

# Environmental benefits of recycling

## Appendix 1 – Metals

Aluminium, copper and steel



Environment,  
Climate Change  
& Water

**Disclaimer**

The Department of Environment, Climate Change and Water NSW has made all reasonable efforts to ensure that the contents of this document are free from factual error. However, the DECCW shall not be liable for any damage or loss, which may occur in relation to any person taking action or not on the basis of this document.

**Published by**

Department of Environment, Climate Change and Water NSW  
59–61 Goulburn Street  
PO Box A290  
Sydney South 1232  
Ph: (02) 9995 5000 (switchboard)  
Ph: 131 555 (environment information and publications requests)  
Ph: 1300 361 967 (national parks information and publications requests)  
Fax: (02) 9995 5999  
TTY: (02) 9211 4723  
Email: [info@environment.nsw.gov.au](mailto:info@environment.nsw.gov.au)  
Website: [www.environment.nsw.gov.au](http://www.environment.nsw.gov.au)

DECCW 2010/58

ISBN 978 1 74232 530 9

June 2010

© Copyright Department of Environment, Climate Change and Water NSW June 2010

The Department of Environment, Climate Change and Water NSW is pleased to allow this material to be reproduced in whole or in part, provided the meaning is unchanged and its source, publisher and authorship are acknowledged.

## Table of contents

<b>Understanding network diagrams .....</b>	<b>4</b>
<b>Aluminium cans and scrap.....</b>	<b>5</b>
<b><i>Process description</i>.....</b>	<b>5</b>
A) Kerbside collection system.....	6
Processes considered.....	6
Results.....	7
Key assumptions .....	7
Data quality table and comment.....	9
B) C&I and C&D collection system .....	9
Processes considered.....	9
Results.....	9
Key assumptions .....	10
Data quality table and comment.....	11
<b><i>References</i> .....</b>	<b>12</b>
Network diagrams — Kerbside collection .....	13
Network diagrams — C&I and C&D collection.....	17
<b>Copper .....</b>	<b>21</b>
<b><i>Process description</i>.....</b>	<b>21</b>
Results.....	21
Key assumptions .....	22
Data quality table and comment.....	23
<b><i>References</i> .....</b>	<b>24</b>
Network diagrams — C&I and C&D collection.....	25
<b>Steel packaging cans and scrap.....</b>	<b>29</b>
<b><i>Process description</i>.....</b>	<b>29</b>
A) Kerbside collection system .....	30
Processes considered.....	30
Results.....	31
Key assumptions .....	31
Data Quality table and comment.....	33
B) C&I and C&D collection system .....	33
Processes considered.....	33
Results.....	33
Key assumptions .....	34
Data quality table and comment.....	35
<b><i>References</i> .....</b>	<b>35</b>
Network diagrams — Kerbside collection .....	36
Network diagrams — C&I and C&D collection.....	40

## List of tables and figures

Figure 1:	Sample network diagram. ....	4
Figure 2:	Processes considered in determining the net impacts of the recycling process from kerbside and C&I and C&D sources.....	6
Table 1:	Benefits and impacts of recycling of aluminium cans from kerbside sources (per 1 tonne of waste cans collected).....	7
Table 2:	Inventory for recycling aluminium cans, kerbside source (1 tonne) .....	8
Table 3:	Data quality for life cycle inventory data modelled for recycling and landfilling of aluminium cans, kerbside source .....	9
Table 4:	Benefits and impacts of recycling aluminium waste from C&I and C&D sources (per tonne). ....	10
Table 5:	Inventory for recycling aluminium waste from C&I and C&D source (1 tonne).....	11
Table 6:	Data quality for life cycle inventory data modelled for recycling and landfilling of aluminium waste from C&I and C&D source .....	12
Figure 3:	Kerbside collection — Recycling process network diagram — Green house gases indicator .....	13
Figure 4:	Kerbside collection — Recycling process network diagram — Cumulative energy demand indicator. ....	14
Figure 5:	Kerbside collection — Recycling process network diagram — Water indicator. ....	15
Figure 6:	Kerbside collection — Recycling process network diagram — Solid waste indicator.....	16
Figure 7:	C&I and C&D collection — Recycling process network diagram — Green house gases indicator.....	17
Figure 8:	C&I and C&D collection — Recycling process network diagram — Cumulative energy demand indicator. ....	18
Figure 9:	C&I and C&D collection — Recycling process network diagram — Water indicator ....	19
Figure 10:	C&I and C&D collection — Recycling process network diagram — Solid waste indicator.....	20
Figure 11:	Processes considered in determining the net impacts of the recycling process from C&I and C&D sources.....	21
Table 7:	Benefits and impacts of recycling copper from C&I and C&D sources (per tonne). ....	22
Table 8:	Inventory for recycling copper from C&I and C&D (1 tonne).....	23
Table 9:	Data quality for life cycle inventory data modelled for recycling and landfilling of copper, from C&I and C&D (1 tonne) .....	24
Figure 12:	Recycling process network diagram — Green house gases indicator. ....	25
Figure 13:	Recycling process network diagram — Cumulative energy demand indicator.....	26
Figure 14:	Recycling process network diagram — Water indicator. ....	27
Figure 15:	Recycling process network diagram — Solid waste indicator.....	28
Figure 16:	Processes considered in determining the net impacts of the recycling process from kerbside and CI&CD sources.....	30
Table 10:	Benefits and impacts of recycling steel cans from kerbside sources (per tonne).....	31
Table 11:	Inventory for recycling steel cans, kerbside source (1 tonne).....	32
Table 12:	Data quality for life cycle inventory data modelled for recycling and landfilling of packaging steel cans, kerbside source (1 tonne) .....	33

Table 13: Benefits and impacts of recycling steel scrap waste from C&I and C&D sources (per tonne) .....	34
Table 14: Inventory for recycling of steel waste from C&I and C&D source (1 tonne) .....	34
Table 15: Data quality for life cycle inventory data modelled for recycling and landfilling of scrap steel, C&I and C&D source (1 tonne) .....	35
Figure 17: Recycling process network diagram — Green house gases indicator. ....	36
Figure 18: Recycling process network diagram — Cumulative energy demand indicator. ....	37
Figure 19: Recycling process network diagram — Water indicator .....	38
Figure 20: Recycling process network diagram — Solid waste indicator.....	39
Figure 21: Recycling process network diagram — Green house gases indicator .....	40
Figure 22: Recycling process network diagram — Cumulative energy demand indicator.....	41
Figure 23: Recycling process network diagram — Water indicator. ....	42

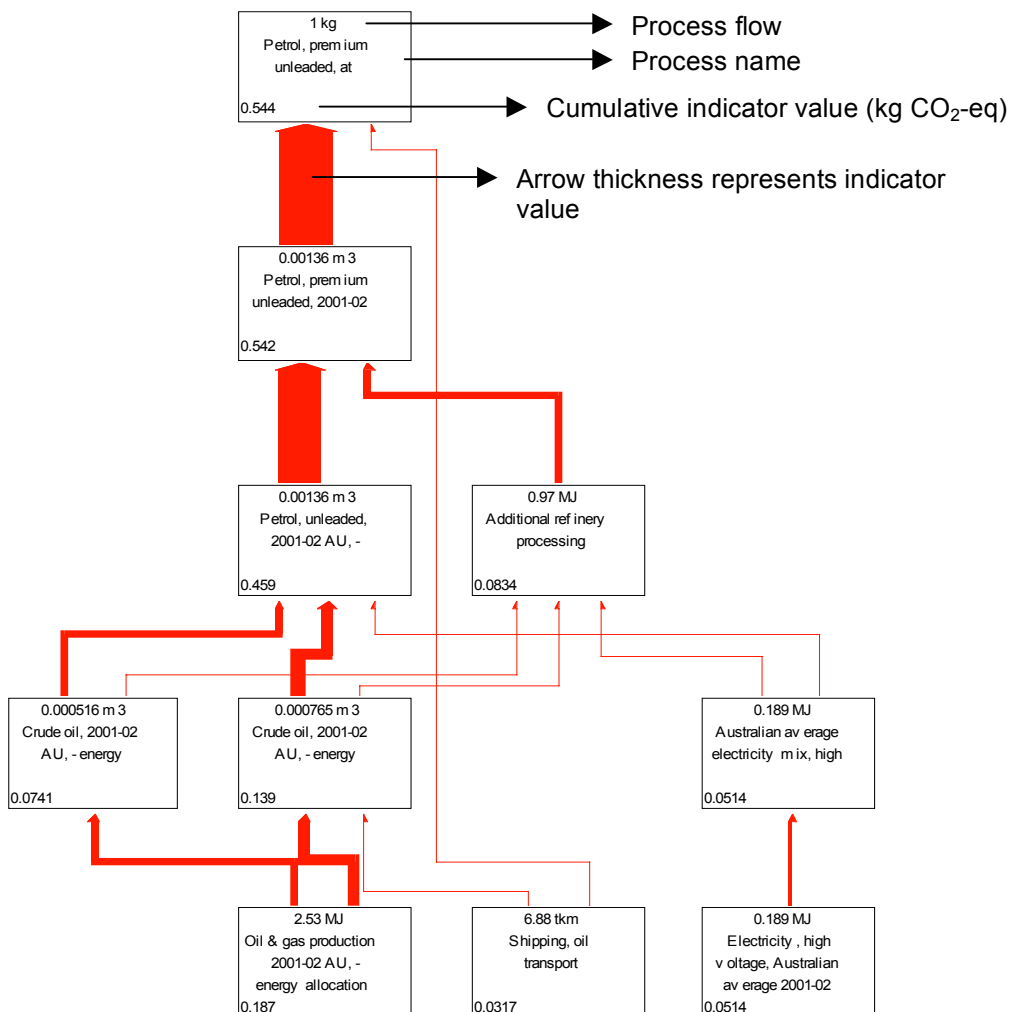
## Understanding network diagrams

This appendix presents the data sources and assumptions used in modelling the life cycle stages. Most of the data is contained and modelled in LCA software and consists of hundreds of individual unit process processes. To help provide transparency on the inventories used for the background processes, process network diagrams are presented.

To interpret the process network, start at the top of the tree representing the functional output of the process (e.g. petrol premium unleaded, shown in Figure 1). The amount and unit of the process is shown in the upper number in the unit process box (1kg). The lower number (in the bottom left hand corner) represents an indicator value which, in this case, is set to show cumulative greenhouse gas contributions in kilograms of equivalent carbon dioxide (CO<sub>2</sub> eq). The arrow thickness represents the indicator value (the thicker the arrow the more impact that process is contributing). Note that minor processes may not be physically shown in the process network if the indicator value falls below a specific cut-off level, though their contribution to the overall functional unit (the top box in the diagram) is still included. The network diagram may also be truncated at the bottom to improve readability of the networks. Finally, some diagrams may not show the process flows for confidentiality reasons.

Some network diagrams will include green process flow arrows. These arrows represent beneficial flows (negative impacts) and are common when viewing recycling processes. In recycling processes, negative cumulative indicator values (lower left hand corner) will typically be associated with avoided processes, such as avoided primary material production and avoided landfill.

**Figure 1: Sample network diagram.**



## Aluminium cans and scrap

### *Process description*

Aluminium cans and aluminium scrap are both considered in this inventory. Reprocessing is assumed to be undertaken in a similar fashion for both cans and scrap, however collection is assumed to differ for each form (cans being sourced from both municipal waste and C&I and C&D sources, whereas scrap tends to come from C&I and C&D sources only).

Aluminium cans are made from aluminium sheet with thin layers of lacquers on the inside and outside surfaces, along with ink on the outside surface. The cans have three components, the main can body, the lid and the opening tab. All of these components are made from aluminium. Reprocessing of aluminium is undertaken at Yennora NSW. The process involves remelting of used beverage cans with other external and internal scrap streams to produce aluminium ingots for aluminium sheet production.

