 eq / kg
Air	Methane, bromodifluoro-, Halon 1201	404	kg CO2 eq / kg
Air	Methane, bromotrifluoro-, Halon 1301	7140	kg CO2 eq / kg
Air	Methane, chlorodifluoro-, HCFC-22	1810	kg CO2 eq / kg
Air	Methane, chlorotrifluoro-, CFC-13	14400	kg CO2 eq / kg
Air	Methane, dibromo-	1.54	kg CO2 eq / kg
Air	Methane, dichloro-, HCC-30	8.7	kg CO2 eq / kg
Air	Methane, dichlorodifluoro-, CFC-12	10900	kg CO2 eq / kg
Air	Methane, dichlorofluoro-, HCFC-21	151	kg CO2 eq / kg
Air	Methane, difluoro-, HFC-32	675	kg CO2 eq / kg
Air	Methane, fluoro-, HFC-41	92	kg CO2 eq / kg
Air	Methane, fossil	25	kg CO2 eq / kg
Air	Methane, monochloro-, R-40	13	kg CO2 eq / kg
Air	Methane, tetrachloro-, CFC-10	1400	kg CO2 eq / kg
Air	Methane, tetrafluoro-, CFC-14	7390	kg CO2 eq / kg
Air	Methane, trichlorofluoro-, CFC-11	4750	kg CO2 eq / kg
Air	Methane, trifluoro-, HFC-23	14800	kg CO2 eq / kg
Air	Nitrogen fluoride	17200	kg CO2 eq / kg
Air	Pentane, 2,3-dihydroperfluoro-, HFC-4310mee	1640	kg CO2 eq / kg
Air	Pentane, perfluoro-	9160	kg CO2 eq / kg
Air	PFC-9-1-18	7500	kg CO2 eq / kg
Air	PFPMIE	10300	kg CO2 eq / kg
Air	Propane, 1,1,1,2,2,3-hexafluoro-, HFC-236cb	1340	kg CO2 eq / kg
Air	Propane, 1,1,1,2,3,3-hexafluoro-, HFC-236ea	1370	kg CO2 eq / kg
Air	Propane, 1,1,1,2,3,3,3-heptafluoro-, HFC-227ea	3220	kg CO2 eq / kg
Air	Propane, 1,1,1,3,3,3-hexafluoro-, HCFC-236fa	9810	kg CO2 eq / kg
Air	Propane, 1,1,2,2,3-pentafluoro-, HFC-245ca	693	kg CO2 eq / kg
Air	Propane, 1,1,3,3-tetrafluoro-, HFC-245fa	1030	kg CO2 eq / kg
Air	Propane, 1,3-dichloro-1,1,2,2,3-pentafluoro-, HCFC-225cb	595	kg CO2 eq / kg
Air	Propane, 3,3-dichloro-1,1,1,2,2-pentafluoro-, HCFC-225ca	122	kg CO2 eq / kg
Air	Propane, perfluoro-	8830	kg CO2 eq / kg
Air	Sulfur hexafluoride	22800	kg CO2 eq / kg
Air	Sulphur, trifluoromethyl pentafluoride	17700	kg CO2 eq / kg

Eutrophication potential			
Compartment	Substance	Factor	Unit
Air	Ammonia	0.35	kg PO4--- eq / kg
Water	Ammonia	0.35	kg PO4--- eq / kg
Soil	Ammonia	0.35	kg PO4--- eq / kg
Air	Ammonium, ion	0.33	kg PO4--- eq / kg
Water	Ammonium, ion	0.33	kg PO4--- eq / kg
Soil	Ammonium, ion	0.33	kg PO4--- eq / kg
Water	COD, Chemical Oxygen Demand	0.022	kg PO4--- eq / kg
Air	Nitrate	0.1	kg PO4--- eq / kg
Water	Nitrate	0.1	kg PO4--- eq / kg
Soil	Nitrate	0.1	kg PO4--- eq / kg
Air	Nitric acid	0.1	kg PO4--- eq / kg
Water	Nitric acid	0.1	kg PO4--- eq / kg
Soil	Nitric acid	0.1	kg PO4--- eq / kg
Air	Nitric oxide	0.2	kg PO4--- eq / kg
Water	Nitrite	0.1	kg PO4--- eq / kg
Air	Nitrogen	0.42	kg PO4--- eq / kg
Water	Nitrogen	0.42	kg PO4--- eq / kg
Soil	Nitrogen	0.42	kg PO4--- eq / kg
Air	Nitrogen dioxide	0.13	kg PO4--- eq / kg
Air	Nitrogen oxides	0.13	kg PO4--- eq / kg
Air	Phosphate	1	kg PO4--- eq / kg
Water	Phosphate	1	kg PO4--- eq / kg
Soil	Phosphate	1	kg PO4--- eq / kg
Air	Phosphoric acid	0.97	kg PO4--- eq / kg
Water	Phosphoric acid	0.97	kg PO4--- eq / kg
Soil	Phosphoric acid	0.97	kg PO4--- eq / kg
Air	Phosphorus	3.06	kg PO4--- eq / kg
Water	Phosphorus	3.06	kg PO4--- eq / kg
Soil	Phosphorus	3.06	kg PO4--- eq / kg
Air	Phosphorus pentoxide	1.34	kg PO4--- eq / kg
Water	Phosphorus pentoxide	1.34	kg PO4--- eq / kg
Soil	Phosphorus pentoxide	1.34	kg PO4--- eq / kg
Air	Total Nitrogen	0.42	kg PO4--- eq / kg
Water	Total Nitrogen	0.42	kg PO4--- eq / kg
Soil	Total Nitrogen	0.42	kg PO4--- eq / kg
Air	Total Phosphorus	3.06	kg PO4--- eq / kg
Water	Total Phosphorus	3.06	kg PO4--- eq / kg
Soil	Total Phosphorus	3.06	kg PO4--- eq / kg

Photochemical	kg NMVOC		
Compartment	Substance	Factor	Unit
Air	1-Butanol	1.05	kg NMVOC / kg
Air	1-Butene	1.82	kg NMVOC / kg
Air	1-Butene, 2-methyl-	1.3	kg NMVOC / kg
Air	1-Butene, 3-methyl-	1.13	kg NMVOC / kg
Air	1-Hexene	1.48	kg NMVOC / kg
Air	1-Pentene	1.65	kg NMVOC / kg
Air	1-Propanol	0.948	kg NMVOC / kg
Air	2-Butanol	0.676	kg NMVOC / kg
Air	2-Butanone, 3-methyl-	0.615	kg NMVOC / kg
Air	2-Butanone, 3,3-dimethyl-	0.546	kg NMVOC / kg
Air	2-Butene (cis)	1.94	kg NMVOC / kg
Air	2-Butene (trans)	1.91	kg NMVOC / kg
Air	2-Hexanone	0.966	kg NMVOC / kg
Air	2-Hexene (cis)	1.81	kg NMVOC / kg
Air	2-Hexene (trans)	1.81	kg NMVOC / kg
Air	2-Methyl-1-propanol	0.608	kg NMVOC / kg
Air	2-Methyl-2-butene	1.42	kg NMVOC / kg
Air	2-Methyl pentane	0.709	kg NMVOC / kg
Air	2-Pentanone	0.926	kg NMVOC / kg
Air	2-Pentene (cis)	1.89	kg NMVOC / kg
Air	2-Pentene (trans)	1.89	kg NMVOC / kg
Air	2-Propanol	0.318	kg NMVOC / kg
Air	3-Hexanone	1.01	kg NMVOC / kg
Air	3-Methyl-1-butanol	0.731	kg NMVOC / kg
Air	3-Pentanol	1.01	kg NMVOC / kg
Air	4-Methyl-2-pentanone	0.828	kg NMVOC / kg
Air	Acetaldehyde	1.08	kg NMVOC / kg
Air	Acetic acid	0.164	kg NMVOC / kg
Air	Acetic acid, methyl ester	0.0997	kg NMVOC / kg
Air	Acetic acid, propyl ester	0.476	kg NMVOC / kg
Air	Acetone	0.159	kg NMVOC / kg
Air	Alcohol, diacetone	0.519	kg NMVOC / kg
Air	Aldehydes, unspecified	0.927	kg NMVOC / kg
Air	Benzaldehyde	-0.155	kg NMVOC / kg
Air	Benzene	0.368	kg NMVOC / kg
Air	Benzene, 1-propyl-	1.07	kg NMVOC / kg
Air	Benzene, 1,2,3-trimethyl-	2.14	kg NMVOC / kg
Air	Benzene, 1,2,4-trimethyl-	2.16	kg NMVOC / kg
Air	Benzene, 1,3,5-trimethyl-	2.33	kg NMVOC / kg
Air	Benzene, 3,5-dimethylethyl-	2.23	kg NMVOC / kg
Air	Benzene, ethyl-	1.23	kg NMVOC / kg
Air	Butadiene	1.44	kg NMVOC / kg
Air	Butanal	1.34	kg NMVOC / kg
Air	Butane	0.595	kg NMVOC / kg
Air	Butane, 2,2-dimethyl-	0.407	kg NMVOC / kg
Air	Butane, 2,3-dimethyl-	0.914	kg NMVOC / kg
Air	Butanol, 2-methyl-1-	0.826	kg NMVOC / kg
Air	Butanol, 2-methyl-2-	0.385	kg NMVOC / kg
Air	Butanol, 3-methyl-2-	0.686	kg NMVOC / kg
Air	Butyl acetate	0.454	kg NMVOC / kg
Air	Carbon monoxide	0.0456	kg NMVOC / kg
Air	Carbon monoxide, biogenic	0.0456	kg NMVOC / kg
Air	Carbon monoxide, fossil	0.0456	kg NMVOC / kg
Air	Chloroform	0.0389	kg NMVOC / kg
Air	Cumene	0.845	kg NMVOC / kg
Air	Cyclohexane	0.49	kg NMVOC / kg
Air	Cyclohexanol	0.875	kg NMVOC / kg
Air	Cyclohexanone	0.505	kg NMVOC / kg
Air	Decane	0.649	kg NMVOC / kg
Air	Diethyl ether	0.752	kg NMVOC / kg
Air	Diethyl ketone	0.699	kg NMVOC / kg
Air	Diisopropyl ether	0.672	kg NMVOC / kg
Air	Dimethyl carbonate	0.0422	kg NMVOC / kg