Aluminium scrap has varied forms including window frames, furniture, manufacturing off-cuts etc. Once collected processing is assumed to be similar as aluminium cans, and is undertaken at the Yennora, NSW facility.

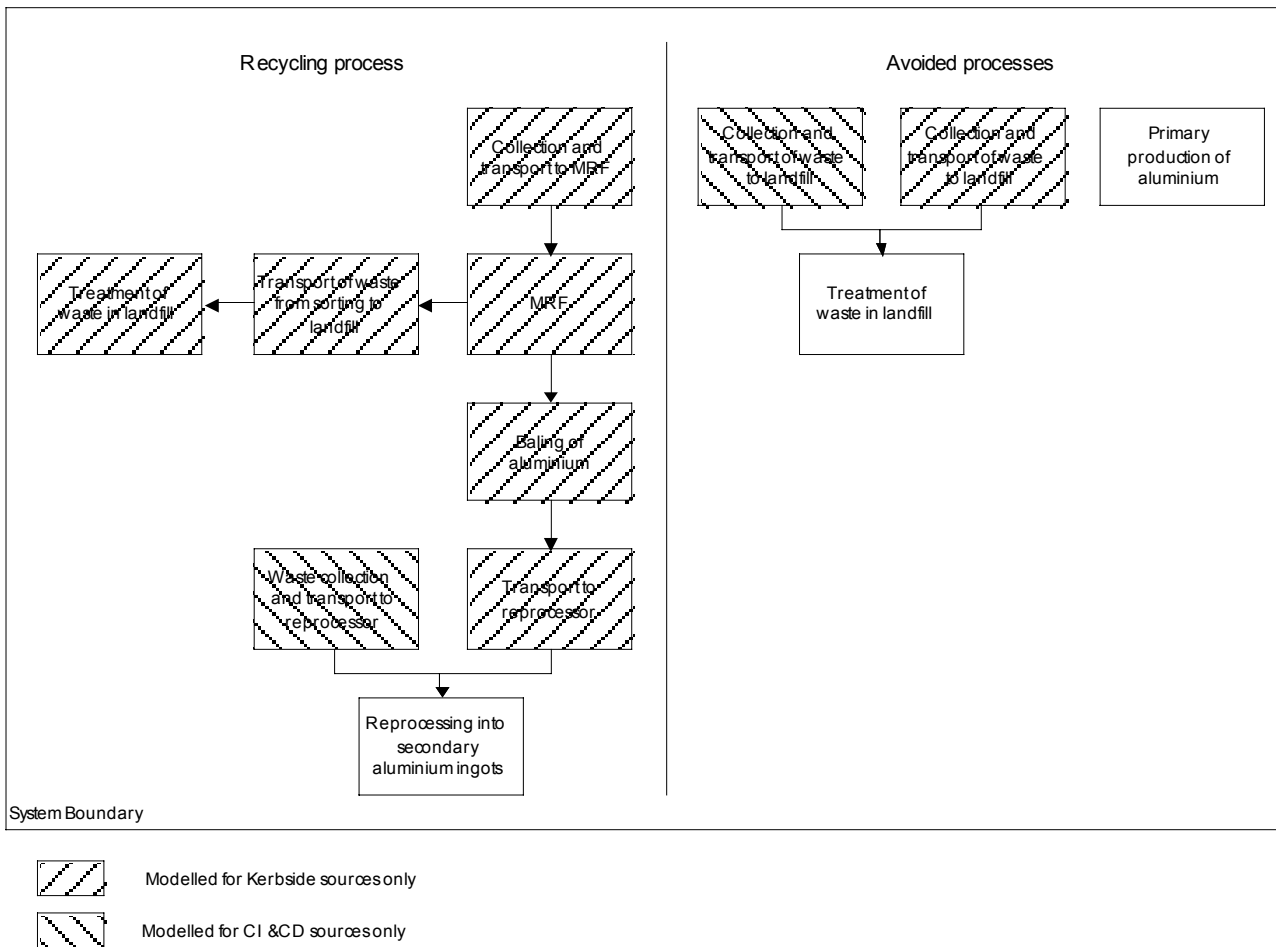
#### **Two collection systems for waste aluminium were considered in the model:**

- A) Kerbside collection — municipal collection of aluminium cans in commingled form households and processing through a Materials Recovery Facility (MRF)
- B) C&I and C&D collection — the segregated waste collected is sent directly to the reprocessing site without any sorting process, or associated losses. Aluminium cans and scrap are collected through this system.

The unique nature of each collection system drives differences in the impacts associated with aluminium recycling. For this reason the aluminium recycling processes considered and impacts generated have been described separately in the following sections, according to the collection method used.

Figure 2 illustrates the processes considered in determining the overall impact of aluminium can recycling from kerbside and C&I and C&D sources, and aluminium scrap from C&I and C&D sources (shown to the left of the vertical line), and the processes considered in determining the overall impact of the avoided processes (shown to the right of the vertical line).

**Figure 2: Processes considered in determining the net impacts of the recycling process from kerbside and C&I and C&D sources.**



## A) Kerbside collection system

### *Processes considered*

The kerbside collection system involves collection of waste for recycling from the kerbside and transport to a Materials Recovery Facility (MRF) which sorts the commingled materials in the recycling stream. The model developed takes into account transportation impacts as well as sorting impacts incurred to bring the material from the kerbside to the MRF. During sorting, waste material is generated and transported to landfill.

Once at the reprocessing facility, the model considers the impacts of material reprocessing required to convert the waste material into aluminium ingots. Losses associated with this process are included in the analysis. Figure 2 illustrates the processes considered (processes unique to kerbside collection have been shaded accordingly).

In order to determine the net benefit of recycling a material, it is also necessary to consider the processes avoided when recycling is undertaken. Figure 2 also illustrates the processes that would be avoided if waste aluminium cans were to be recycled (shown to the right of the vertical line). Two main avoided processes are considered; the collection and disposal to landfill of waste aluminium cans from the kerbside, and the primary manufacture of aluminium ingots from virgin resources.



## Results

Considering both the recycling process flows and the avoided process flows, described in Figure 2, an inventory of environmental flows was developed. This inventory was then assessed using the Australian Impact Assessment Method, with results described in Table 1.

**Table 1: Benefits and impacts of recycling of aluminium cans from kerbside sources (per 1 tonne of waste cans collected). Benefits are shown negative, impacts are shown positive.**

Impact category	Unit	<u>Recycling process impacts</u> (Figure 1 - left side)	<u>Avoided process impacts</u> (Figure 1 - right side)			<u>Net benefits of recycling</u>
		Collection, sorting and reprocessing	Collection and landfill	Primary material production	Total avoided impacts	
Global warming	t CO <sub>2</sub>	0.70	-0.20	-16.4	-16.6	-15.9
Cumulative energy demand	GJ LHV	10.0	-2.83	-178	-181	-171
Water use	kL H <sub>2</sub> O	0.99	-0.02	-183	-183	-182
Solid waste	tonnes	0.18	-1.00	-0.58	-1.58	-1.40

Network diagrams detailing key processes that influence the impacts listed in Table 1 are shown in Figure 3 to Figure 6. For further information regarding interpretation of network diagrams, refer to Understanding Network Diagrams (Figure 1).

## Key assumptions

Table 2 describes the key processes and data sources used to determine the benefits and impacts associated with recycling 1 tonne of aluminium cans from a kerbside source. The table also includes the products and processes avoided when 1 tonne of aluminium cans are recycled.

**Table 2: Inventory for recycling aluminium cans, kerbside source (1 tonne)**

Item	Flow	Unit	Comment
<b>Recycling Process flows (Figure 2 — left hand side)</b>			
Waste collection and transport to MRF	19.8	m <sup>3</sup>	18m <sup>3</sup> /tonne plus 10% for other material collected with it but disposed of at MRF, Grant (2001a) Transport model for kerbside collection based on Grant (2001b); refer appendices for discussion on transport. Emission of the truck from Apelbaum (2001), NGGIC (1997) and other sources.
Sorting of aluminium at Material Recovery Facility (MRF)	19.8	m <sup>3</sup>	18m <sup>3</sup> /tonne plus 10% for other material collected with it but disposed of at MRF, Grant (2001a) Energy inputs from Nishtala (1997) and estimated from equipment specifications
Baling of aluminium	0.90	tonne	Estimated 10% loss at MRF Electricity inputs from Nishtala (1997), 12kWh per tonne.
Transport from MRF to reprocessor	20	km	Emissions from transport based on an articulated truck, 15 tonne load on 30 tonne truck. Trucking model developed from data provided by Apelbaum (2001)
Reprocessing into secondary aluminium ingots	0.90	tonne	Recycled ingot produces around 5% less usable metal, so reprocessing 900 kg of aluminium waste ends up with 855 kg of reprocessed aluminium output. The process model developed is structured around input material so 0.9 tonne is used to describe the flow. Aggregated data from Australian Aluminium Council (1998)
Transport of waste from sorting to landfill	20	km	Emissions from transport based on an articulated truck, 28 tonne load on 30 tonne truck. Trucking model developed from data provided by Apelbaum (2001)
Treatment of waste in landfill	0.1	tonne	Material discarded at MRF treated in landfill.
<b>Avoided processes (Figure 2 — right hand side)</b>			
Collection and transport of waste to landfill	19.8	m <sup>3</sup>	Waste collection avoided by sending material to MRF above. Transport model for kerbside collection based on Grant (2001b); refer appendices for discussion on transport. Emission of the truck from Apelbaum (2001), NGGIC (1997) and other sources.
Treatment of waste aluminium in landfill	1	tonne	Operation of the landfill. Data derived from a personal communication with S. Middleton, Pacific Waste, NSW, 1998 Emissions factors from Nielson (1998). Model comprises fuel and electricity consumption associated with operating a typical landfill.
Primary production of aluminium	0.855	tonne	Aluminium reprocessing is assumed to generate 950 kg of aluminium per tonne reprocessed (5% loss as described above). Therefore for 900kg reprocessed 855kg of aluminium is produced thereby avoiding 855kg of virgin aluminium production. Inputs in terms of energy and materials from Australian Aluminium Council (1998) Emissions factors based on 2002 National Pollutant Inventory (NPI), (2004) Transport to Sydney regional store taken into account (160 km)

### *Data quality table and comment*

Table 3 presents a summary of the data quality for the main processes considered. It shows the data sources used; if they are general data or specific to a company; the age of the data; the geographic location that the data were based on; and, the nature of the technology considered.

**Table 3: Data quality for life cycle inventory data modelled for recycling and landfilling of aluminium cans, kerbside source**

	<b>Primary data source</b>	<b>Geography</b>	<b>Data Age</b>	<b>Technology</b>	<b>Representativeness</b>
Impacts of transportation modes	Grant, NGGIC (1997)	European data adapted to Australian conditions and Australian data	1997–2005	Average technology	Mixed data
Reprocessing aluminium	AAC (1998) aggregated data	Australia, NSW	1995–1999	Average technology	Data from a specific company and process
Avoided primary aluminium product	Australian Aluminium Council study(1998)	Australia	1998	Average technology	Mixed data
Avoided landfill impacts	Nielson (1998)	Australia	1995–1999	Unspecified	Mixed data

## **B) C&I and C&D collection system**

### *Processes considered*

In the case of the C&I and C&D collection system, it has been assumed that segregated waste collected is sent directly to the reprocessing site without any sorting process, or associated losses. The model developed takes into account transportation impacts incurred to bring the material from C&I and C&D sources to the material reprocessing facility. The model is essentially the same as that for kerbside collection, however collection processes are simplified, and loss rates adjusted. The system is also described in Figure 2 (processes unique to C&I, C&D processing have been shaded accordingly).

### *Results*

Considering both the recycling process flows and the avoided process flows, described in Figure 2, an inventory of environmental flows was developed. This inventory was then assessed using the Australian Impact Assessment Method, with results described in Table 4.

**Table 4: Benefits and impacts of recycling aluminium waste from C&I and C&D sources (per tonne). Benefits are shown negative, impacts are shown positive.**

Impact category	Unit	Recycling process impacts (Figure 1 – left side)	Avoided process impacts (Figure 1 – right side)			Net benefits of recycling
		Collection, sorting and reprocessing	Collection and landfill	Primary material production	Total avoided impacts	
Global warming	t CO <sub>2</sub>	0.46	-0.01	-18.2	-18.2	-17.7
Cumulative energy demand	GJ/HV	6.82	-0.13	-198	-198	-191
Water use	kL H <sub>2</sub> O	1.01	0.00	-203	-203	-202
Solid waste	tonnes	0.08	-1.00	-0.64	-1.64	-1.56

Network diagrams detailing key processes that influence the impacts listed in Table 4 are shown in Figure 7 to Figure 10. For further information regarding interpretation of network diagrams, refer to Understanding Network Diagrams (Figure 1).

### *Key assumptions*

Table 5 describes the key processes and data sources used to determine the benefits and impacts associated with the recycling of 1 tonne of aluminium waste from C&I and C&D sources. The table also includes the products and processes avoided when 1 tonne of aluminium waste is recycled.

**Table 5 Inventory for recycling aluminium waste from C&I and C&D source (1 tonne)**

Item	Flow	Unit	Comment
<b>Recycling Process flows (Figure 2 — left hand side)</b>			
Waste collection and transport to reprocessor	20	km	20km distance estimate based on a simplified transport analysis for Sydney, refer appendices for discussion on transport. Emissions from transport based on a trucking model developed by the Centre for Design, incorporating trucking data from Apelbaum (2001), Truck backhaul ratio assumed to be 1:2.
Reprocessing into secondary aluminium ingots	1	tonne	Recycled ingot produces around 5% less usable metal, so reprocessing 1000 kg of aluminium waste ends up with 950 kg of reprocessed aluminium output. The process model developed is structured around input material so 1 tonne is used to describe the flow. Aggregated data from Australian Aluminium Council (1998)
<b>Avoided processes (Figure 2 — left hand side)</b>			
Collection and transport of waste to landfill	20	km	20km distance estimate based on a simplified transport analysis for Sydney, refer appendices for discussion on transport. Emissions from transport based on a trucking model developed by the Centre for Design, incorporating trucking data from Apelbaum (2001), Truck backhaul ratio assumed to be 1:2.
Treatment of waste in landfill	1	tonne	Operation to the landfill from a personal communication with S. Middleton, Pacific Waste, NSW, 1998 Emissions factors from Nielson (1998)
Primary production of aluminium	0.95	tonne	Aluminium reprocessing is assumed to generate 950 kg of aluminium per tonne reprocessed (5% loss as described above). Inputs in terms of energy and materials from Australian Aluminium Council (1998) Emissions factors based on 2002 National Pollutant Inventory (NPI), (2004) Transport to Sydney regional store taken into account (160 km)

**Data quality table and comment**

Table 6 presents a summary of the data quality for the main processes considered. It shows the data sources used; if they are general data or specific to a company; the age of the data; the geographic location that the data were based on; and, the nature of the technology considered.

**Table 6: Data quality for life cycle inventory data modelled for recycling and landfilling of aluminium waste from C&I and C&D source**

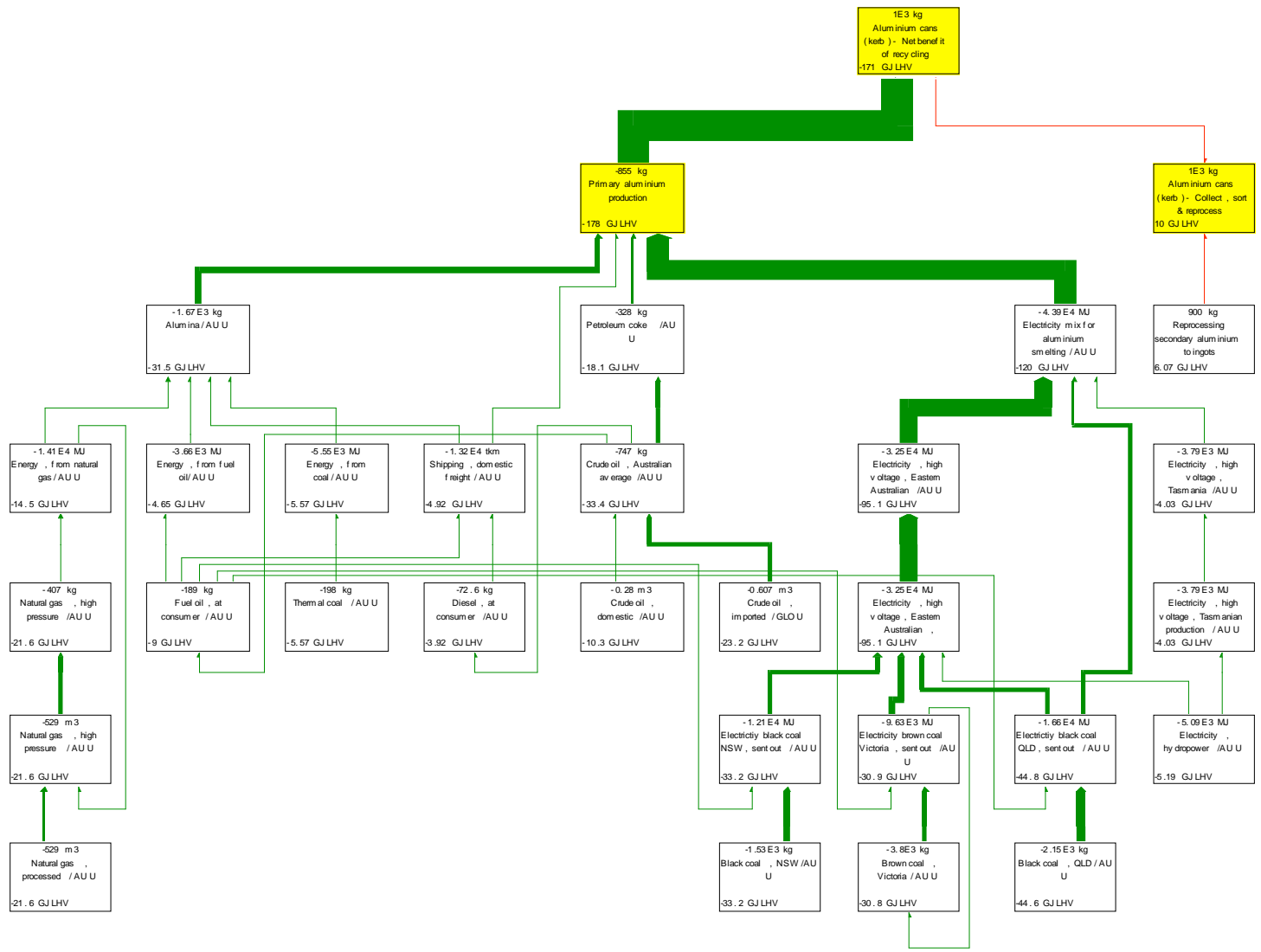
	Primary data source	Geography	Data Age	Technology	Representativeness
Impacts of transportation modes	Apelbaum consulting group (2001)	Australia	2001	Average	Average from all suppliers
Transportation distances	Estimate	Sydney	2009	Average	Estimate based on simple radial transport model
Reprocessing aluminium	AAC (1998) aggregated data	Australia, NSW	1995–1999	Average technology	Data from a specific company and process
Avoided primary aluminium product	Australian Aluminium Council study(1998)	Australia	1998	Average technology	Mixed data
Avoided landfill impacts	Nielson (1998)	Australia	1995–1999	Unspecified	Mixed data

## References

- Apelbaum Consulting Group (2001), Australian Transport facts 2001 Tables in Excel Format, Blackburn, Victoria.
- Australian Aluminium Council (AAC) (1998), Australian Primary Aluminium Life Cycle Inventory
- DEH (2004), National Pollutant Inventory Data for year 2002, Department of Environment, Canberra.
- Grant, T., James, K., Lundie, S., Sonneveld, K., (2001a), Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria, EcoRecycle, Melbourne
- Grant, T., James, K.L., Lundie, S., Sonneveld, K., Beavis, P. (2001b), Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in New South Wales, NSW Environment Protection Authority, Sydney
- National Greenhouse Gas Inventory Committee (1997), National Greenhouse Gas Inventory 1995 with Methodology Supplement, Environment Australia, Canberra Australia
- Nielson, P., Hauschild, M., (1998): Product Emissions from Municipal Solid Waste Landfills. Part 1: Landfill Model. Int J LCA 3 (3) 158–168, Landsberg
- Nishtala, S., Solano-Mora, E., (1997), Description of the Material Recovery Facilities Process Model: Design, Cost, and Life-Cycle Inventory, Research Triangle Institute and North Carolina State University
- Wang, F. (1996). Solid Waste Integrated Management Model. PhD Thesis in the Department of Chemical and Metallurgical Engineering. Melbourne, RMIT.

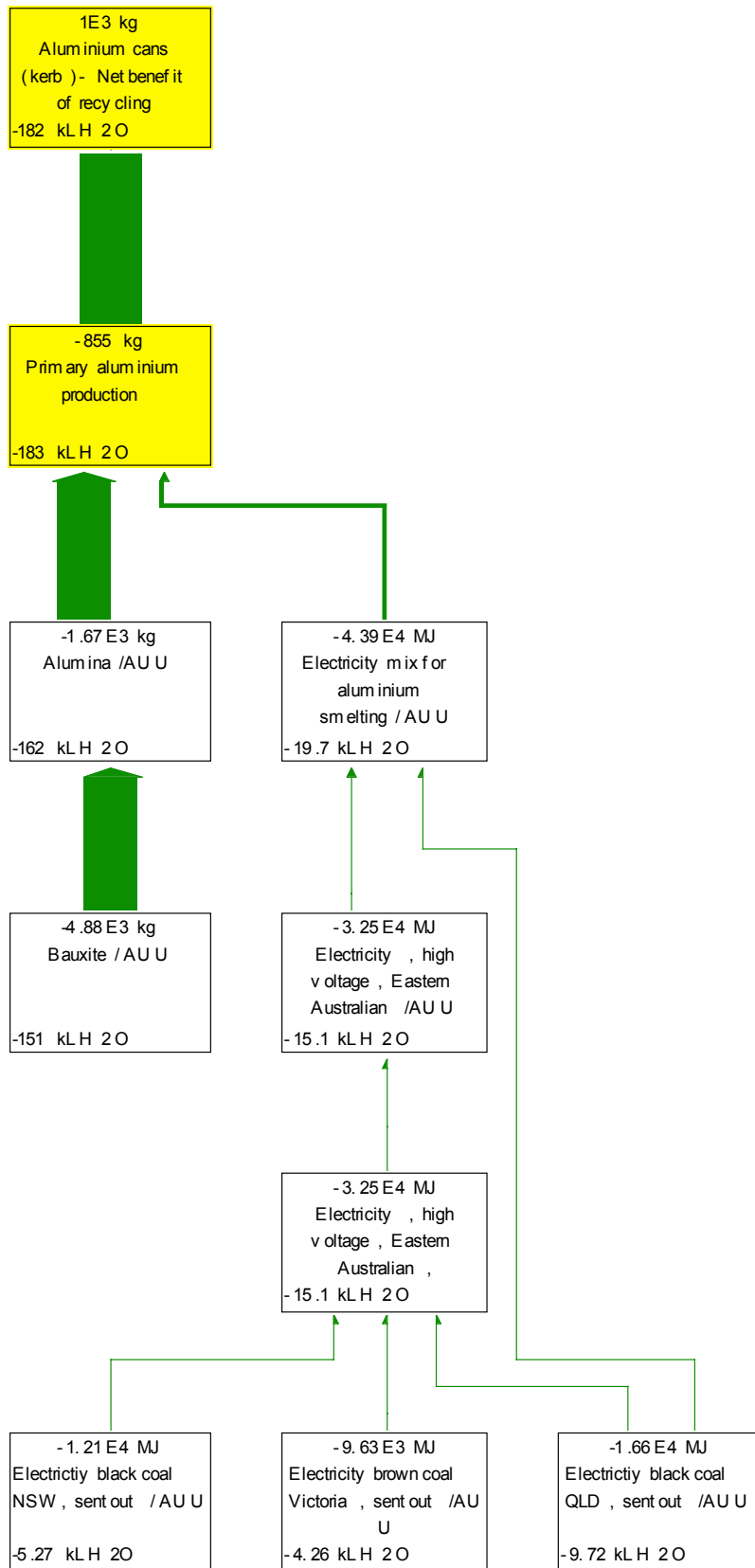


**Figure 4: Kerbside collection — Recycling process network diagram — Cumulative energy demand indicator. Processes contributing less than 2% to total are not shown. Major processes from results table above are shown shaded.**