Photochemical	kg NMVOC		
Compartment	Substance	Factor	Unit
Air	Dimethyl ether	0.319	kg NMVOC / kg
Air	Dodecane	0.603	kg NMVOC / kg
Air	Ethane	0.208	kg NMVOC / kg
Air	Ethane, 1,1,1-trichloro-, HCFC-140	0.0152	kg NMVOC / kg
Air	Ethanol	0.674	kg NMVOC / kg
Air	Ethanol, 2-butoxy-	0.816	kg NMVOC / kg
Air	Ethanol, 2-methoxy-	0.519	kg NMVOC / kg
Air	Ethene	1.69	kg NMVOC / kg
Air	Ethene, dichloro- (cis)	0.755	kg NMVOC / kg
Air	Ethene, dichloro- (trans)	0.662	kg NMVOC / kg
Air	Ethene, tetrachloro-	0.049	kg NMVOC / kg
Air	Ethene, trichloro-	0.549	kg NMVOC / kg
Air	Ethyl acetate	0.353	kg NMVOC / kg
Air	Ethylene glycol	0.63	kg NMVOC / kg
Air	Ethylene glycol monoethyl ether	0.652	kg NMVOC / kg
Air	Ethyne	0.144	kg NMVOC / kg
Air	Formaldehyde	0.877	kg NMVOC / kg
Air	Formic acid	0.0541	kg NMVOC / kg
Air	Heptane	0.834	kg NMVOC / kg
Air	Hexane	0.814	kg NMVOC / kg
Air	Hexane, 2-methyl-	0.694	kg NMVOC / kg
Air	Hexane, 3-methyl-	0.615	kg NMVOC / kg
Air	Hydrocarbons, aliphatic, alkanes, cyclic	0.476	kg NMVOC / kg
Air	Hydrocarbons, aromatic	0.397	kg NMVOC / kg
Air	Hydrocarbons, chlorinated	0.125	kg NMVOC / kg
Air	Isobutane	0.519	kg NMVOC / kg
Air	Isobutene	1.06	kg NMVOC / kg
Air	Isobutyraldehyde	0.868	kg NMVOC / kg
Air	Isopentane	0.684	kg NMVOC / kg
Air	Isoprene	1.84	kg NMVOC / kg
Air	Isopropyl acetate	0.356	kg NMVOC / kg
Air	m-Xylene	1.87	kg NMVOC / kg
Air	Methane, biogenic	0.0101	kg NMVOC / kg
Air	Methane, dichloro-, HCC-30	0.115	kg NMVOC / kg
Air	Methane, dimethoxy-	0.277	kg NMVOC / kg
Air	Methane, fossil	0.0101	kg NMVOC / kg
Air	Methane, monochloro-, R-40	0.00845	kg NMVOC / kg
Air	Methanol	0.236	kg NMVOC / kg
Air	Methyl ethyl ketone	0.63	kg NMVOC / kg
Air	Methyl formate	0.0456	kg NMVOC / kg
Air	Nitrogen oxides	1	kg NMVOC / kg
Air	NMVOC, non-methane volatile organic compounds, unspecified orig	1	kg NMVOC / kg
Air	Nonane	0.699	kg NMVOC / kg
Air	o-Xylene	1.78	kg NMVOC / kg
Air	Octane	0.765	kg NMVOC / kg
Air	p-Xylene	1.71	kg NMVOC / kg
Air	Pentanal	1.29	kg NMVOC / kg
Air	Pentane	0.667	kg NMVOC / kg
Air	Pentane, 3-methyl-	0.809	kg NMVOC / kg
Air	Propanal	1.35	kg NMVOC / kg
Air	Propane	0.297	kg NMVOC / kg
Air	Propane, 2,2-dimethyl-	0.292	kg NMVOC / kg
Air	Propene	1.9	kg NMVOC / kg
Air	Propionic acid	0.253	kg NMVOC / kg
Air	Propylene glycol	0.772	kg NMVOC / kg
Air	Propylene glycol methyl ether	0.6	kg NMVOC / kg
Air	Propylene glycol t-butyl ether	0.782	kg NMVOC / kg
Air	s-Butyl acetate	0.465	kg NMVOC / kg
Air	Styrene	0.24	kg NMVOC / kg
Air	Sulfur dioxide	0.0811	kg NMVOC / kg
Air	Sulfur oxides	0.0811	kg NMVOC / kg
Air	t-Butyl acetate	0.0895	kg NMVOC / kg
Air	t-Butyl alcohol	0.179	kg NMVOC / kg
Air	t-Butyl ethyl ether	0.412	kg NMVOC / kg
Air	t-Butyl methyl ether	0.296	kg NMVOC / kg
Air	Toluene	1.08	kg NMVOC / kg
Air	Toluene, 2-ethyl-	1.52	kg NMVOC / kg
Air	Toluene, 3-ethyl-	1.72	kg NMVOC / kg
Air	Toluene, 3,5-diethyl-	2.19	kg NMVOC / kg
Air	Toluene, 4-ethyl-	1.53	kg NMVOC / kg
Air	Undecane	0.649	kg NMVOC / kg
Air	VOC, volatile organic compounds	1	kg NMVOC / kg
Air	Xylene	1.787	kg NMVOC / kg

Minerals depletion			
Compartment	Substance	Factor	Unit
Raw	Aluminium, 24% in bauxite, 11% in crude ore, in ground	0.00644	$ / kg
Raw	Aluminium, in ground	0.00644	$ / kg
Raw	Bauxite, in ground	0.00644	$ / kg
Raw	Chromium, 25.5% in chromite, 11.6% in crude ore, in ground	1.78	$ / kg
Raw	Chromium, in ground	1.78	$ / kg
Raw	Cobalt, in ground	0.0722	$ / kg
Raw	Copper, 0.52% in sulfide, Cu 0.27% and Mo 8.2E-3% in crude ore, i	3.05	$ / kg
Raw	Copper, 0.59% in sulfide, Cu 0.22% and Mo 8.2E-3% in crude ore, i	3.05	$ / kg
Raw	Copper, 0.97% in sulfide, Cu 0.36% and Mo 4.1E-2% in crude ore, i	3.05	$ / kg
Raw	Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, i	3.05	$ / kg
Raw	Copper, 1.13% in sulfide, Cu 0.76% and Ni 0.76% in crude ore, in g	3.05	$ / kg
Raw	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, i	3.05	$ / kg
Raw	Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, i	3.05	$ / kg
Raw	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, i	3.05	$ / kg
Raw	Copper, Cu 0.38%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Pb 0.014%	3.05	$ / kg
Raw	Copper, extracted for use	3.05	$ / kg
Raw	Copper, in ground	3.05	$ / kg
Raw	Copper, related unused extraction	3.05	$ / kg
Raw	Cu, Cu 3.2E+0%, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+	3.05	$ / kg
Raw	Cu, Cu 5.2E-2%, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2	3.05	$ / kg
Raw	Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore, in ground	5000	$ / kg
Raw	Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore, in ground	5000	$ / kg
Raw	Gold, Au 1.4E-4%, in ore, in ground	5000	$ / kg
Raw	Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore, in ground	5000	$ / kg
Raw	Gold, Au 4.3E-4%, in ore, in ground	5000	$ / kg
Raw	Gold, Au 4.9E-5%, in ore, in ground	5000	$ / kg
Raw	Gold, Au 6.7E-4%, in ore, in ground	5000	$ / kg
Raw	Gold, Au 7.1E-4%, in ore, in ground	5000	$ / kg
Raw	Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%,	5000	$ / kg
Raw	Gold, in ground	5000	$ / kg
Raw	Iridium, in ground	6.61	$ / kg
Raw	Iron ore, in ground	0.0715	$ / kg
Raw	Iron, 46% in ore, 25% in crude ore, in ground	0.0715	$ / kg
Raw	Iron, in ground	0.0715	$ / kg
Raw	Lead, 5%, in sulfide, Pb 2.97% and Zn 5.34% in crude ore, in groun	0.126	$ / kg
Raw	Lead, 5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In, in ground	0.126	$ / kg
Raw	Lead, in ground	0.126	$ / kg
Raw	Lead, Pb 0.014%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%,	0.126	$ / kg
Raw	Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in g	5.48	$ / kg
Raw	Manganese, in ground	5.48	$ / kg
Raw	Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crud	14.8	$ / kg
Raw	Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crud	14.8	$ / kg
Raw	Molybdenum, 0.016% in sulfide, Mo 8.2E-3% and Cu 0.27% in crud	14.8	$ / kg
Raw	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.22% in crud	14.8	$ / kg
Raw	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crud	14.8	$ / kg
Raw	Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crud	14.8	$ / kg
Raw	Molybdenum, 0.11% in sulfide, Mo 0.41% and Cu 0.36% in crude o	14.8	$ / kg
Raw	Molybdenum, 0.11% in sulfide, Mo 4.1E-2% and Cu 0.36% in crude	14.8	$ / kg
Raw	Molybdenum, in ground	14.8	$ / kg
Raw	Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in gr	0.896	$ / kg
Raw	Nickel, 1.13% in sulfides, 0.76% in crude ore, in ground	0.896	$ / kg
Raw	Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	0.896	$ / kg
Raw	Nickel, in ground	0.896	$ / kg
Raw	Osmium, in ground	464	$ / kg
Raw	Palladium, in ground	273	$ / kg
Raw	Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2	273	$ / kg
Raw	Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+	273	$ / kg
Raw	Platinum, in ground	11600	$ / kg
Raw	Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0	11600	$ / kg
Raw	Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2%	11600	$ / kg
Raw	Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+	1450	$ / kg
Raw	Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2	1450	$ / kg
Raw	Rhodium, in ground	1450	$ / kg
Raw	Ruthenium, in ground	144	$ / kg
Raw	Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In, in ground	20.5	$ / kg
Raw	Silver, 0.01% in crude ore, in ground	20.5	$ / kg
Raw	Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore, in gro	20.5	$ / kg
Raw	Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore, in ground	20.5	$ / kg
Raw	Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore, in ground	20.5	$ / kg
Raw	Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore, in ground	20.5	$ / kg
Raw	Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%,	20.5	$ / kg
Raw	Silver, in ground	20.5	$ / kg
Raw	Tin, 79% in cassiterite, 0.1% in crude ore, in ground	90.9	$ / kg
Raw	Tin, in ground	90.9	$ / kg
Raw	Uranium, in ground	8.76	$ / kg
Raw	Zinc 9%, in sulfide, Zn 5.34% and Pb 2.97% in crude ore, in ground	0.161	$ / kg
Raw	Zinc 9%, Lead 5%, in sulfide, in ground	0.161	$ / kg
Raw	Zinc ore, in ground	0.161	$ / kg
Raw	Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	0.161	$ / kg
Raw	Zinc, in ground	0.161	$ / kg
Raw	Zinc, Zn 0.63%, Au 9.7E-4%, Ag 9.7E-4%, Cu 0.38%, Pb 0.014%, i	0.161	$ / kg