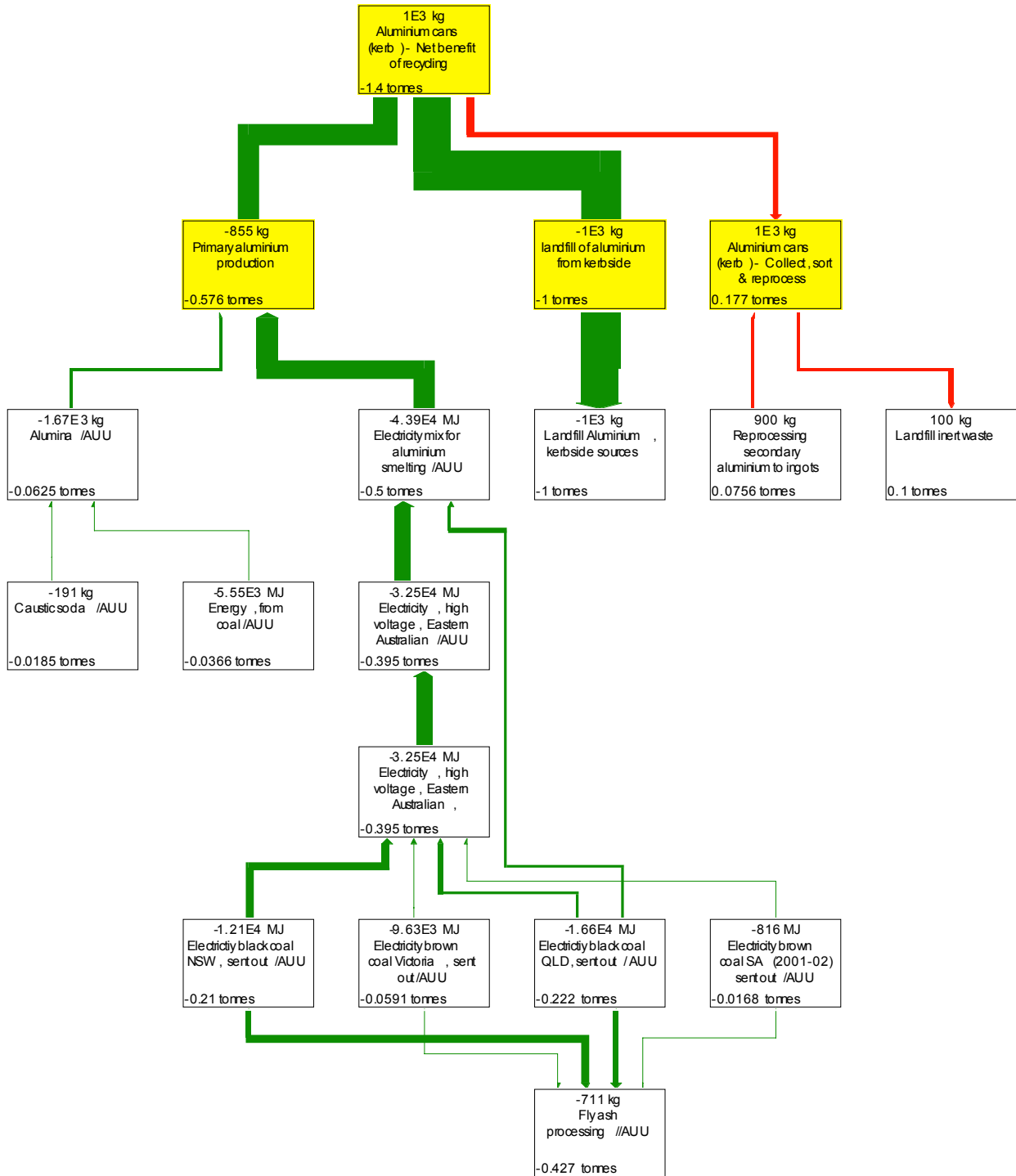




**Figure 5: Kerbside collection — Recycling process network diagram — Water indicator. Processes contributing less than 1% to total are not shown. Major processes from results table above are shown shaded.**

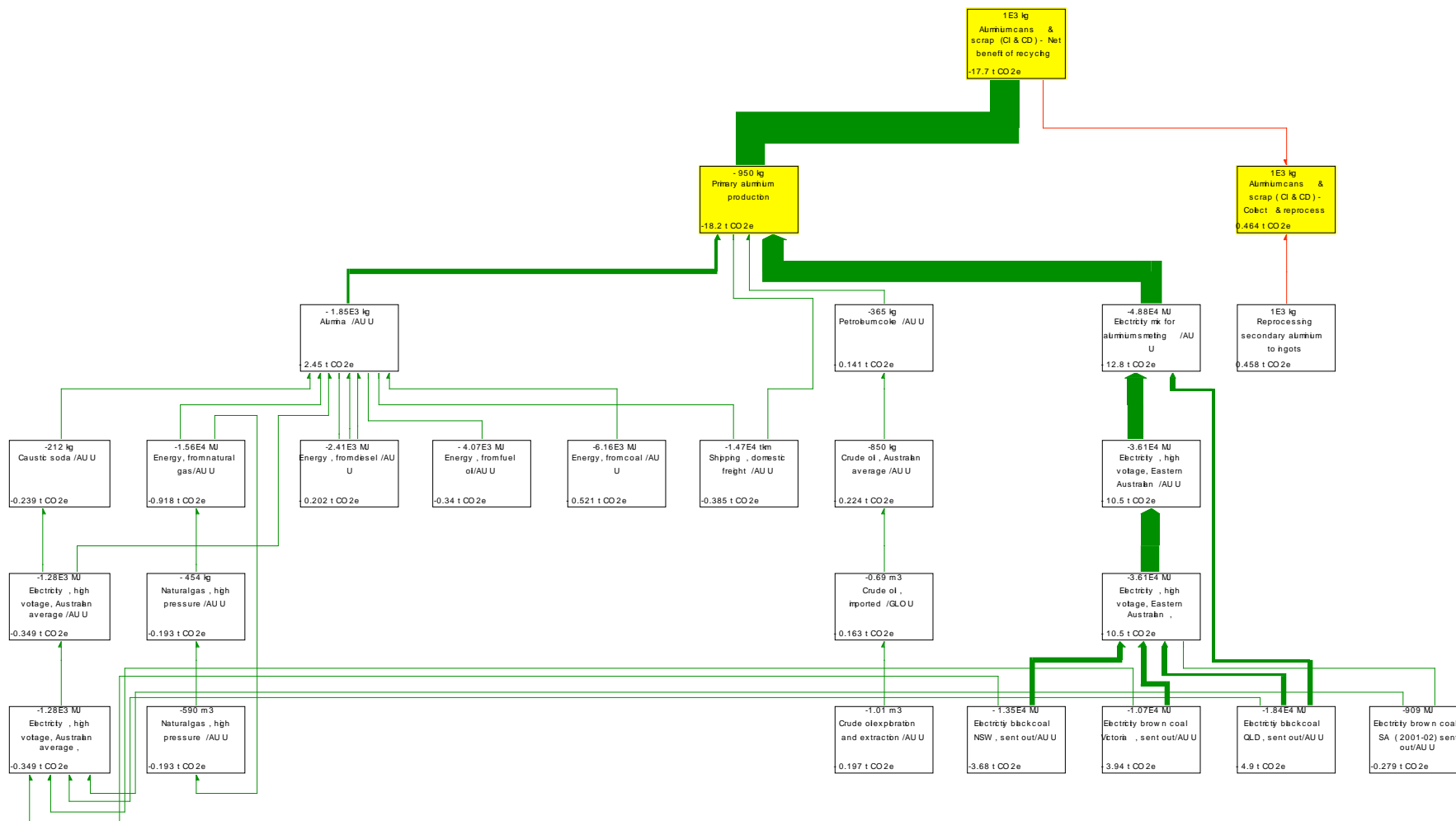


**Figure 6: Kerbside collection — Recycling process network diagram — Solid waste indicator.** Processes contributing less than 1% to total are not shown. Major processes from results table above are shown shaded.

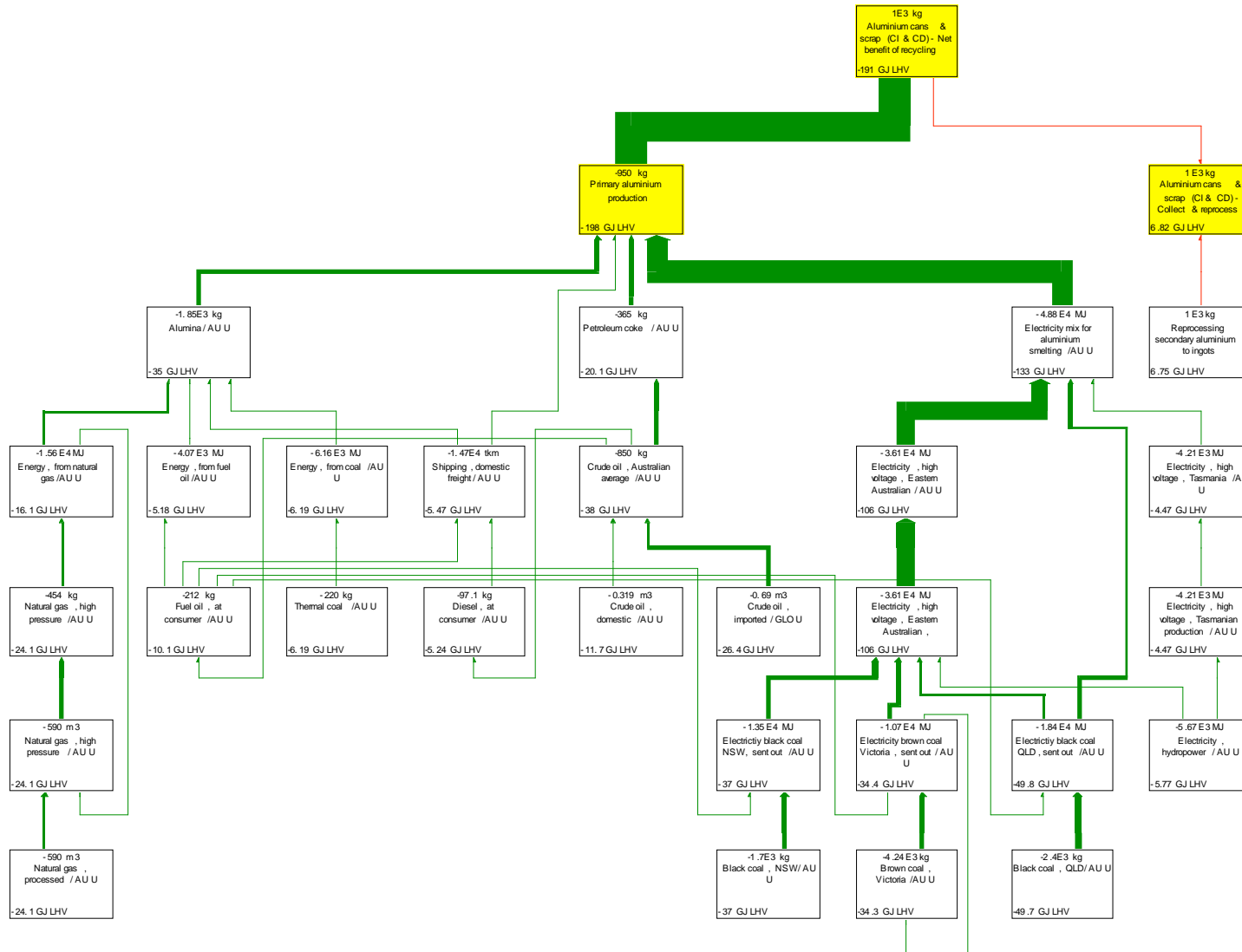


### Network diagrams — C&I and C&D collection

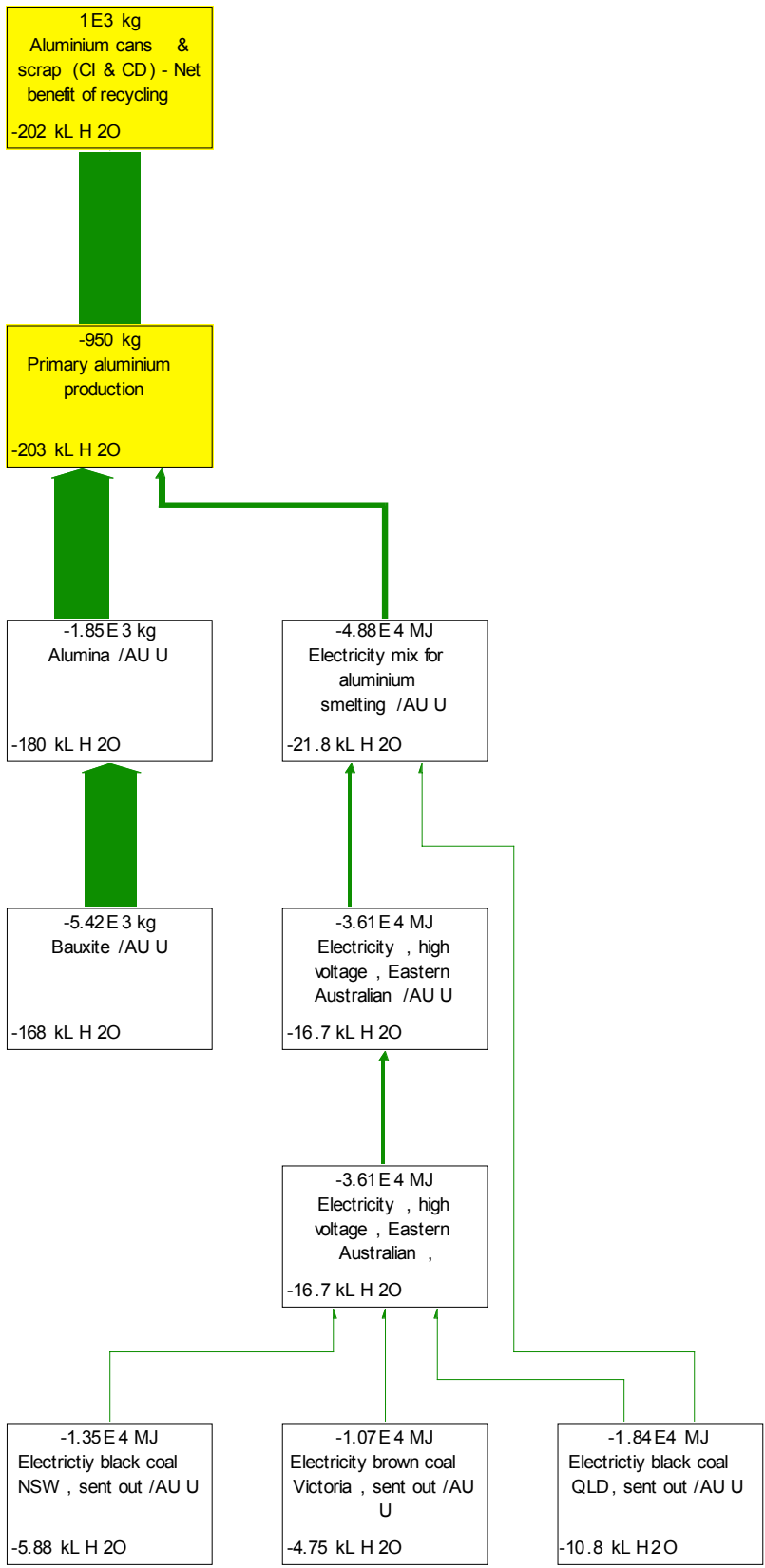
Figure 7: C&I and C&D collection — Recycling process network diagram — Green house gases indicator. Processes contributing less than 1% to total are not shown. Major processes from results table above are shown shaded.



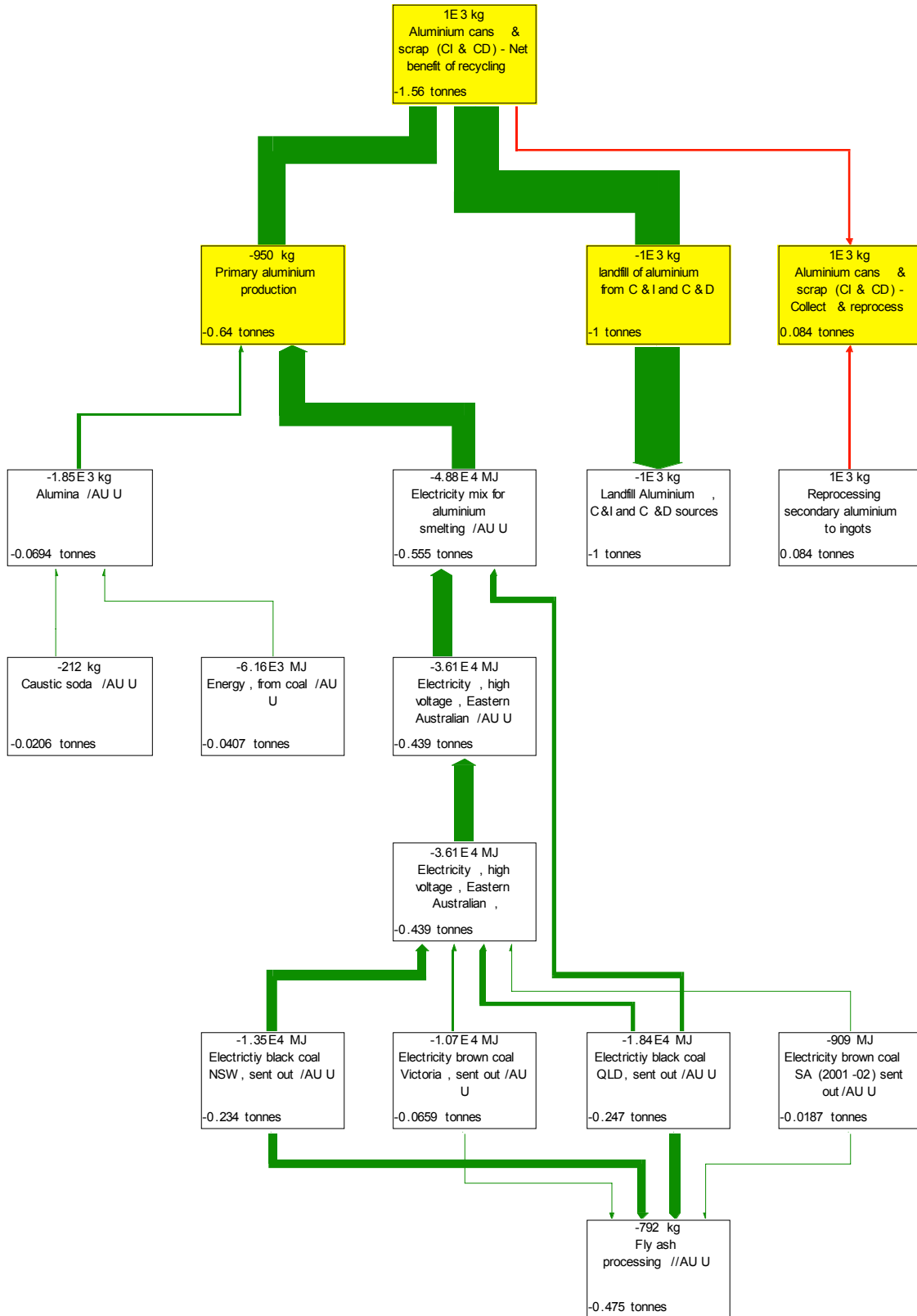
**Figure 8: C&I and C&D collection — Recycling process network diagram — Cumulative energy demand indicator. Processes contributing less than 2% to total are not shown. Major processes from results table above are shown shaded.**



**Figure 9: C&I and C&D collection — Recycling process network diagram — Water indicator.** Processes contributing less than 1% to total are not shown. Major processes from results table above are shown shaded.



**Figure 10: C&I and C&D collection — Recycling process network diagram — Solid waste indicator.** Processes contributing less than 1% to total are not shown. Major processes from results table above are shown shaded.



# Copper

## Process description

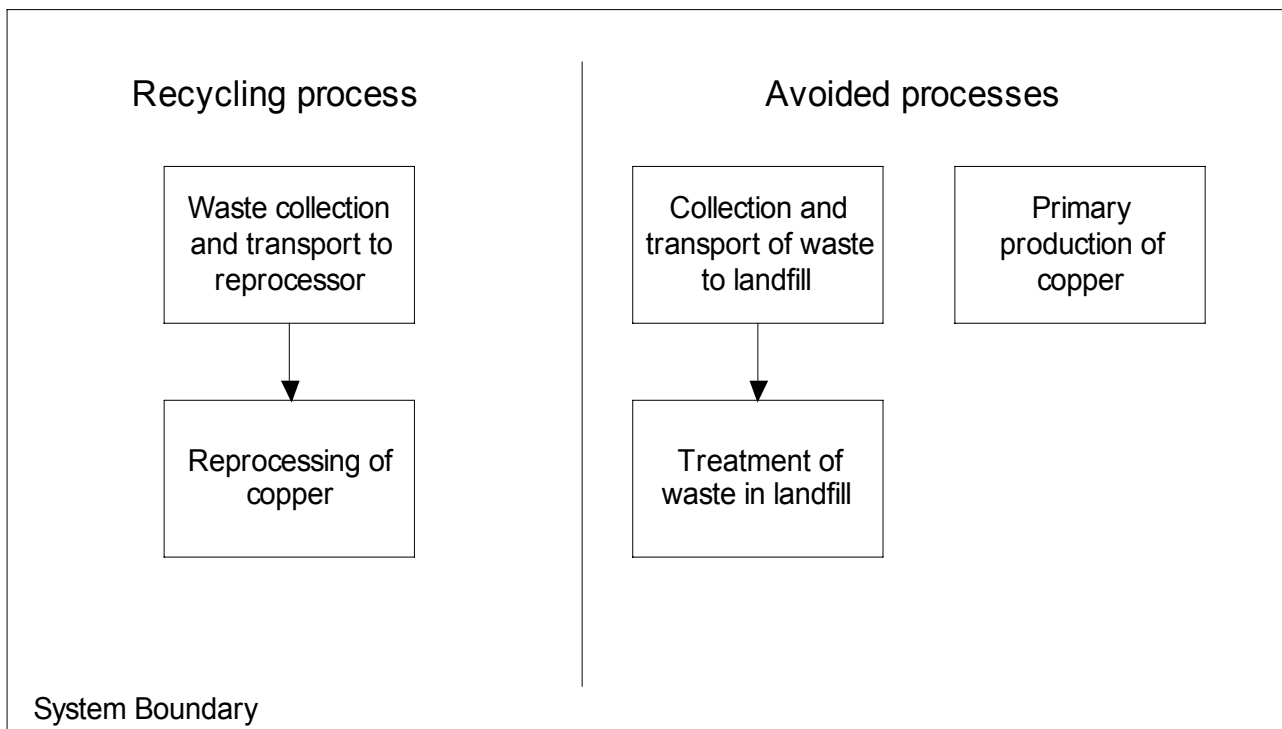
Copper is usually used as a thermal or electrical conductor, a building material or as a constituent of various metal alloys. Reprocessing of copper involves remelting of scrap directly without refining, or re-refining of copper scrap to reduce undesirable impurities (such as solder residues or other contaminants). In this case, copper waste has been used as a substitute for virgin copper.