Fossil fuel depletion			
Compartment	Substance	Factor	Unit
Raw	Coal, 13.3 MJ per kg, in ground	0.01563	$ / kg
Raw	Coal, 18 MJ per kg, in ground	0.02114	$ / kg
Raw	Coal, 18.0 MJ per kg, in ground	0.02114	$ / kg
Raw	Coal, 18.5 MJ per kg, in ground	0.02223	$ / kg
Raw	Coal, 19.5 MJ per kg, in ground	0.02343	$ / kg
Raw	Coal, 20.0 MJ per kg, in ground	0.02403	$ / kg
Raw	Coal, 20.5 MJ per kg, in ground	0.02463	$ / kg
Raw	Coal, 21.5 MJ per kg, in ground	0.02583	$ / kg
Raw	Coal, 22.1 MJ per kg, in ground	0.02655	$ / kg
Raw	Coal, 22.4 MJ per kg, in ground	0.02691	$ / kg
Raw	Coal, 22.6 MJ per kg, in ground	0.02715	$ / kg
Raw	Coal, 22.8 MJ per kg, in ground	0.02739	$ / kg
Raw	Coal, 23.0 MJ per kg, in ground	0.02763	$ / kg
Raw	Coal, 24.0 MJ per kg, in ground	0.02883	$ / kg
Raw	Coal, 24.1 MJ per kg, in ground	0.02895	$ / kg
Raw	Coal, 26.4 MJ per kg, in ground	0.031	$ / kg
Raw	Coal, 27.1 MJ per kg, in ground	0.03255	$ / kg
Raw	Coal, 28.0 MJ per kg, in ground	0.03363	$ / kg
Raw	Coal, 28.6 MJ per kg, in ground	0.03435	$ / kg
Raw	Coal, 29.0 MJ per kg, in ground	0.03483	$ / kg
Raw	Coal, 29.3 MJ per kg, in ground	0.03439	$ / kg
Raw	Coal, 30.3 MJ per kg, in ground	0.03639	$ / kg
Raw	Coal, 30.6 MJ per kg, in ground	0.03675	$ / kg
Raw	Coal, brown (lignite)	0.01163	$ / kg
Raw	Coal, brown, 10 MJ per kg, in ground	0.01173	$ / kg
Raw	Coal, brown, 10.0 MJ per kg, in ground	0.01173	$ / kg
Raw	Coal, brown, 14.1 MJ per kg, in ground	0.01682	$ / kg
Raw	Coal, brown, 14.4 MJ per kg, in ground	0.0167	$ / kg
Raw	Coal, brown, 15 MJ per kg, in ground	0.01718	$ / kg
Raw	Coal, brown, 15.0 MJ per kg, in ground	0.0179	$ / kg
Raw	Coal, brown, 7.9 MJ per kg, in ground	0.00938	$ / kg
Raw	Coal, brown, 8 MJ per kg, in ground	0.009361	$ / kg
Raw	Coal, brown, 8.0 MJ per kg, in ground	0.009361	$ / kg
Raw	Coal, brown, 8.1 MJ per kg, in ground	0.00962	$ / kg
Raw	Coal, brown, 8.2 MJ per kg, in ground	0.00974	$ / kg
Raw	Coal, brown, 9.9 MJ per kg, in ground	0.01178	$ / kg
Raw	Coal, brown, in ground	0.01163	$ / kg
Raw	Coal, brown, in ground, 12MJ/kg	0.0143	$ / kg
Raw	Coal, feedstock, 26.4 MJ per kg, in ground	0.031	$ / kg
Raw	Coal, hard, unspecified, in ground	0.02241	$ / kg
Raw	Coal, hard, unspecified, in ground, 24MJ/kg	0.02883	$ / kg
Raw	Energy, from coal	0.001173	$ / MJ
Raw	Energy, from coal, brown	0.001173	$ / MJ
Raw	Energy, from gas, natural	0.001111	$ / MJ
Raw	Energy, from oil	0.001173	$ / MJ
Raw	Energy, from peat	0.001173	$ / MJ
Raw	Energy, from sulfur	0.001173	$ / MJ
Raw	Gas, mine, off-gas, process, coal mining/kg	0.05555	$ / kg
Raw	Gas, mine, off-gas, process, coal mining/m3	0.04425	$ / m3
Raw	Gas, natural (0,8 kg/m3)	0.04321	$ / m3
Raw	Gas, natural, 30.3 MJ per kg, in ground	0.0374	$ / kg
Raw	Gas, natural, 31.65 MJ per m3, in ground	0.03838	$ / m3
Raw	Gas, natural, 35 MJ per m3, in ground	0.04321	$ / m3
Raw	Gas, natural, 35.0 MJ per m3, in ground	0.0424	$ / m3
Raw	Gas, natural, 35.2 MJ per m3, in ground	0.04264	$ / m3
Raw	Gas, natural, 35.9 MJ per m3, in ground	0.04348	$ / m3
Raw	Gas, natural, 36.6 MJ per m3, in ground	0.04518	$ / m3
Raw	Gas, natural, 38.8 MJ per m3, in ground	0.04696	$ / m3
Raw	Gas, natural, 39.0 MJ per m3, in ground	0.0472	$ / m3
Raw	Gas, natural, 42.0 MJ per m3, in ground	0.0508	$ / m3
Raw	Gas, natural, 46.8 MJ per kg, in ground	0.05758	$ / kg
Raw	Gas, natural, 50.3 MJ per kg, in ground	0.06076	$ / kg
Raw	Gas, natural, 51.3 MJ per kg, in ground	0.06196	$ / kg
Raw	Gas, natural, feedstock, 35 MJ per m3, in ground	0.04321	$ / m3
Raw	Gas, natural, feedstock, 35.0 MJ per m3, in ground	0.04321	$ / m3
Raw	Gas, natural, feedstock, 46.8 MJ per kg, in ground	0.05758	$ / kg
Raw	Gas, natural, in ground	0.04257	$ / m3
Raw	Gas, natural, in ground, 35MJ/m3	0.04321	$ / m3
Raw	Gas, off-gas, oil production, in ground	0.04425	$ / m3
Raw	Gas, off-gas, oil production, in ground, 35MJ/m3	0.04321	$ / m3
Raw	Gas, petroleum, 35 MJ per m3, in ground	0.04321	$ / m3
Raw	Methane	0.06175	$ / kg
Raw	Oil	0.05371	$ / kg
Raw	Oil, crude, 38400 MJ per m3, in ground	47.41	$ / m3
Raw	Oil, crude, 41 MJ per kg, in ground	0.05062	$ / kg
Raw	Oil, crude, 41.0 MJ per kg, in ground	0.05062	$ / kg
Raw	Oil, crude, 41.9 MJ per kg, in ground	0.05008	$ / kg
Raw	Oil, crude, 42 MJ per kg, in ground	0.05187	$ / kg
Raw	Oil, crude, 42.0 MJ per kg, in ground	0.05187	$ / kg
Raw	Oil, crude, 42.6 MJ per kg, in ground	0.05239	$ / kg
Raw	Oil, crude, 42.7 MJ per kg, in ground	0.05291	$ / kg
Raw	Oil, crude, 42.8 MJ per kg, in ground	0.05116	$ / kg
Raw	Oil, crude, 43.4 MJ per kg, in ground	0.05188	$ / kg
Raw	Oil, crude, 44.0 MJ per kg, in ground	0.0526	$ / kg
Raw	Oil, crude, 44.6 MJ per kg, in ground	0.05332	$ / kg
Raw	Oil, crude, 45.0 MJ per kg, in ground	0.0538	$ / kg
Raw	Oil, crude, feedstock, 41 MJ per kg, in ground	0.05062	$ / kg
Raw	Oil, crude, feedstock, 42 MJ per kg, in ground	0.05187	$ / kg
Raw	Oil, crude, in ground	0.05371	$ / kg
Raw	Oil, crude, in ground, 45MJ/kg	0.0538	$ / kg
Raw	Peat, in ground	0.01163	$ / kg
Raw	Peat, in ground, 13MJ/kg	0.0155	$ / kg

Land use			
Compartment	Substance	Factor	Unit
Raw	Occupation ; arable	1	ha.a / ha a
Raw	Occupation ; arid arable	1	ha.a / ha a
Raw	Occupation ; forest	1	ha.a / ha a
Raw	Occupation ; pasture and meadow ; intensive	1	ha.a / ha a
Raw	Occupation ; urban ; continuously built	1	ha.a / ha a
Raw	Occupation, arable	1	ha.a / ha a
Raw	Occupation, arable, integrated	1	ha.a / ha a
Raw	Occupation, arable, intensive	1	ha.a / ha a
Raw	Occupation, arable, non-irrigated	1	ha.a / ha a
Raw	Occupation, arable, non-irrigated, diverse-intensive	1	ha.a / ha a
Raw	Occupation, arable, non-irrigated, fallow	1	ha.a / ha a
Raw	Occupation, arable, non-irrigated, monotone-intensive	1	ha.a / ha a
Raw	Occupation, arable, organic	1	ha.a / ha a
Raw	Occupation, arid arable	1	ha.a / ha a
Raw	Occupation, construction site	1	ha.a / ha a
Raw	Occupation, dump site	1	ha.a / ha a
Raw	Occupation, dump site, benthos	1	ha.a / ha a
Raw	Occupation, dump site, radioactive	1	ha.a / ha a
Raw	Occupation, dump site, radioactive, high	1	ha.a / ha a
Raw	Occupation, dump site, radioactive, low-medium	1	ha.a / ha a
Raw	Occupation, forest	1	ha.a / ha a
Raw	Occupation, forest, extensive	1	ha.a / ha a
Raw	Occupation, forest, intensive	1	ha.a / ha a
Raw	Occupation, forest, intensive, clear-cutting	1	ha.a / ha a
Raw	Occupation, forest, intensive, normal	1	ha.a / ha a
Raw	Occupation, forest, intensive, short-cycle	1	ha.a / ha a
Raw	Occupation, hardwood production	1	ha.a / ha a
Raw	Occupation, heterogeneous, agricultural	1	ha.a / ha a
Raw	Occupation, industrial area	1	ha.a / ha a
Raw	Occupation, industrial area, benthos	1	ha.a / ha a
Raw	Occupation, industrial area, built up	1	ha.a / ha a
Raw	Occupation, industrial area, vegetation	1	ha.a / ha a
Raw	Occupation, mineral extraction site	1	ha.a / ha a
Raw	Occupation, oil and gas extraction site	1	ha.a / ha a
Raw	Occupation, other forest production	1	ha.a / ha a
Raw	Occupation, pasture and meadow	1	ha.a / ha a
Raw	Occupation, pasture and meadow, extensive	1	ha.a / ha a
Raw	Occupation, pasture and meadow, intensive	1	ha.a / ha a
Raw	Occupation, pasture and meadow, organic	1	ha.a / ha a
Raw	Occupation, permanent crop	1	ha.a / ha a
Raw	Occupation, permanent crop, fruit	1	ha.a / ha a
Raw	Occupation, permanent crop, fruit, extensive	1	ha.a / ha a
Raw	Occupation, permanent crop, fruit, intensive	1	ha.a / ha a
Raw	Occupation, permanent crop, fruit, organic	1	ha.a / ha a
Raw	Occupation, permanent crop, vine	1	ha.a / ha a
Raw	Occupation, permanent crop, vine, extensive	1	ha.a / ha a
Raw	Occupation, permanent crop, vine, intensive	1	ha.a / ha a
Raw	Occupation, pipelines	1	ha.a / ha a
Raw	Occupation, softwood production	1	ha.a / ha a
Raw	Occupation, traffic area	1	ha.a / ha a
Raw	Occupation, traffic area, rail embankment	1	ha.a / ha a
Raw	Occupation, traffic area, rail network	1	ha.a / ha a
Raw	Occupation, traffic area, road embankment	1	ha.a / ha a
Raw	Occupation, traffic area, road network	1	ha.a / ha a
Raw	Occupation, traffic area, sea transport	1	ha.a / ha a
Raw	Occupation, unknown	1	ha.a / ha a
Raw	Occupation, urban, continuously built	1	ha.a / ha a
Raw	Occupation, urban, discontinuously built	1	ha.a / ha a
Raw	Occupation, urban, green areas	1	ha.a / ha a
Raw	Occupation, water bodies, artificial	1	ha.a / ha a
Raw	Occupation, water bodies, inland	1	ha.a / ha a
Raw	Occupation, water bodies, sea	1	ha.a / ha a
Raw	Occupation, water courses, artificial	1	ha.a / ha a