Only one collection systems for waste copper waste was considered in the model:

C&I and C&D collection — the segregated waste collected is sent directly to the reprocessing site without any sorting process, or associated losses. The model developed takes into account transportation impacts incurred to bring the material from C&I and C&D sources to the material reprocessing facility. Once at the reprocessing facility, the model considers the impacts of material reprocessing required to convert the waste material into secondary copper. Losses associated with this process are included in the analysis.

Figure 11 illustrates the processes considered in determining the overall impact of copper recycling from C&I and C&D sources (shown to the left of the vertical line), and the processes considered in determining the impact of the processes avoided when recycling copper (shown to the right of the vertical line).

**Figure 11: Processes considered in determining the net impacts of the recycling process from C&I and C&D sources.**



## Results

Considering both the recycling process flows and the avoided process flows, described in Figure 11, an inventory of environmental flows was developed. This inventory was then assessed using the Australian Impact Assessment Method, with results described in Table 7.

**Table 7: Benefits and impacts of recycling copper from C&I and C&D sources (per tonne). Benefits are shown negative, impacts are shown positive.**

Impact category	Unit	<u>Recycling process impacts</u> (Figure 10 - left hand side)	<u>Avoided process impacts</u> (Figure 10 - right hand side)			<u>Net benefits of recycling</u>
		Collection and reprocessing	Collection and landfill	Primary material production	Total avoided impacts	
Green house gases	t CO <sub>2</sub>	1.85	-0.01	-5.27	-5.28	-3.43
Cumulative energy demand	GJ LHV	21.24	-0.13	-57.20	-57.34	-36.09
Water use	KL H <sub>2</sub> O	1.79	0.00	-7.76	-7.76	-5.97
Solid waste	tonnes	0.09	-1.00	-0.19	-1.19	-1.10

Network diagrams detailing key processes that influence the impacts listed in Table 7 are shown in Figure 12 to Figure 15. For further information regarding interpretation of network diagrams, refer to Understanding Network Diagrams (Figure 1).

### *Key assumptions*

Table 8 describes the key processes and data sources used to determine the benefits and impacts associated with the collection, recycling and reprocessing of 1 tonne of copper. The table also includes the products and processes avoided when 1 tonne of copper is recycled.



**Table 8: Inventory for recycling copper from C&I and C&D (1 tonne)**

Item	Flow	Unit	Comment
<b>Process flows (Figure 11 – left hand side)</b>			
Waste collection and transport to reprocessor	20	km	20km distance estimate based on a simplified transport analysis for Sydney. Refer appendices for discussion on transport. Emissions from transport based on a trucking model developed from Apelbaum (2001), NGGI (2004) and other sources. Truck backhaul ratio assumed to be 1:2.
Reprocessing of copper	1	tonne	Impacts related to the production of secondary copper from EcoInvent database, adjusted for Australian conditions (energy and materials data have been changed to Australian data).
<b>Avoided process (Figure 11 – right hand side)</b>			
Collection and transport of waste to landfill	20	km	20km distance estimate based on a simplified transport analysis for Sydney, refer appendices for discussion on transport. Emissions from transport based on a trucking model developed by the Centre for Design, incorporating trucking data from Apelbaum (2001), Truck backhaul ratio assumed to be 1:2.
Landfill of copper	1	tonne	Emission factors for total plastics from Tellus (1992). Operation to the landfill from a personal communication with S. Middleton, Pacific Waste, NSW, 1998
Primary production of copper	0.95	tonne	Assumption that recycled ingot produces around 5% less usable metal than virgin ingot production. Energy input from Norgate (2000) Impacts from the production of electricity high voltage in Australia are based on ESAA, 2003 and other sources.

**Data quality table and comment**

Table 9 presents a summary of the data quality for the main processes considered. It shows the data sources used; if they are general data or specific to a company; the age of the data; the geographic location that the data were based on; and, the nature of the technology considered.

**Table 9: Data quality for life cycle inventory data modelled for recycling and landfilling of copper, from C&I and C&D (1 tonne)**

	Primary data source	Geography	Data Age	Technology	Representativeness
Impacts of transportation modes	EcoInvent, NNGI	European data adapted to Australian conditions and Australian data	1997–2005	Average technology	Mixed data
Transportation distances	Estimate	Sydney	2009	Average	Estimate based on simple radial transport model
Production of recycled copper	Adapted from Eco-Invent	European data adapted to Australian conditions	2004	Average	Mixed data
Avoided virgin copper production	Norgate (2000), ESAA (2003)	Australia	2004	Average technology	Average of all suppliers
Avoided landfill impacts	Tellus Institute	Australia	1999	Unspecified	Mixed Data

## References

Electricity Supply Association of Australia (2003), Electricity Australia 2003

National Greenhouse Gas Inventory Committee (2004), National Greenhouse Gas Inventory, with methodology supplements, Australian Greenhouse Office.

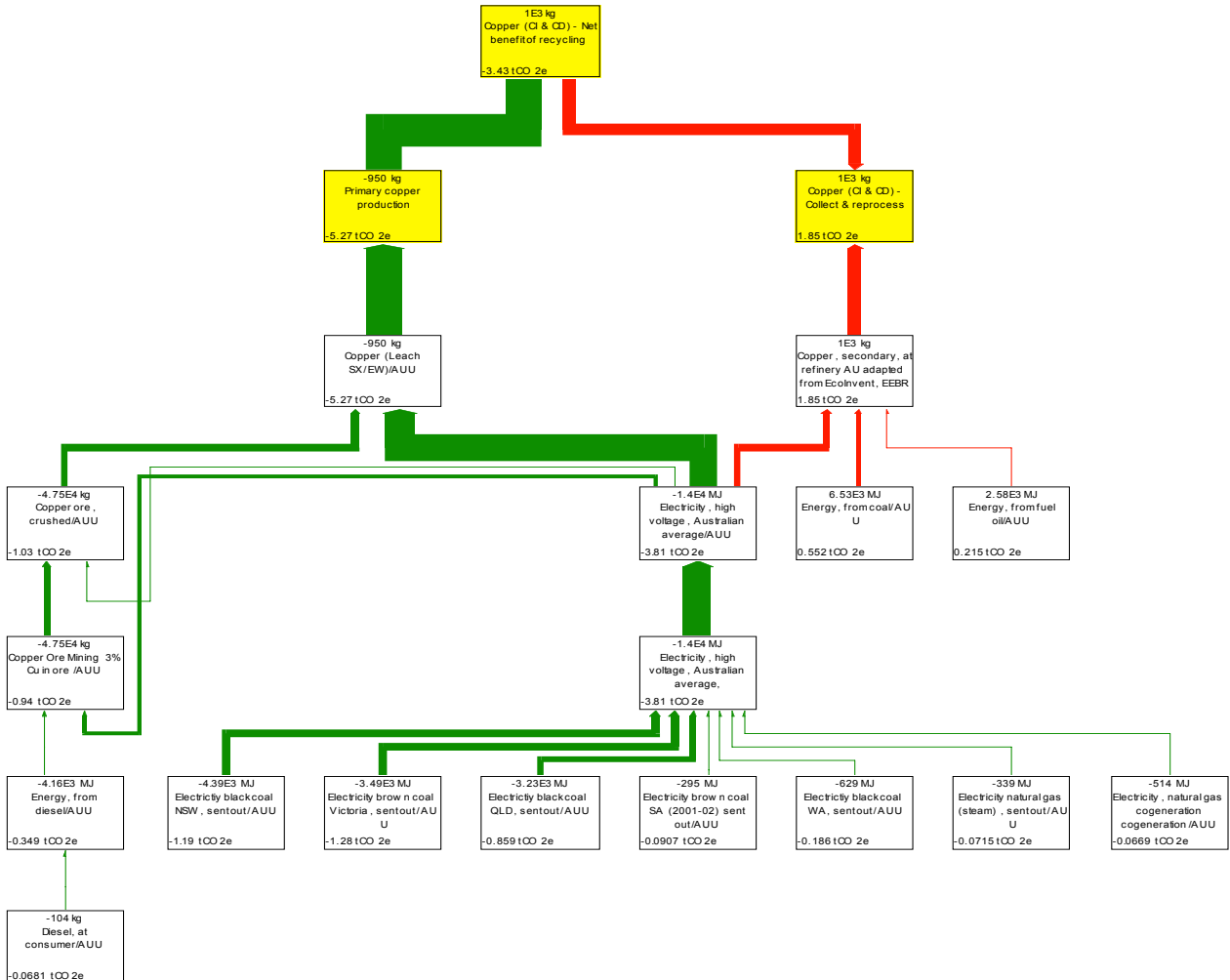
Norgate, T.E., Rankin, W.J. (2000), Life Cycle Assessment of copper and nickel production CSIRO Minerals, Clayton, Victoria, Australia

Swiss Centre for Life Cycle Inventories. (2004). "EcoInvent Database version 1.01." from <http://www.ecoinvent.ch/en/index.htm>