Water use			
Compartment	Substance	Factor	Unit
Raw	Water, cooling	1	kL H2O / m3
Raw	Water, cooling, drinking	1	kL H2O / t
Raw	Water, cooling, recirculated	1	kL H2O / t
Raw	Water, cooling, river	1	kL H2O / t
Raw	Water, cooling, salt, ocean	1	kL H2O / t
Raw	Water, cooling, surface	1	kL H2O / t
Raw	Water, cooling, unspecified natural origin/kg	1	kL H2O / t
Raw	Water, cooling, unspecified natural origin/m3	1	kL H2O / m3
Raw	Water, cooling, unspecified/kg	1	kL H2O / t
Raw	Water, cooling, well, in ground	1	kL H2O / t
Raw	Water, cooling/kg	1	kL H2O / t
Raw	Water, cooling/m3	1	kL H2O / m3
Raw	Water, drinking	1	kL H2O / t
Raw	Water, fresh	1	kL H2O / m3
Raw	Water, from Victorian catchments	1	kL H2O / m3
Raw	Water, lake	1	kL H2O / m3
Raw	Water, mining, unspecified natural origin/m3	1	kL H2O / m3
Raw	Water, process	1	kL H2O / m3
Raw	Water, process and cooling, unspecified natural origin	1	kL H2O / m3
Raw	Water, process, drinking	1	kL H2O / t
Raw	Water, process, river	1	kL H2O / t
Raw	Water, process, salt, ocean	1	kL H2O / t
Raw	Water, process, surface	1	kL H2O / t
Raw	Water, process, unspecified natural origin/kg	1	kL H2O / t
Raw	Water, process, unspecified natural origin/m3	1	kL H2O / m3
Raw	Water, process, well, in ground	1	kL H2O / t
Raw	Water, process/kg	1	kL H2O / t
Raw	Water, process/m3	1	kL H2O / m3
Raw	Water, reticulated supply	1	kL H2O / m3
Raw	Water, river	1	kL H2O / m3
Raw	Water, river; GIS: ;Catchment: Brisbane River; Country: AU	1	kL H2O / m3
Raw	Water, salt, ocean	1	kL H2O / m3
Raw	Water, salt, ocean/kg	1	kL H2O / t
Raw	Water, salt, sole	1	kL H2O / m3
Raw	Water, stormwater	1	kL H2O / t
Raw	Water, surface	1	kL H2O / t
Raw	Water, unspecified natural origin /kg	1	kL H2O / t
Raw	Water, unspecified natural origin/kg	1	kL H2O / t
Raw	Water, unspecified natural origin/m3	1	kL H2O / m3
Raw	Water, uptake by crop	1	kL H2O / m3
Raw	Water, well, in ground	1	kL H2O / m3
Raw	Water, well, in ground /kg	1	kL H2O / t
Raw	Water, well, in ground/m3	1	kL H2O / m3

Solid waste			
Compartment	Substance	Factor	Unit
Waste	Abfaelle-Inertst.dep	1	kg / kg
Waste	Abfaelle-Restst.dep	1	kg / kg
Waste	agriculture waste	1	kg / kg
Waste	Aluminium waste	1	kg / kg
Waste	Asbestos	1	kg / kg
Waste	ash	1	kg / kg
Waste	Asphalt waste	1	kg / kg
Waste	Bauspgut-Inertst.dep	1	kg / kg
Waste	bauxite residue	1	kg / kg
Waste	Beton-Inertst.dep	1	kg / kg
Waste	Bilge oil	1	kg / kg
Waste	Biosolids to land application	1	kg / kg
Waste	Bitumen waste	1	kg / kg
Waste	Bohrabfall-Landf	1	kg / kg
Waste	Bohrabfall-Rstst.dep	1	kg / kg
Waste	Bulk waste, unspecified	1	kg / kg
Waste	CaF6 octahedra	1	kg / kg
Waste	Calcium fluoride waste	1	kg / kg
Waste	cardboard	1	kg / kg
Waste	Cardboard waste	1	kg / kg
Waste	Carton waste	1	kg / kg
Waste	Catalyst waste	1	kg / kg
Waste	Cathode iron ingots waste	1	kg / kg
Waste	Cathode loss	1	kg / kg
Waste	Chemical waste, inert	1	kg / kg
Waste	Chemical waste, regulated	1	kg / kg
Waste	Chemical waste, unspecified	1	kg / kg
Waste	Chromium waste	1	kg / kg
Waste	Coal ash	1	kg / kg
Waste	Coal tailings	1	kg / kg
Waste	Compost	1	kg / kg
Waste	Construction waste	1	kg / kg
Waste	Copper absorbent waste	1	kg / kg
Waste	Copper waste	1	kg / kg
Waste	Crude oil	1	kg / kg
Waste	Deckfarbe-Inrtst.dep	1	kg / kg
Waste	Depnrte-Flugasche	1	kg / kg
Waste	Dross	1	kg / kg
Waste	Dross for recycling	1	kg / kg
Waste	Dust, break-out	1	kg / kg
Waste	Dust, unspecified	1	kg / kg
Waste	dye waste (tw)	1	kg / kg
Waste	E-saving bulb plastic waste	1	kg / kg
Waste	E-saving bulb waste	1	kg / kg
Waste	Electronic waste	1	kg / kg
Waste	Electrostatic filter dust	1	kg / kg
Waste	Erdgasl-Inertst.dep	1	kg / kg
Waste	fat residues	1	kg / kg
Waste	fatty bleaching earth	1	kg / kg
Waste	FGC residues (mswi)	1	kg / kg
Waste	Fish	1	kg / kg
Waste	Fluoride waste	1	kg / kg
Waste	Fly ash	1	kg / kg
Waste	Food biomass waste, DK	1	kg / kg
Waste	Gas pipe waste	1	kg / kg
Waste	Glass waste	1	kg / kg
Waste	gypsum	1	kg / kg
Waste	Ion exchanger sludge	1	kg / kg
Waste	Iron	1	kg / kg
Waste	Iron waste	1	kg / kg
Waste	Iron, Scrap	1	kg / kg
Waste	jarosite	1	kg / kg
Waste	Kat-Sonderabfalldep	1	kg / kg
Waste	Klkstrst-Inertst.dep	1	kg / kg
Waste	Kupfer-Inertst.dep	1	kg / kg
Waste	Light bulb waste	1	kg / kg
Waste	limestone	1	kg / kg
Waste	Limestone waste	1	kg / kg
Waste	Liquidpaperboard	1	kg / kg
Waste	meat waste	1	kg / kg
Waste	Mercury hydroxide	1	kg / kg
Waste	Metal waste	1	kg / kg
Waste	Mineral waste	1	kg / kg
Waste	Mineral waste, from mining	1	kg / kg
Waste	Mineral waste, from wool	1	kg / kg
Waste	Mineral wool waste	1	kg / kg

Solid waste			
Compartment	Substance	Factor	Unit
Waste	Minwolle-Inertst.dep	1	kg / kg
Waste	Monasite	1	kg / kg
Waste	Neutralized Acid Effluent	1	kg / kg
Waste	non magenetic fines	1	kg / kg
Waste	Oil separator sludge	1	kg / kg
Waste	Oil waste	1	kg / kg
Waste	Packaging waste, paper and board	1	kg / kg
Waste	Packaging waste, plastic	1	kg / kg
Waste	Packaging waste, steel	1	kg / kg
Waste	Packaging waste, unspecified	1	kg / kg
Waste	Packaging waste, wood	1	kg / kg
Waste	Paint waste	1	kg / kg
Waste	Particleboard waste	1	kg / kg
Waste	Photovoltaic cell waste	1	kg / kg
Waste	Photovoltaic panel waste	1	kg / kg
Waste	Photovoltaic production waste	1	kg / kg
Waste	Photovoltaic/EVA cell waste	1	kg / kg
Waste	Plastic waste	1	kg / kg
Waste	Polyethylene waste	1	kg / kg
Waste	Polystyrene waste	1	kg / kg
Waste	Polyvinyl chloride waste	1	kg / kg
Waste	Prescribed liquid waste	100	kg / m3
Waste	Printed circuitboards waste	1	kg / kg
Waste	Process waste	1	kg / kg
Waste	Production waste	1	kg / kg
Waste	Production waste, not inert	1	kg / kg
Waste	Propylene glycol	1	kg / kg
Waste	Propylene glycol waste	1	kg / kg
Waste	Radioactive tailings	1	kg / kg
Waste	Rafschlamm-Landf	1	kg / kg
Waste	Rckst-Entkrb-Restst.dep	1	kg / kg
Waste	Rckst-Kuehlturmtassen	1	kg / kg
Waste	Red mud	1	kg / kg
Waste	Refinery sludge	1	kg / kg
Waste	Refractory	1	kg / kg
Waste	Rejects	1	kg / kg
Waste	Rejects, corrugated cardboard	1	kg / kg
Waste	Residues	1	kg / kg
Waste	Schweissstaub-Sabf	1	kg / kg
Waste	Slag (uranium conversion)	1	kg / kg
Waste	Slags	1	kg / kg
Waste	Slags and ashes	1	kg / kg
Waste	Sludge	1	kg / kg
Waste	Slurry	1	kg / kg
Waste	Sodium hydroxide	1	kg / kg
Waste	Soot	1	kg / kg
Waste	spent potliner	1	kg / kg
Waste	Stahl-Inertst.dep	1	kg / kg
Waste	Steel waste	1	kg / kg
Waste	Steinkohle-Asche-Dep	1	kg / kg
Waste	Steinkohleberge-Dep	1	kg / kg
Waste	Stones and rubble	1	kg / kg
Waste	stover residue	1	kg / kg
Waste	Straw ash	1	kg / kg
Waste	Tails	1	kg / kg
Waste	Tin waste	1	kg / kg
Waste	Tinder from rolling drum	1	kg / kg
Waste	Waste in bioactive landfill	1	kg / kg
Waste	Waste in incineration	1	kg / kg
Waste	Waste in inert landfill	1	kg / kg
Waste	Waste in licenced landfill	1	kg / kg
Waste	waste reststoffdeponie	1	kg / kg
Waste	Waste returned to mine	1	kg / kg
Waste	Waste to recycling	1	kg / kg
Waste	waste, refinery sludges	1	kg / kg
Waste	Waste, chemicals, inert	1	kg / kg
Waste	Waste, filter dust	1	kg / kg
Waste	Waste, final, inert	1	kg / kg
Waste	Waste, fly ash	1	kg / kg
Waste	Waste, from construction	1	kg / kg
Waste	Waste, from drilling, unspecified	1	kg / kg
Waste	Waste, from incinerator	1	kg / kg
Waste	Waste, household	1	kg / kg
Waste	Waste, Hrad	1	kg / kg
Waste	Waste, industrial	1	kg / kg
Waste	Waste, Inert	1	kg / kg
Waste	Waste, inorganic	1	kg / kg
Waste	Waste, Ionexchange, toxic	1	kg / kg
Waste	Waste, limestone	1	kg / kg
Waste	Waste, mining	1	kg / kg
Waste	waste, non-prescribed	1	kg / kg
Waste	waste, non-prescribed/m3	500	kg / m3
Waste	Waste, nuclear, high active	1	kg / kg
Waste	Waste, nuclear, high active/m3	2000	kg / m3
Waste	Waste, nuclear, low-medium active	1	kg / kg
Waste	Waste, nuclear, low-medium active/m3	2000	kg / m3
Waste	Waste, nuclear, low active	1	kg / kg
Waste	Waste, nuclear, low and medium active/m3	2000	kg / m3
Waste	Waste, nuclear, medium active	1	kg / kg
Waste	Waste, nuclear, unspecified/kg	1	kg / kg
Waste	Waste, oil	1	kg / kg
Waste	Waste, organic	1	kg / kg
Waste	Waste, paint	1	kg / kg
Waste	Waste, regulated chemicals	1	kg / kg
Waste	Waste, rubber	1	kg / kg
Waste	Waste, Shedder dust	1	kg / kg
Waste	Waste, sludge	1	kg / kg
Waste	Waste, soil	1	kg / kg
Waste	Waste, solid	1	kg / kg
Waste	Waste, Tin	1	kg / kg
Waste	Waste, tinplate steel	1	kg / kg
Waste	Waste, to incineration	1	kg / kg
Waste	Waste, toxic	1	kg / kg
Waste	Waste, unspecified	1	kg / kg
Waste	Waste, unspecified/m3	500	kg / m3
Waste	Waste, zeolite	1	kg / kg
Waste	Welding dust	1	kg / kg
Waste	Wood and wood waste	1	kg / kg
Waste	Wood ashes	1	kg / kg
Waste	Wood waste	1	kg / kg
Waste	Wood, sawdust	1	kg / kg
Waste	Zeolite waste	1	kg / kg
Waste	Zeolithe-Inertst.dep	1	kg / kg
Waste	Zinc waste	1	kg / kg

Cumulative energy demand

Compartment	Substance	Factor	Unit
Raw	bagasse	8.7	MJ LHV / kg
Raw	Biomass	15	MJ LHV / kg
Raw	Biomass, feedstock	1	MJ LHV / MJ
Raw	Coal, 13.3 MJ per kg, in ground	13.3	MJ LHV / kg
Raw	Coal, 18.0 MJ per kg, in ground	18	MJ LHV / kg
Raw	Coal, 18.5 MJ per kg, in ground	18.5	MJ LHV / kg
Raw	Coal, 19.5 MJ per kg, in ground	19.5	MJ LHV / kg
Raw	Coal, 20.0 MJ per kg, in ground	20	MJ LHV / kg
Raw	Coal, 20.5 MJ per kg, in ground	20.5	MJ LHV / kg
Raw	Coal, 21.5 MJ per kg, in ground	21.5	MJ LHV / kg
Raw	Coal, 22.1 MJ per kg, in ground	22.1	MJ LHV / kg
Raw	Coal, 22.4 MJ per kg, in ground	22.4	MJ LHV / kg
Raw	Coal, 22.6 MJ per kg, in ground	22.6	MJ LHV / kg
Raw	Coal, 22.8 MJ per kg, in ground	22.8	MJ LHV / kg
Raw	Coal, 23.0 MJ per kg, in ground	23	MJ LHV / kg
Raw	Coal, 24.0 MJ per kg, in ground	24	MJ LHV / kg
Raw	Coal, 24.1 MJ per kg, in ground	24.1	MJ LHV / kg
Raw	Coal, 26.4 MJ per kg, in ground	26.4	MJ LHV / kg
Raw	Coal, 27.1 MJ per kg, in ground	27.1	MJ LHV / kg
Raw	Coal, 28.0 MJ per kg, in ground	28	MJ LHV / kg
Raw	Coal, 28.6 MJ per kg, in ground	28.6	MJ LHV / kg
Raw	Coal, 29.0 MJ per kg, in ground	29	MJ LHV / kg
Raw	Coal, 29.3 MJ per kg, in ground	29.3	MJ LHV / kg
Raw	Coal, 30.3 MJ per kg, in ground	30.3	MJ LHV / kg
Raw	Coal, 30.6 MJ per kg, in ground	30.6	MJ LHV / kg
Raw	Coal, brown, 10.0 MJ per kg, in ground	10	MJ LHV / kg
Raw	Coal, brown, 14.1 MJ per kg, in ground	14.1	MJ LHV / kg
Raw	Coal, brown, 14.4 MJ per kg, in ground	14.4	MJ LHV / kg
Raw	Coal, brown, 15 MJ per kg, in ground	15	MJ LHV / kg
Raw	Coal, brown, 15.0 MJ per kg, in ground	15	MJ LHV / kg
Raw	Coal, brown, 7.9 MJ per kg, in ground	7.9	MJ LHV / kg
Raw	Coal, brown, 8.0 MJ per kg, in ground	8	MJ LHV / kg
Raw	Coal, brown, 8.1 MJ per kg, in ground	8.1	MJ LHV / kg
Raw	Coal, brown, 8.2 MJ per kg, in ground	8.2	MJ LHV / kg
Raw	Coal, brown, 9.9 MJ per kg, in ground	9.9	MJ LHV / kg
Raw	Coal, brown, in ground	12	MJ LHV / kg
Raw	Coal, feedstock, 26.4 MJ per kg, in ground	26.4	MJ LHV / kg
Raw	Coal, hard, unspecified, in ground	24	MJ LHV / kg
Raw	Energy, from ADO	1	MJ LHV / MJ
Raw	Energy, from Auto gasoline-leaded	1	MJ LHV / MJ
Raw	Energy, from Auto gasoline-unleaded	1	MJ LHV / MJ
Raw	Energy, from Aviation gasoline	1	MJ LHV / MJ
Raw	Energy, from Aviation turbine fuel	1	MJ LHV / MJ
Raw	Energy, from bagasse	1	MJ LHV / MJ
Raw	Energy, from biomass	1	MJ LHV / MJ
Raw	Energy, from brown coal briquetts	1	MJ LHV / MJ
Raw	Energy, from coal	1	MJ LHV / MJ
Raw	Energy, from coal byproducts	1	MJ LHV / MJ
Raw	Energy, from coal, brown	1	MJ LHV / MJ
Raw	Energy, from coke	1	MJ LHV / MJ
Raw	Energy, from Fuel oil	1	MJ LHV / MJ
Raw	Energy, from gas, natural	1	MJ LHV / MJ
Raw	Energy, from geothermal	1	MJ LHV / MJ
Raw	Energy, from Heating oil	1	MJ LHV / MJ
Raw	Energy, from hydro power	1	MJ LHV / MJ
Raw	Energy, from hydrogen	1	MJ LHV / MJ
Raw	Energy, from IDF	1	MJ LHV / MJ
Raw	Energy, from Lighting kerosene	1	MJ LHV / MJ
Raw	Energy, from liquified petroleum gas, feedstock	1	MJ LHV / MJ
Raw	Energy, from LPG	1	MJ LHV / MJ
Raw	Energy, from Natural gas	1	MJ LHV / MJ
Raw	Energy, from oil	1	MJ LHV / MJ
Raw	Energy, from peat	1	MJ LHV / MJ
Raw	Energy, from Petroleum products nec	1	MJ LHV / MJ
Raw	Energy, from Power kerosene	1	MJ LHV / MJ
Raw	Energy, from solar	1	MJ LHV / MJ
Raw	Energy, from sulfur	1	MJ LHV / MJ
Raw	Energy, from tidal	1	MJ LHV / MJ
Raw	Energy, from Town gas	1	MJ LHV / MJ
Raw	Energy, from uranium	1	MJ LHV / MJ
Raw	Energy, from waves	1	MJ LHV / MJ
Raw	Energy, from wood	1	MJ LHV / MJ
Raw	Energy, geothermal	1	MJ LHV / MJ
Raw	Energy, gross calorific value, in biomass	0.904762	MJ LHV / MJ
Raw	Energy, in Solvents	1	MJ LHV / MJ
Raw	Energy, kinetic (in wind), converted	1	MJ LHV / MJ
Raw	Energy, potential (in hydropower reservoir), converted	1	MJ LHV / MJ
Raw	Energy, recovered	1	MJ LHV / MJ
Raw	Energy, unspecified	1	MJ LHV / MJ
Raw	Gas, natural, 30.3 MJ per kg, in ground	30.3	MJ LHV / kg
Raw	Gas, natural, 31.65 MJ per m3, in ground	31.65	MJ LHV / m3
Raw	Gas, natural, 35 MJ per m3, in ground	35	MJ LHV / m3
Raw	Gas, natural, 35.0 MJ per m3, in ground	35	MJ LHV / m3
Raw	Gas, natural, 35.2 MJ per m3, in ground	35.2	MJ LHV / m3
Raw	Gas, natural, 35.9 MJ per m3, in ground	35.9	MJ LHV / m3
Raw	Gas, natural, 36.6 MJ per m3, in ground	36.6	MJ LHV / m3
Raw	Gas, natural, 38.8 MJ per m3, in ground	38.8	MJ LHV / m3
Raw	Gas, natural, 39.0 MJ per m3, in ground	39	MJ LHV / m3
Raw	Gas, natural, 42.0 MJ per m3, in ground	42	MJ LHV / m3
Raw	Gas, natural, 46.8 MJ per kg, in ground	46.8	MJ LHV / kg
Raw	Gas, natural, 50.3 MJ per kg, in ground	50.3	MJ LHV / kg
Raw	Gas, natural, 51.3 MJ per kg, in ground	51.3	MJ LHV / kg
Raw	Gas, natural, feedstock, 35 MJ per m3, in ground	35	MJ LHV / m3
Raw	Gas, natural, feedstock, 35.0 MJ per m3, in ground	35	MJ LHV / m3
Raw	Gas, natural, feedstock, 46.8 MJ per kg, in ground	46.8	MJ LHV / kg
Raw	Gas, natural, in ground	35	MJ LHV / m3
Raw	Gas, off-gas, 35.0 MJ per m3, oil production, in ground	35	MJ LHV / m3
Raw	Gas, off-gas, oil production, in ground	35	MJ LHV / m3
Raw	Gas, petroleum, 35 MJ per m3, in ground	35	MJ LHV / m3
Raw	Methane	35.9	MJ LHV / kg
Raw	Mining gas, 30 MJ per kg	30	MJ LHV / kg
Raw	Oil, crude, 38400 MJ per m3, in ground	38400	MJ LHV / m3
Raw	Oil, crude, 41 MJ per kg, in ground	41	MJ LHV / kg
Raw	Oil, crude, 41.0 MJ per kg, in ground	41	MJ LHV / kg
Raw	Oil, crude, 41.9 MJ per kg, in ground	41.9	MJ LHV / kg
Raw	Oil, crude, 42.0 MJ per kg, in ground	42	MJ LHV / kg
Raw	Oil, crude, 42.6 MJ per kg, in ground	42.6	MJ LHV / kg
Raw	Oil, crude, 42.7 MJ per kg, in ground	42.7	MJ LHV / kg
Raw	Oil, crude, 42.8 MJ per kg, in ground	42.8	MJ LHV / kg
Raw	Oil, crude, 43.4 MJ per kg, in ground	43.4	MJ LHV / kg
Raw	Oil, crude, 44.0 MJ per kg, in ground	44	MJ LHV / kg
Raw	Oil, crude, 44.6 MJ per kg, in ground	44.6	MJ LHV / kg
Raw	Oil, crude, 45.0 MJ per kg, in ground	45	MJ LHV / kg
Raw	Oil, crude, feedstock, 41 MJ per kg, in ground	41	MJ LHV / kg
Raw	Oil, crude, feedstock, 42 MJ per kg, in ground	42	MJ LHV / kg
Raw	Oil, crude, in ground	45	MJ LHV / kg
Raw	Secondary wood	15.3	MJ LHV / kg
Raw	Uranium ore, 1.11 GJ per kg, in ground	1110	MJ LHV / kg
Raw	Uranium, 2291 GJ per kg, in ground	2291000	MJ LHV / kg
Raw	Uranium, 336 GJ per kg, in ground	336000	MJ LHV / kg
Raw	Uranium, 451 GJ per kg, in ground	451000	MJ LHV / kg
Raw	Uranium, 560 GJ per kg, in ground	560000	MJ LHV / kg
Raw	Uranium, in ground	451000	MJ LHV / kg
Raw	Water, barrage	0.01	MJ LHV / kg
Raw	Water, through turbine	0.01	MJ LHV / l
Raw	Wood and cardboard waste	15.3	MJ LHV / kg
Raw	Wood and wood waste, 10.5 MJ per kg	10.5	MJ LHV / kg
Raw	Wood, feedstock	15.3	MJ LHV / kg
Raw	Wood, unspecified, standing/kg	15.3	MJ LHV / kg