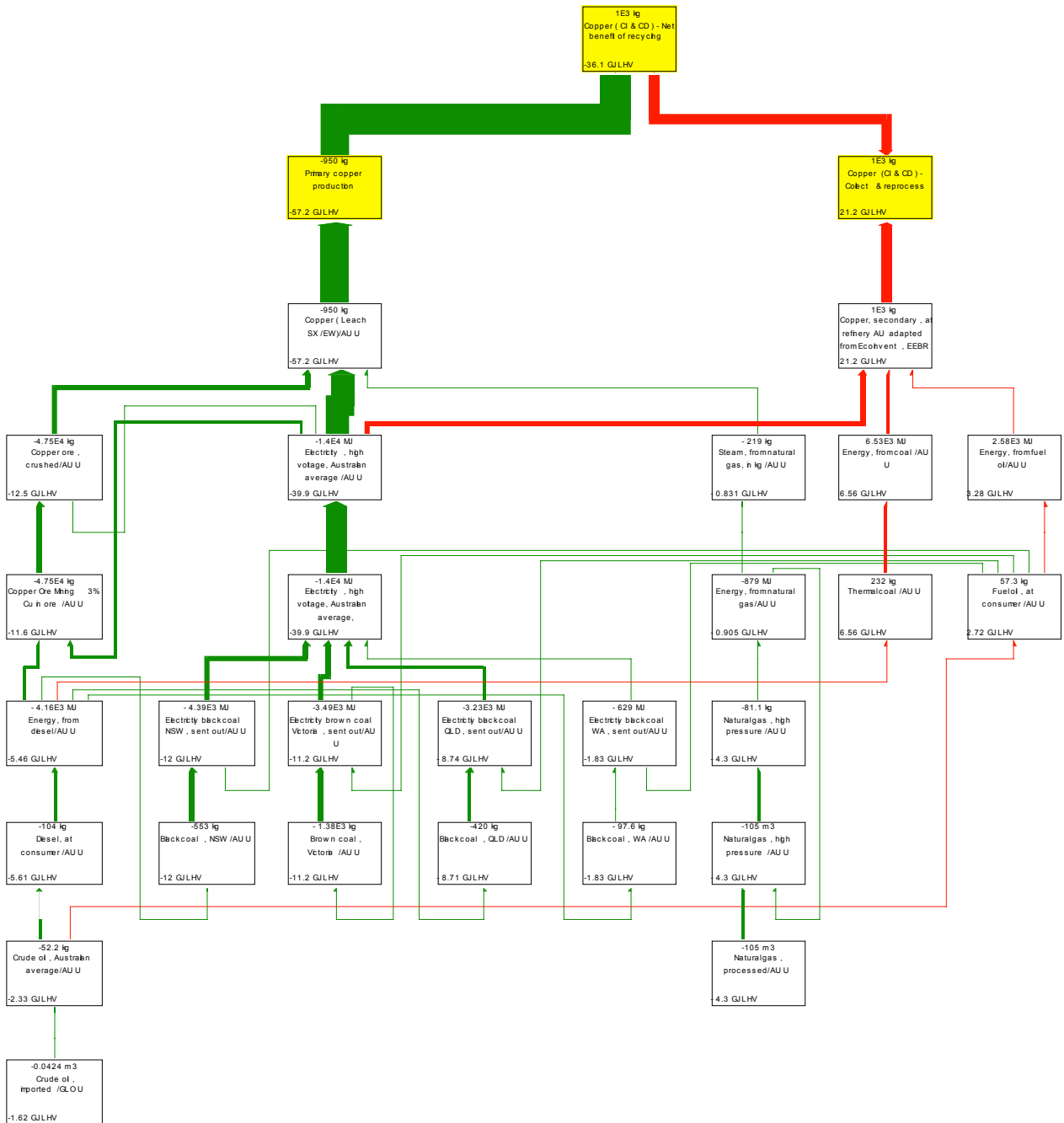
Tellus Packaging Study (1992), Assessing the impacts of production and disposal of packaging and public policy measure to alter its mix, Tellus Institute, USA

## Network diagrams — C&I and C&D collection

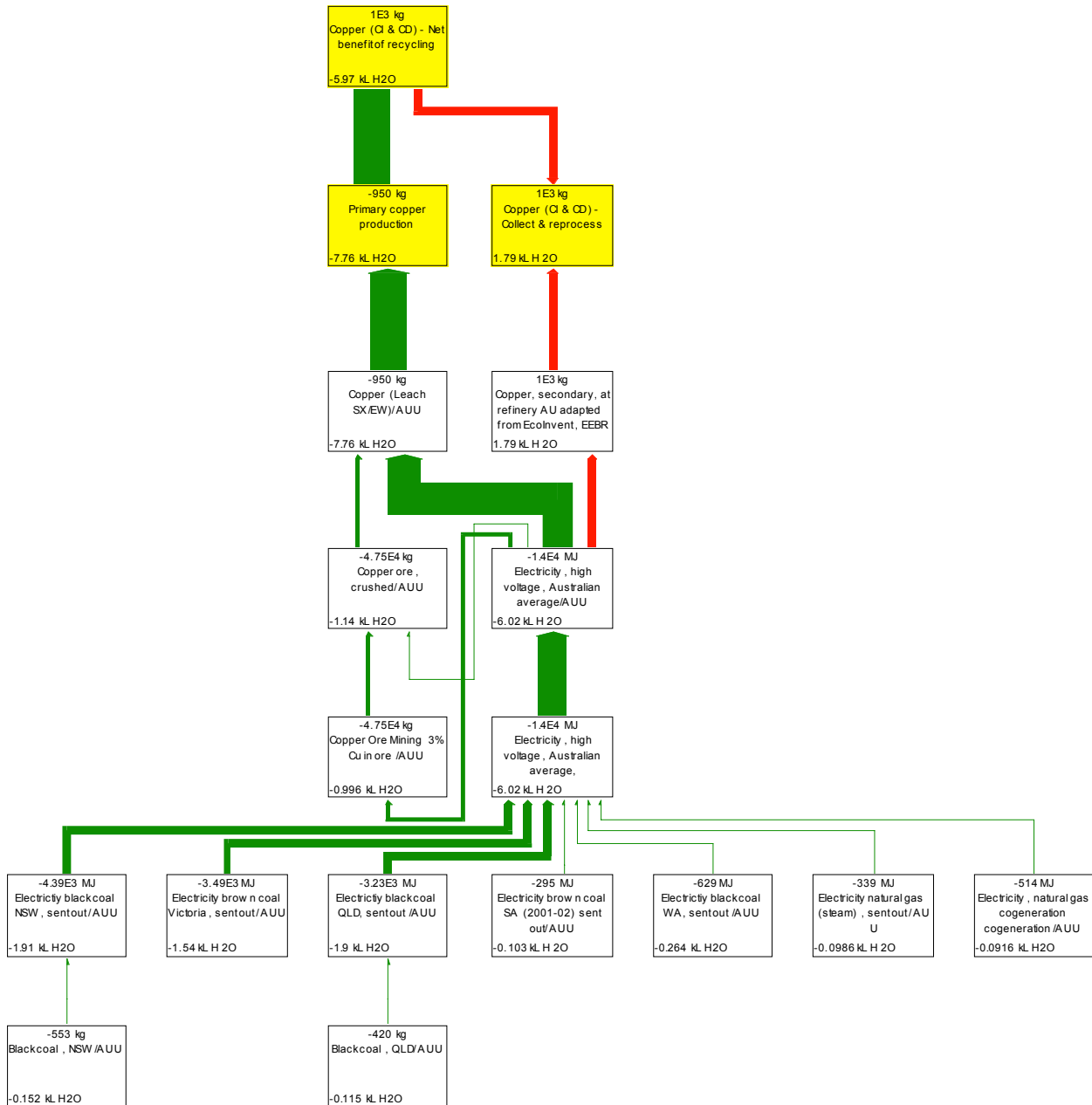
Figure 12: Recycling process network diagram — Green house gases indicator. Processes contributing less than 1% to total not shown. Major processes from results table above are shown shaded.



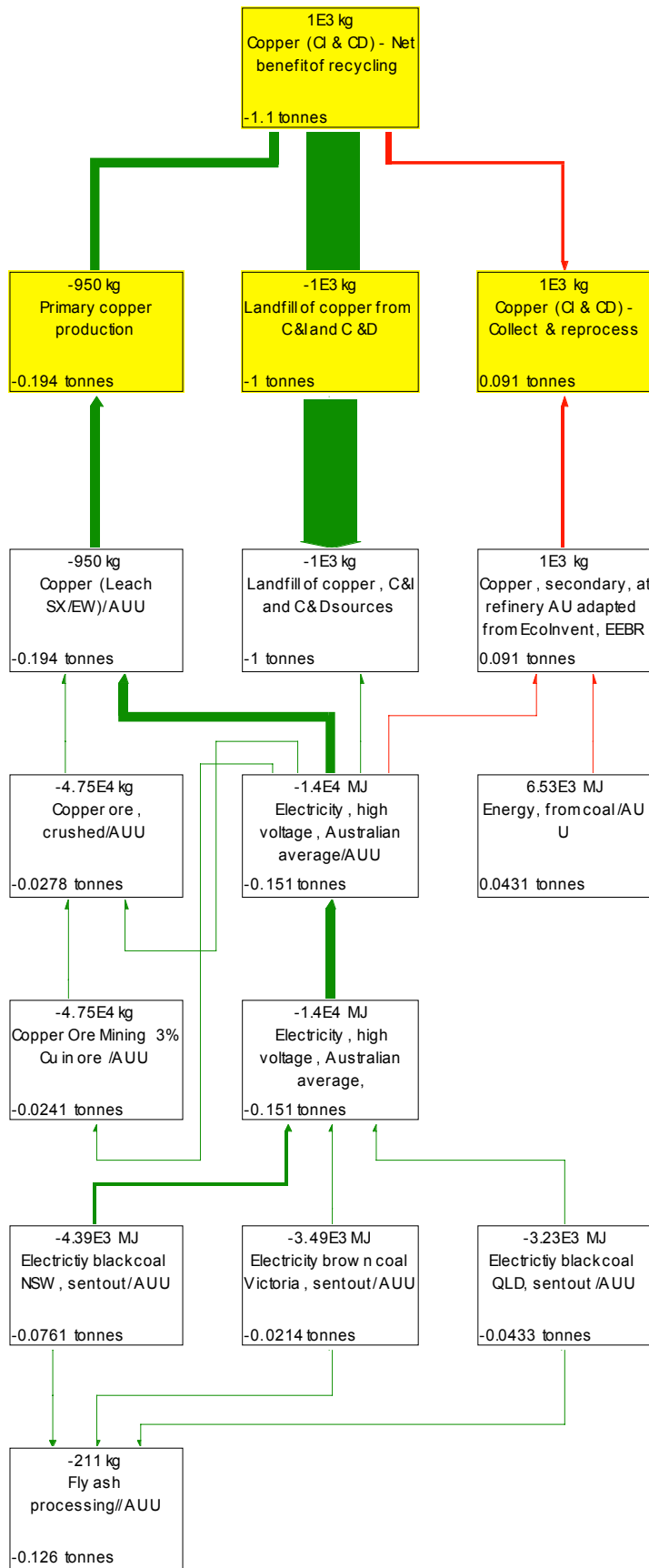
**Figure 13: Recycling process network diagram — Cumulative energy demand indicator. Processes contributing less than 2.5% to total are not shown. Major processes from results table above are shown shaded.**



**Figure 14: Recycling process network diagram — Water indicator. Processes contributing less than 1% to total are not shown. Major processes from results table above are shown shaded.**



**Figure 15: Recycling process network diagram — Solid waste indicator. Processes contributing less than 1% to total are not shown. Major processes from results table above are shown shaded.**



## Steel packaging cans and scrap

### *Process description*

Steel packaging cans and steel scrap are both considered in this inventory. Reprocessing is assumed to be undertaken in a similar fashion for both cans and scrap; however collection is assumed to differ for each form (cans being sourced from municipal waste, whereas scrap tends to come from C&I and C&D sources only).

Steel is an alloy, mostly constituted of iron (more than 95%), with other alloying elements such as carbon, manganese, or chromium. Steel tin-plate cans are composed of steel, covered by a layer of tin on both sides, then a layer of lacquer inside. The three-piece can, which consists of “a body having a welded seam in conjunction with two end components”, is the most common steel can type (Kraus, 1997). When recycled, steel can be reprocessed via either a Blast Furnace-Basic Oxygen Furnace (BF-BOF) or in an electric arc furnace (EAF). In this assessment it is assumed that the EAF process of a local steel reprocessor will dominate as a reprocessing destination (as EAF furnaces are typically co-located with population centres). It is assumed that the reprocessing of steel is undertaken at BHP Woollongong NSW.

Steel is also widely used in construction, e.g. to produce the steel skeleton of many modern structures (stadium, skyscrapers, etc), and in many other applications. Once collected, processing is assumed to be similar as steel packaging cans, and is undertaken at the BHP Woollongong, NSW facility.