Appendix E – Reviewer comments

The following table of comments is compiled from the minutes of the Stakeholder Review Panel meeting held 14/6/2013 and chaired by Kel Dummett. In attendance at this meeting were: Attendees: Andrew Carre (RMIT), Kel Dummett (SV), Nick Chrisant (SV), Marcus Fogarty (SV), Robert Francis (SITA), Nancy Wei (Visy), Miro Krmpotic (Huhtamaki), Alwyn Babb (Hume City Council), Joe Pickin (Blue Environment)

Apologies: Michael Wood (Enviromix), Dom Tenace (SKM), Peter Burry (Pacia), Krista Imberger (Pacia), Enda Crossin (RMIT)

As agreed early in the review process, comments are attributed collectively when made by Interested Parties (IP) and specifically when made by other participants. Comments received prior to and following the SRP meeting are also included.

The table below also includes comments from

Key to reviewers:

IP = Interested party, industry participants
LCA = LCA expert, Joe Pickin
CP = Commissioning Party, Sustainability Victoria
RMIT = RMIT University, study author organisation

Table 59 Comments recorded from the minutes of the SRP meeting held 11/12/2012.

No.	Reviewer	Comment	Author reply/action	Report section impacted
1	Author	Am unhappy with steel inventory representativeness. Need to adopt local inventory (in place of Europe).	Steel inventory changed to adopt Energetics (Australian) inventory in place of Ecoinvent.	8
2	IP	Alternative waste treatments to recycling and landfill need to be addressed, even if out of scope (eg. waste to energy)	Added section.	3.5
3	IP	Results are hard to find in report. Aspects of literature review and methodology could move to an appendix.	Literature review reduced and methodological aspects moved to Appendix A – Life Cycle Assessment and Recycling	Appendix A – Life Cycle Assessment and Recycling
4	CP	Basic report result is hard to find. It must be easy to see: a) Is recycling an benefit and by how much What has changed from the previous study	Material by material detailed results tables moved to Appendix C – Detailed Results by Material	Appendix C – Detailed Results by Material
5	CP	Results need to be directly compared to prior study and differences explained.	Added comparison section 11.1	11.1
6	LCA	Executive summary does not seem to capture the complete report findings. Inventory outcomes in particular are not summarised, nor are they in the main report. Key assumptions are not presented in the executive summary, and their implications are not communicated.	Added a summary of the inventory to the main report. Also added material by material inventory comparison.	8.1
7	LCA	Avoided products selected in the inventory need to be clearly summarised.	Added tables summarising key assumptions for each material under each system.	Table 32, Table 33, Table 34
8	LCA	Garden and green waste reprocessing model does not reflect reality of composted product use. The model suggests that all compost is used in applications where benefits will be derived in terms of water use and fertilisers. This is unlikely in situations such as council use and remediation. It's arguable that in many applications there are no benefits (at least this position is conservative).	Agree. A range of scenarios has been developed for green and garden waste. A 'Balanced Estimate' scenario has been selected as a basis for estimating the benefits of green and organic processing.	8.1.4
9	LCA	Sensitivity analysis needs to address methane capture rates for landfill.	Added sensitivity study addressing this issue	11.2.5
10	CP	Report should address common perceptions	Added sensitivity study that addresses	11.2.2

No.	Reviewer	Comment	Author reply/action	Report section impacted
		about recycling, such as the impact of international reprocessing.	international reprocessing and transport.	
11	LCA	Results for paper recycling suggest that little benefit is gained from recycling paper. This is a change from the last report and may be due to the choice of avoided product. In this study recovered paper is solely used in packaging manufacture, which is assumed to avoid kraft paper manufacture from forest sources. In the prior study, newsprint manufacture from thermo mechanical pulp (TMP) was avoided, which has a higher impact to produce. Please justify this decision.	Waste newsprint processor contacted. Confirmed that waste paper from the kerbside is no longer used for newsprint production. Most likely pathway is therefore packaging paper production, therefore avoiding kraft paper manufacture. A review of the inventory showed that energy in biomass was not being fully counted. This has been fixed, resulting in a favourable energy outcome when recycling paper.	8.1.5
12	CP	Other issues such as the implications of Container Deposit Legislation or alternative waste disposal options (such as waste to energy) should be presented. Understand these may be out of scope.	Although out of scope, it is agreed that it would be good to address the possible impact CDL might have on the recycling system. Subsequent consideration of this topic has led to the conclusion of the authors that the effect CDL will have is not straightforward, hence a simple inclusion and discussion is not possible, nor recommended. Of concern is anecdotal feedback from some reprocessors regarding the business model of the sorting facility (MRF) will be adversely impacted by CDL as it may divert revenue earning materials (such as metals or glass) from the facility. Rather than increasing the recovery rates of materials this could have the effect of reducing the recovery of materials, as sorting becomes less viable. The authors do not advocate this position, but admit that the CDL intervention would need to be studied specifically to make meaningful comment as feedback effects are at least plausible. It is therefore suggested that CDL be addressed in a separate study that looks specifically at the policy.	No change
13	CP	Results discussion should place more emphasis on materials and their contributions. Councils need to know what is worth collecting.	Results discussion has been enhanced to add graphs for each indicator that describe material contributions.	10
14	LCA	Time is required to consider model outcomes and thoroughly test robustness of conclusions.	Additional sensitivity analysis has been completed along with additional internal review of the report.	
15	RMIT	Discussed acknowledgement.	Added section.	2.1

Table 60 Comments received in addition to those presented at the SRP meeting.

No.	Reviewer	Comment	Author reply/action	Report section impacted
1	CP	Need to address: Transport, highlighting low env. impact of transport, especially in per unit terms	For collection added section	11.2.1
2	CP	Need to address: Overseas processing – not always bad: cleaner grids in S. Korea, Malaysia etc.	Added section	11.2.2
3	CP	Need to address: back loading of ships – either exclude on basis that you discussed re primary purpose of ship journey or if you include impact then add comment that it could be excluded.	Added sentence under section	11.2.2
4	CP	Need to address: New processes for recycling plastics	New processes for processing plastics are relevant to the consequential analysis and are addressed .	11.3.3.5
5	CP	Need to address: GW benefits of landfill	Carbon storage in landfill has been added to the results presentation by key process (eg. Table 38). Landfill energy generation and storage have also been added to the main report under 8.1.2.3	Table 38 and 8.1.2.3

No.	Reviewer	Comment	Author reply/action	Report section impacted
6	CP	Need to address: Waste to energy Implications on study of CDL e.g. potentially cleaner materials because it will encourage source separation – especially of bottles (and less breakages, hence less fines). Acknowledge this may be out of scope	As per item 12, initial investigations into CDL suggest that outcomes are not clear cut. We recommend a separate review of the policy, utilising outcomes from this study and other sources.	No change
7	IP	85% too high for glass recovery. 50% too low. Actual result somewhere in between.	Uncertainty with this element has been addressed in a sensitivity study. Additional results added to show impact upon glass only.	Section 11.2.4

Table 61 LCA Reviewer comments received as part of formal review.

No.	Reviewer	Comment	Author reply/action	Report section impacted
1	LCA	For transparency, the Executive Summary of this important report should provide a stand-alone account of the project and its findings, including the inventory report. It would be desirable to include information on key assumptions, the materials and processes that contribute the most to the benefits, the main reasons for the main benefits, and the findings of the sensitivity analysis. More explanation is needed for Table 1. Is this the best estimate of the net environmental impacts of the recycling system vs. alternative system? It would be worth contextualising these indicators (see comments in relation to Section 5.8). The meaning of paragraph 3 on p.5 should be made clearer for the lay reader. Use of the terms 'attributional' and 'consequential' necessitates explanatory information about these terms (definitions or reference to definitions), and clarification for how they are used within the study (see comment #3).	Added inventory summary and impact assessment summary to executive summary. These tables seek to highlight assumptions that have been made complete the explanation of the methodology. Results tables have been expanded to include results per functional unit and results per tonne recovered. The discussion of results has also been expanded to highlight key systemic drivers. An explanation of consequential and attributional approaches has been included. Uncertainty discussion has been included as well as the methods used to address uncertainty.	Executive Summary
2	LCA	One of the stated secondary goals of the LCA is to "identify impacts associated with unit processes within the recycling system, including transport …" (p.15). The results by process (p.37 Table 18) itemise 'collection recycling' and 'collection landfill' but do not appear to consider all transport collectively for each system. Subject to client confirmation, the secondary goal does not appear to have been achieved. In response to last December's draft goal and scope document for this project, I pointed to the advantages of providing results that distinguish between Melbourne, regional and rural areas. The reported results do not readily provide for this level of analysis.	Key processes have been addressed as follows: Collection is shown, which is the primary transportation element. Transport is also addressed as a sensitivity study and in detail in the inventory. <u>Recycling System processes</u> Collection Sorting Local Reprocessing International Reprocessing Carbon Storage - Soil <u>Alternative System processes</u> Collection Disposal Operations Local Production International Production Carbon Storage – Landfill	9
3	LCA	The roles of these two types of analysis in the study are not clear, and some of the statements about their use seem inconsistent: • LCA report p.26 para. 1: "In determining the impacts of the existing system, a fundamentally attributional approach has been employed that characterises impacts based on the existing systems operation." • LCA report p.55 para. 4: "… this study … adopts a mix of consequential and attributional approaches. … The inherent, consequential assumption … is that the reprocessing of material recovered from the	Accept that consequential and attributional have been overly repeated throughout the report, in some cases inconsistently. To address this, both words have been reviewed in context to ensure consistency of application. In many cases, reference to the perspectives is secondary to other outcomes so has been removed. Areas of focused discussion remain the consequential analysis undertaken in the validation section.	Throughout the report and Section 11.3.

No.	Reviewer	Comment	Author reply/action	Report section impacted
		recycling stream materials always offsets the need to produce virgin material." • Inventory report p.31 para. 2: "… this study aims to understand landfill impacts prospectively" • Inventory report p.48 para 2: "…the primary application has been assumed to be agriculture". "Although … there is no evidence that it represents the bulk of organic product use in Victoria, … agricultural applications represent an area for future growth". The approach taken needs to be consistent across all processes and indicators.		
4	LCA	I was confused by the approach taken in relation to markets for composting. There are descriptive inconsistencies: • The LCA report, p.59, 11.3.2.7 opens by saying: "The main market for reprocessed organic material is agriculture." • The inventory report p.48 para. 2 states that: "there is no evidence that [agriculture] represents the bulk of organic product use in Victoria". My understanding is that compost use in agriculture is very limited, potentially representing a few percent of the total[10]. The inventory report p.43 Table 26 shows a 'base case' assumption that 50% of compost is used in agricultural settings. The text on p.48 notes this is inconsistent with current market circumstances, and provides two justifications: • Para 2: "…agricultural applications represent an area for future growth". This is inconsistent with the commitment to use an attributional approach. Para. 3 "fundamental data limitations associated with other applications". This seems unreasonable unless it can be argued that the data on agricultural use is a reasonable proxy for other uses.	Inconsistency has emerged between the consequential analysis and the main report. A review of the ROU report suggests that NSW and WA are sending compost products to about 15% of the total market base. Exactly how much of this is from kerbside waste is unclear. A section has been added in the inventory report addressing these data. In light of this information the base-case agriculture application rate has been reduced to 25%. 15% would most likely be too conservative as it would suggest that no other applications generate benefits similar to those seen for agriculture. Uncertainty in this area is a key challenge of the study, which is also addressed through the sensitivity analysis (which has been amended to accommodate the change in the base case).	Appendix B – Inventory Report, Section 4.1
5	LCA	The inventory report p.43 Table 26 provides a full range of estimates for carbon storage in soil, from 0% to 100%. It selects 50% as the 'base case' value for carbon storage over the 100-year assessment timeframe, and uses the other values in sensitivity analysis. The estimates coincide with the assumptions about markets – in the 'conservative' assumptions where material is used wholly for the urban amenity market, no carbon benefit is assumed. I have two issues: • The 50% base case value and the 100% 'optimistic' value seem high. A literature review for a large European LCA (Smith et al, Waste Management Options and Climate Change) estimated an average retention half-life of 28 years. I believe this value was used in the original Grant et al. (2001) LCA. I appreciate that there are major uncertainties	The table presents the scenarios in a fashion that is confusing. The percentages do not describe a fraction of the total amount, rather they describe a fraction of the amount identified carbon storage when compost is used in an agriculture application. It is acknowledged that this is confusing, so an alternative table presentation has been developed that employs absolute values rather than percentages. Carbon storage in landfill is calculated on a material by material basis, summarised in Table 18. Carbon storage in soil when compost is applied in urban amenity applications is assumed to be zero, although actual storage	Updated section 8.1.4 and Appendix B – Inventory Report

[10] Some data on Victorian compost markets is given in the ROU's 2009 industry statistics, available at: http://www.recycledorganics.com/publications/#survey

No.	Reviewer	Comment	Author reply/action	Report section impacted
		and variability in relation to carbon storage, and it may be reasonable to consider higher values in the context of a continuous stream of compost application, but a rationale would be appropriate. • No reason is apparent as to why a potential carbon storage benefit exists when compost is applied agriculturally but not when it is used in urban amenity markets. My colleague Bill Grant, who is a compost expert, believes carbon storage is likely to be higher in a non-agricultural setting as addition of nitrogen in agriculture may lead to loss of soil carbon. This is a topical issue in the context of the Carbon Farming Initiative. Using sensitivity analysis to deal with this difficulty is a good idea.	is unknown. As for other benefits attributable to compost use (water savings, fertiliser reductions), the conservative approach taken assumes that no benefits are attributable. This approach is acknowledged as potentially understating the benefit of compost in these applications. Sensitivity analysis is used to address this uncertainty.	
6	LCA	The results section could be enhanced to provide additional important information, including identification of: • the key uncertainties – i.e. those that have the greatest impact on results when set at the extremes of their uncertainty range • the materials that provide the most benefit, both in general and per unit mass • the processes responsible for the greatest burdens or benefits • separate emphasis on the organic and comingled streams, to provide support for decisions by particular councils on the environmental costs and benefits or organics recovery.	Agree. Have added sections addressing key uncertainties. Each indicator now discusses impacts by process and by material allowing key process and materials to be identified. We have deliberately integrated garden and green waste into the discussion, although it can also be assessed on its own. We believe there is sufficient transparency, especially when combined with dedicated sensitivity studies to allow interested readers to assess the organics program. For this reason it is left as is.	10
7	LCA	Sensitivity analysis should be undertaken in relation to key uncertainties – i.e. those that have the greatest impact on results when set at the extremes of their uncertainty range. I think that's what has been done but it should be stated and demonstrated. It was not always clear to me whether the sensitivity analysis was undertaken across the entire functional unit or for the relevant materials only. For example, whether the sensitivity analysis on the proportion of glass cullet recovered is for glass or for all materials. I suggest that the most reasonable approach would be to undertake the analysis focusing on relevant materials, then summarise the impact on all materials. These and other issues could be addressed in an introduction for section 11.2 that: defines 'sensitivity analysis'; describes the approach taken for determining which aspects were selected for sensitivity analysis; lists the aspects selected for sensitivity testing and the reasons for their selection; defines the 'baseline'; describes the analytical approach; and describes the method for reporting the variations in results relative to the baseline. The bottom half of each table ('Percentage of the baseline') appears to refer to benefits of the baseline. Is this reporting approach consistent with the discussion on the 'signing convention' given on p.36? If it is to be maintained, I suggest the label is clarified.	Added introduction to the sensitivity analysis section. Have added discussion by material (where relevant) and by system. This improves the analysis, which is also added to the conclusions and exec sum.	0
8	LCA	The reports would benefit from an edit to improve readability and check for typographic errors etc. I have submitted by email marked-up versions of the two documents with various minor comments of this nature.	A complete review of both reports has been undertaken by the authors. Agree with statement as many adjustments have been made.	Entire report
9	LCA	Clarification is needed as to how recycling from landfills (e.g. metals) is considered in both the recycling and alternative systems,	Recycling from landfills is not assumed. It is assumed that once placed in the kerbside bin waste will move to the face of the landfill	Added in 8.1.2

No.	Reviewer	Comment	Author reply/action	Report section impacted
		including a rationale.	without further review. An inspection of the operation of the landfill facility at Hallam Rd, Hampton Park, showed that waste trucks moved directly to the landfill face where loads were emptied, then waste was bulldozed and compacted. The operation was so intense as to preclude sorting, as is the case for trailer drop-off operations. The assumption is therefore that no pre-sort occurs at landfill. Words to this affect have been added to the report.	
10	LCA	I suggest the description of the indicators is enhanced to clarify that actual impacts may depend on issues such as whether or not the emission occurs in a city, and that they may not be experienced directly by Victorians.	Added qualifying remarks to IAM section	5.8
11	LCA	The categorisations here are confusing. The heading 'Recycling System processes (excl. green and garden)' contains a sub-heading 'soil carbon storage', implying green and garden wastes are included. Also, most of the sub-headings under the heading 'alternative system processes' are also relevant to the recycling system. Table 18 also relies on this categorisation, and is consequently difficult to interpret.	Headings are confusing. These have been re-written to remove contradictions. In addition two figures have been added diagrammatically showing process definitions.	8
12	LCA	There appears to be an assumption throughout this section that reduced demand for virgin product will always lead to reduced demand for recyclate. For example, 11.3.3.2 states that: "If a decrease in demand for aluminium cans produced in Australia was to occur, then the demand for reprocessed aluminium would reduce." But it is possible that use of recycled aluminium is constrained by supply, and that additional recyclate could be used even if overall demand declined. I don't think this issue significantly affects the conclusions of the section, but the text needs to be checked.	The analysis assumes that recycled aluminium and primary aluminium are functionally indistinguishable. This arguably true for aluminium and metals, but possibly not so for some other materials. In general the approach assumes that reductions in demand will increase the likelihood of recovered materials becoming waste (or at least make them less attractive to recover). Added paragraph to this effect	11.3.1
13	LCA	The last sentence may be misleading. Is it suggesting that only 100 Monte Carlo simulations were undertaken? This contradicts the information at the top of p.37. Is it suggesting that recycling out-performed landfill 95% of the time across each parameter, or across all parameters, or across the majority of parameters?	1000 simulations were undertaken for the entire system and for each material system individually. This has been corrected.	12
14	LCA	While counter-intuitive, I accept the rationale that some portion of the C is neither emitted nor stored during the timeframe considered. However, that portion would be very small. I suggest this is confirmed via a mass balance assessment, given that the factors for this calculation use a mixture of sources (DCCEE/NGERS & Barlaz).	Agree that a carbon balance is important. For each material considered a FOD worksheet was completed which enforces this balance (presented in Appendix A). On each sheet a small residual equal to that fraction of the degradable carbon that will decompose which has not decomposed because it is at the tail of the decay function. A sentence referring to this has been added.	Appendix B – Inventory Report Section 3.3.4
15	LCA	The text states that: "Landfill operation and infrastructure … are allocated to each waste placed in the landfill on a mass basis". Hopefully this includes waste deposited in putrescible landfills that does not form part of this LCA. This should be clarified, the tonnage fractions in each category should be stated and their source made clear.	Added sentence clarifying that landfill infrastructure assumes capacity of 1.8 million tonnes.	Appendix B – Inventory Report Section 3.5
16	LCA	The emission factors for composting from Andersen *et al.* are quite different from those provided in the National Greenhouse and Energy Reporting System (recently revised to 16kg CO_2-e/t for CH_4 and 30kg CO_2-e/t for N_2O). I suggest you consider using the NGERS values in a sensitivity assessment.	Had not seen this. Have maintained reference to Andersen, but added NGERS. Have adopted NGERS as is Australian based.	Appendix B – Inventory Report Section 4.4.3.1
17	LCA	It is not clear what this table represents. I'm	Correct. Have amended caption.	Appendix B –

No.	Reviewer	Comment	Author reply/action	Report section impacted
		guessing it's the inputs and outputs associated with the production of a tonne of paper, but can't see where this is stated.		Inventory Report Table 53
18	LCA	The cited source for the data in this table is not correct.	Source is correct. Statement says calculated from data in fig 23 of SV 2011.	Appendix B – Inventory Report Table 74
19	LCA	These should be labelled by material type to allow reader interpretation.	Yes. Labels added.	Appendix to inventory report.
20	LCA	The methane correction factor is set at 0.71 – why is this? Table 19 (p.31) says this factor is set to equal 1, which is the appropriate value. Similarly, the DOC_f factors for all materials are given as 0.5, which is inconsistent with the correct values given in Table 18. If these values are incorrect in the actual calculation, the correct results for waste organics could be significantly different from those presented.	Incorrect tables pasted from different worksheet. Correct tables added. MCF is 1.0. Values now consistent with Table 18.	Appendix to inventory report.

Appendix F – Reviewer letter

blue environment pty ltd

ABN 78 118 663 997
Suite 212B , 757 Bourke Street DOCKLANDS Vic 3008
phone (03) 8102 9372
or (03) 5426 3536
email: blue@blueenvironment.com.au
web: www.blueenvironment.com.au

Our ref: P373
18 July 2013

Andrew Carre
Centre for Design at RMIT University
Andrew.Carre@RMIT.edu.au

Dear Andrew

Re. critical review of the draft life cycle assessment of kerbside recyclables

I have read in detail the draft report *Lifecycle Assessment of Kerbside Recyclables* and the appendicised *Inventory Report*, both dated 3 July 2013. I read them cognisant of the guidance set out in section 6.1 of the international standard on life cycle assessment ISO 14044, which requires the critical review process to ensure that:

- the methods used to carry out the LCA are consistent with the standard
- the methods used to carry out the LCA are scientifically and technically valid
- the data used are appropriate and reasonable in relation to the goal of the study
- the interpretations reflect the limitations identified and the goal of the study
- the study report is transparent and consistent.

In my opinion, the report conforms to these requirements and provides a well-researched assessment of the benefits of recycling, subject to an appropriate response to the comments tabulated in the attachment to this letter. The level of detail in the comments reflects the importance of this study to Victorian waste policy. The comments focus on: identification of significant issues; completeness and consistency of the evaluation; data appropriateness; and transparency and clarity of reporting. They are given in three categories: general issues; specific issues for the LCA report; and specific issues with the inventory report.

For the record, I confirm that I have expertise in the development of life cycle assessments, the related data and uncertainties, and the Victorian waste sector. I gained this expertise through 19 years of professional experience and academic study, encompassing six years' employment by EcoRecycle Victoria and EPA Victoria, around 150 consultancies in the waste sector, and a PhD on waste policy.

If you have any queries please contact me on 0403 562 621.

Yours sincerely

Joe Pickin
Director

Attached: Detailed comments on the draft life cycle assessment of kerbside recyclables
Submitted by email: Marked up versions of the draft report *Lifecycle Assessment of Kerbside Recyclables* and the appendicised *Inventory Report*.

Attachment – detailed comments on draft life cycle assessment of kerbside recyclables

#	Location / issue	Comment
General issues		
1	Executive Summary	For transparency, the Executive Summary of this important report should provide a stand-alone account of the project and its findings, including the inventory report. It would be desirable to include information on key assumptions, the materials and processes that contribute the most to the benefits, the main reasons for the main benefits, and the findings of the sensitivity analysis. More explanation is needed for Table 1. Is this the best estimate of the net environmental impacts of the recycling system vs. alternative system? It would be worth contextualising these indicators (see comments in relation to Section 5.8). The meaning of paragraph 3 on p.5 should be made clearer for the lay reader. Use of the terms 'attributional' and 'consequential' necessitates explanatory information about these terms (definitions or reference to definitions), and clarification for how they are used within the study (see comment #3).
2	Transport	One of the stated secondary goals of the LCA is to "identify impacts associated with unit processes within the recycling system, including transport ..." (p.15). The results by process (p.37 Table 18) itemise 'collection recycling' and 'collection landfill' but do not appear to consider all transport collectively for each system. Subject to client confirmation, the secondary goal does not appear to have been achieved. In response to last December's draft goal and scope document for this project, I pointed to the advantages of providing results that distinguish between Melbourne, regional and rural areas. The reported results do not readily provide for this level of analysis.
3	Consequential and attributional analyses	The roles of these two types of analysis in the study are not clear, and some of the statements about their use seem inconsistent: • LCA report p.26 para. 1: "In determining the impacts of the existing system, a fundamentally attributional approach has been employed that characterises impacts based on the existing systems operation." • LCA report p.55 para. 4: "... this study ... adopts a mix of consequential and attributional approaches. ... The inherent, consequential assumption ... is that the reprocessing of material recovered from the recycling stream materials always offsets the need to produce virgin material." • Inventory report p.31 para. 2: "... this study aims to understand landfill impacts prospectively" • Inventory report p.48 para 2: "...the primary application has been assumed to be agriculture". "Although ... there is no evidence that it represents the bulk of organic product use in Victoria, ... agricultural applications represent an area for future growth". The approach taken needs to be consistent across all processes and indicators.
4	Assumptions about markets for compost	I was confused by the approach taken in relation to markets for composting. There are descriptive inconsistencies: • The LCA report, p.59, 11.3.2.7 opens by saying: "The main market for reprocessed organic material is agriculture."

Page 1

#	Location / issue	Comment
		• The inventory report p.48 para. 2 states that: "there is no evidence that [agriculture] represents the bulk of organic product use in Victoria". My understanding is that compost use in agriculture is very limited, potentially representing a few percent of the total[1]. The inventory report p.43 Table 26 shows a 'base case' assumption that 50% of compost is used in agricultural settings. The text on p.48 notes this is inconsistent with current market circumstances, and provides two justifications: • Para 2: "...agricultural applications represent an area for future growth". This is inconsistent with the commitment to use an attributional approach. • Para. 3 "fundamental data limitations associated with other applications". This seems unreasonable unless it can be argued that the data on agricultural use is a reasonable proxy for other uses.
5	Assumptions about carbon storage associated with use of compost	The inventory report p.43 Table 26 provides a full range of estimates for carbon storage in soil, from 0% to 100%. It selects 50% as the 'base case' value for carbon storage over the 100-year assessment timeframe, and uses the other values in sensitivity analysis. The estimates coincide with the assumptions about markets – in the 'conservative' assumptions where material is used wholly for the urban amenity market, no carbon benefit is assumed. I have two issues: • The 50% base case value and the 100% 'optimistic' value seem high. A literature review for a large European LCA (Smith et al, *Waste Management Options and Climate Change*) estimated an average retention half-life of 28 years. I believe this value was used in the original Grant *et al.* (2001) LCA. I appreciate that there are major uncertainties and variability in relation to carbon storage, and it may be reasonable to consider higher values in the context of a continuous stream of compost application, but a rationale would be appropriate. • No reason is apparent as to why a potential carbon storage benefit exists when compost is applied agriculturally but not when it is used in urban amenity markets. My colleague Bill Grant, who is a compost expert, believes carbon storage is likely to be higher in a non-agricultural setting as addition of nitrogen in agriculture may lead to loss of soil carbon. This is a topical issue in the context of the Carbon Farming Initiative. Using sensitivity analysis to deal with this difficulty is a good idea.
6	Results	The results section could be enhanced to provide additional important information, including identification of: • the key uncertainties – i.e. those that have the greatest impact on results when set at the extremes of their uncertainty range • the materials that provide the most benefit, both in general and per unit mass • the processes responsible for the greatest burdens or benefits • separate emphasis on the organic and comingled streams, to provide support for decisions by particular councils on the environmental costs and benefits or organics recovery.

[1] Some data on Victorian compost markets is given in the ROU's 2009 industry statistics, available at: http://www.recycledorganics.com/publications/#survey

#	Location / issue	Comment
7	Sensitivity analysis	Sensitivity analysis should be undertaken in relation to key uncertainties – i.e. those that have the greatest impact on results when set at the extremes of their uncertainty range. I think that's what has been done but it should be stated and demonstrated. It was not always clear to me whether the sensitivity analysis was undertaken across the entire functional unit or for the relevant materials only. For example, whether the sensitivity analysis on the proportion of glass cullet recovered is for glass or for all materials. I suggest that the most reasonable approach would be to undertake the analysis focusing on relevant materials, then summarise the impact on all materials. These and other issues could be addressed in an introduction for section 11.2 that: defines 'sensitivity analysis'; describes the approach taken for determining which aspects were selected for sensitivity analysis; lists the aspects selected for sensitivity testing and the reasons for their selection; defines the 'baseline'; describes the analytical approach; and describes the method for reporting the variations in results relative to the baseline. The bottom half of each table ('Percentage of the baseline') appears to refer to benefits of the baseline. Is this reporting approach consistent with the discussion on the 'signing convention' given on p.36? If it is to be maintained, I suggest the label is clarified.
8	Readability	The reports would benefit from an edit to improve readability and check for typographic errors etc. I have submitted by email marked-up versions of the two documents with various minor comments of this nature.
Specific issues for the LCA report		
9	p.19, Sections 5.2.3 & 5.2.4	Clarification is needed as to how recycling from landfills (e.g. metals) is considered in both the recycling and alternative systems, including a rationale.
10	p.24, Section 5.8	I suggest the description of the indicators is enhanced to clarify that actual impacts may depend on issues such as whether or not the emission occurs in a city, and that they may not be experienced directly by Victorians.
11	p.27, 'core processes'	The categorisations here are confusing. The heading 'Recycling System processes (excl. green and garden)' contains a sub-heading 'soil carbon storage', implying green and garden wastes are included. Also, most of the sub-headings under the heading 'alternative system processes' are also relevant to the recycling system. Table 18 also relies on this categorisation, and is consequently difficult to interpret.
12	11.3	There appears to be an assumption throughout this section that reduced demand for virgin product will always lead to reduced demand for recyclate. For example, 11.3.3.2 states that: "If a decrease in demand for aluminium cans produced in Australia was to occur, then the demand for reprocessed aluminium would reduce." But it is possible that use of recycled aluminium is constrained by supply, and that additional recyclate could be used even if overall demand declined. I don't think this issue significantly affects the conclusions of the section, but the text needs to be checked.
13	p.62 para 2	The last sentence may be misleading. Is it suggesting that only 100 Monte Carlo simulations were undertaken? This contradicts the information at the top of p.37. Is it suggesting that recycling out-performed landfill 95% of the time across each parameter, or across all parameters, or across the majority of parameters?

#	Location / issue	Comment
Specific issues with the inventory report		
14	p.34 para 2	While counter-intuitive, I accept the rationale that some portion of the C is neither emitted nor stored during the timeframe considered. However, that portion would be very small. I suggest this is confirmed via a mass balance assessment, given that the factors for this calculation use a mixture of sources (DCCEE/NGERS & Barlaz).
15	p.37 para 1	The text states that: "Landfill operation and infrastructure ... are allocated to each waste placed in the landfill on a mass basis". Hopefully this includes waste deposited in putrescible landfills that does not form part of this LCA. This should be clarified, the tonnage fractions in each category should be stated and their source made clear.
16	p.51 & 52, Tables 29 & 30	The emission factors for composting from Andersen *et al.* are quite different from those provided in the National Greenhouse and Energy Reporting System (recently revised to 16kg CO_2-e/t for CH_4 and 30kg CO_2-e/t for N_2O). I suggest you consider using the NGERS values in a sensitivity assessment.
17	p.72 Table 50	It is not clear what this table represents. I'm guessing it's the inputs and outputs associated with the production of a tonne of paper, but can't see where this is stated.
18	p.100 Table 71	The cited source for the data in this table is not correct.
19	Appendices	These should be labelled by material type to allow reader interpretation.
20	Appendices	The methane correction factor is set at 0.71 – why is this? Table 19 (p.31) says this factor is set to equal 1, which is the appropriate value. Similarly, the DOC_f factors for all materials are given as 0.5, which is inconsistent with the correct values given in Table 18. If these values are incorrect in the actual calculation, the correct results for waste organics could be significantly different from those presented.