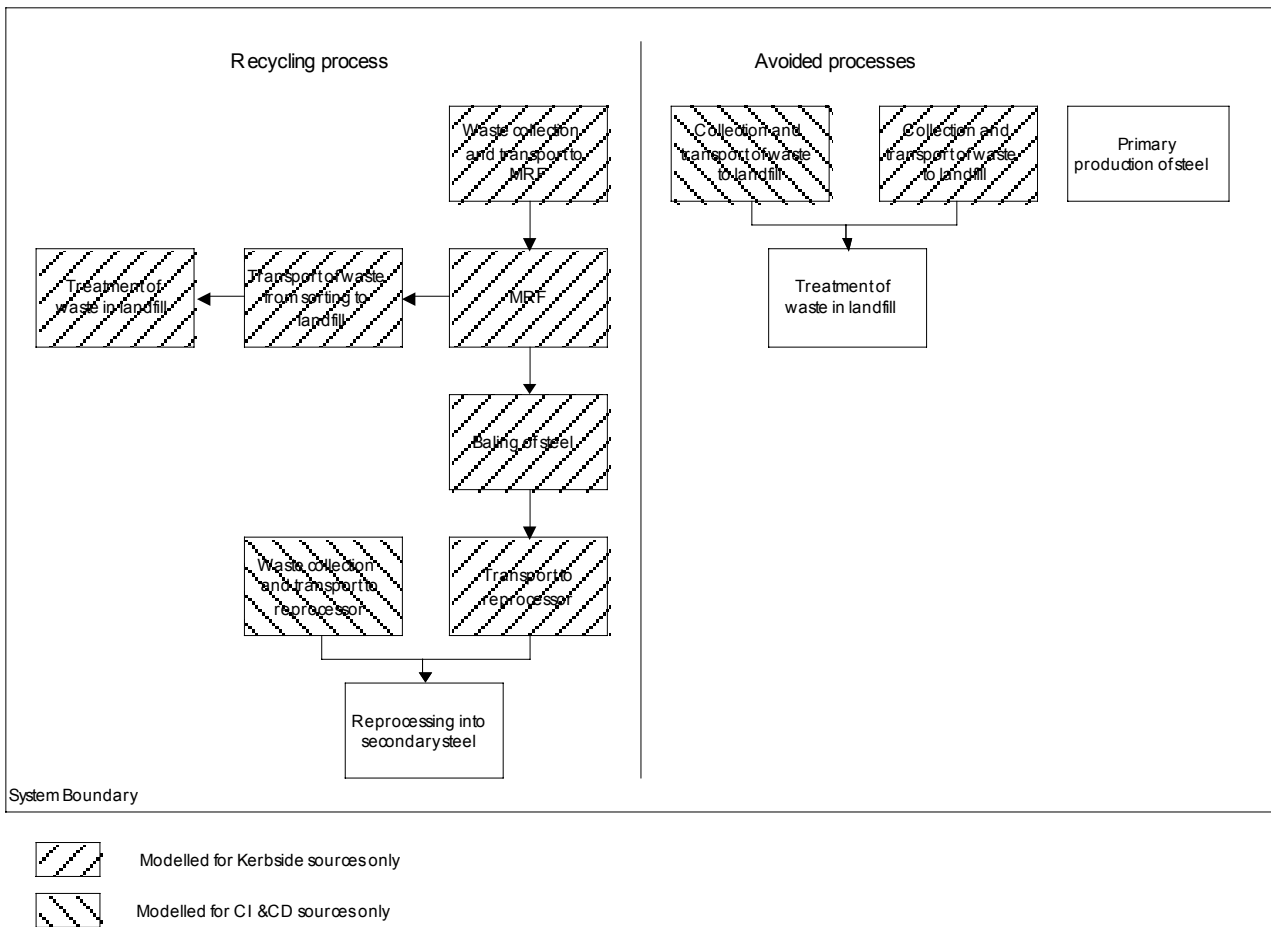
#### **Two collection systems for waste steel were considered in the model:**

- A) Kerbside collection — municipal collection of steel packaging cans in commingled waste from households, and processing through a Materials Recovery Facility (MRF)
- B) C&I and C&D collection — direct transfer of steel scrap from point of waste generation to a reprocessing facility.

The unique nature of each collection system drives differences in the impacts associated with steel recycling. For this reason the steel recycling processes considered and impacts generated have been described separately in the following sections, according to the collection method used.

Figure 16 illustrates the processes considered in determining the overall impact of steel packaging can recycling from kerbside sources and steel scrap from C&I and C&D sources (shown to the left of the vertical line), and the processes considered in determining the overall impact of the avoided processes (shown to the right of the vertical line).

**Figure 16: Processes considered in determining the net impacts of the recycling process from kerbside and CI&CD sources.**



## A) Kerbside collection system

### *Processes considered*

The kerbside collection system involves collection of waste for recycling from the kerbside and transport to a Materials Recovery Facility (MRF), which sorts the commingled materials in the recycling stream. The model developed takes into account transportation impacts as well as sorting impacts incurred to bring the material from the kerbside to the material reprocessing facility. During sorting, waste material is generated and transported to landfill. Once at the reprocessing facility, the model considers the impacts of material reprocessing required to convert the waste material into secondary steel. Losses associated with this process are included in the analysis. The kerbside treatment system is illustrated in Figure 16 (processes unique to kerbside processing are shaded accordingly).

In order to determine the benefit or impact of recycling a material, it is necessary to consider the processes avoided when recycling is undertaken, as well as the processes associated with recycling. Figure 16 also illustrates the processes that would be avoided if waste steel cans are recycled. Two main processes are considered; the collection and disposal to landfill of waste steel cans from the kerbside; and the primary manufacture of steel from virgin resources.



## Results

Considering both the recycling process flows and the avoided process flows, described in Figure 16, an inventory of environmental flows was developed. This inventory was then assessed using the Australian Impact Assessment Method, with results described in Table 10.

**Table 10: Benefits and impacts of recycling steel cans from kerbside sources (per tonne). Benefits are shown negative, impacts are shown positive.**

Impact category	Unit	Recycling process impacts (Figure 15 - left side)	Avoided process impacts (Figure 15 - right side)			Net benefits of recycling
		Collection, sorting and reprocessing	Collection and landfill	Primary material production	Total avoided impacts	
Green house gases	t CO <sub>2</sub>	1.24	-0.13	-1.50	-1.64	-0.40
Cumulative energy demand	GJ LHV	13.72	-1.92	-19.12	-21.04	-7.31
Water use	kL H <sub>2</sub> O	1.62	-0.02	0.68	0.67	2.29
Solid waste	tonnes	0.23	-0.99	-0.20	-1.18	-0.95

Network diagrams detailing key processes that influence the impact listed in Figure 16 are shown in Figure 17 to Figure 24. For further information regarding interpretation of network diagrams, refer to Understanding Network Diagrams (Figure 1).

## Key assumptions

Table 11 describes the key processes and data sources used to determine the benefits and impacts associated with the collection, recycling and reprocessing of 1 tonne of packaging steel can. The table also includes the products and processes avoided when 1 tonne of packaging steel can is recycled.

**Table 11: Inventory for recycling steel cans, kerbside source (1 tonne)**

Item	Flow	Unit	Comment
<b>Recycling process flows (Figure 16 – left hand side)</b>			
Waste collection and transport to MRF	11	m <sup>3</sup>	Based on the assumption of 10 m <sup>3</sup> /tonne plus 1 m <sup>3</sup> /tonne for other material collect with it by disposed at MRF Transport model for kerbside collection based on Grant (2001), refer appendices for discussion on transport. Emission of the truck from NGGIC (1997)
Sorting at Material Recovering Facility (MRF)	11	m <sup>3</sup>	Based on the assumption of 10 m <sup>3</sup> /tonne plus 1 m <sup>3</sup> /tonne for other material collect with it by disposed at MRF Energy inputs from Nishtala (1997) and estimated from equipment specifications
Baling of steel	0.95	tonne	5% is assumed to be lost at MRF. Electricity inputs from Nishtala (1997), 12kWh per tonne.
Transport from MRF to reprocessor	20	km	20km is used as a default value for transport. Refer discussion below Emissions from transport based on a trucking model from Apelbaum (2001)
Reprocessing into secondary steel	0.95	tonne	950kg of steel waste input is estimated to generate 910 kg of reprocessed steel output (equivalent to virgin steel production). Emission data from the production of steel through electric arc furnace from NPI. Input data from Strezov (2006). Estimated electricity consumption: 1.05 kWh per tonne, 0.05 kg liquid oxygen per tonne, 0.05 kg of calcined lime per tonne and 0.014 kg of black coal per tonne.
Transport of waste from sorting to landfill	20	km	Emissions from transport based on an articulated truck, 28 tonne load on 30 tonne truck. Trucking model developed from data provided by Apelbaum (2001).
Treatment of waste in landfill	50	kg	Assumption of 5% recycling reject from MRF treated in landfill Emission factors for steel disposal from a personal communication with Sydney Water Residual Group, 1998, and Finnveden (1996). Operation to the landfill from a personal communication with S. Middleton, Pacific Waste, NSW, 1998.
<b>Avoided process flows (Figure 16 – right hand side)</b>			
Collection and transport of waste to landfill	11	m <sup>3</sup>	Waste collection avoided by sending material to MRF above. Transport model for kerbside collection based on Grant (2001b); refer appendices for discussion on transport. Emission of the truck from Apelbaum (2001), NGGIC (1997) and other sources.
Treatment of waste steel in landfill	1	tonne	Emission factors for steel disposal from a personal communication with Sydney Water Residual Group, 1998, and Finnveden (1996). Operation to the landfill from a personal communication with S. Middleton, Pacific Waste, NSW, 1998.
Primary production of steel	0.91	tonne	Assumption of 50kg loss at MRF and 40kg loss at reprocessing facility, so 0.91 tonne of steel waste is reprocessed, thereby avoiding 0.91t of virgin steel production. Input data from BHP (2000), and other sources. Emission data from NGGIC (1995) and NPI (2002–2003).

### *Data Quality table and comment*

Table 12 presents a summary of the data quality for the main processes considered. It shows the data sources used; if they are general data or specific to a company; the age of the data; the geographic location that the data were based on; and, the nature of the technology considered.

**Table 12: Data quality for life cycle inventory data modelled for recycling and landfilling of packaging steel cans, kerbside source (1 tonne)**

	<b>Primary source data</b>	<b>Geography</b>	<b>Data Age</b>	<b>Technology</b>	<b>Representativeness</b>
Impact of transportation modes	EcoInvent, NGGI, Apelbaum	European data adapted to Australian conditions and Australian data	1997–2005	Average technology	Mixed data
Recycling steel	Strezov (2006), NPI	Average	2000–2004	Average technology	Mixed data
Avoided steel production	BHP (2000)	Australia	2004	Average technology	Data from a specific process and company
Avoided landfill impacts	Finnveden (1996)	Australia	1995–1999	Unspecified	Unspecified

## **B) C&I and C&D collection system**

### *Processes considered*

In the case of the C&I and C&D collection system, it has been assumed that segregated waste collected is sent directly to the reprocessing site without any sorting process, or associated losses. The model developed takes into account transportation impacts incurred to bring the material from C&I and C&D sources to the material reprocessing facility.

Once at the reprocessing facility, the model considers the impacts of material reprocessing required to convert the waste material into secondary steel. Losses associated with this process are included in the analysis. The model also illustrates the processes considered in determining the impact of the processes avoided when recycling steel from C&I and C&D sources. Three main processes are considered, the collection of steel scrap waste and landfill treatment, and the primary manufacture of steel from virgin resources. The system is described in Figure 16 (processes unique to C&I, C&D collection have been shaded accordingly).

### *Results*

Considering both the recycling process flows and the avoided process flows, described in Figure 16, an inventory of environmental flows was developed. This inventory was then assessed using the Australian Impact Assessment Method, with results described in Table 13.

**Table 13: Benefits and impacts of recycling steel scrap waste from C&I and C&D sources (per tonne). Benefits are shown negative, impacts are shown positive.**

Impact category	Unit	<u>Recycling process impacts</u> (Figure 15 - left side)	<u>Avoided process impacts</u> (Figure 15 - right side)			<u>Net benefits of recycling</u>
		Collection, sorting and reprocessing	Collection and landfill	Primary material production	Total avoided impacts	
Green house gases	t CO <sub>2</sub>	1.14	-0.01	-1.57	-1.58	-0.44
Cumulative energy demand	GJ LHV	12.15	-0.13	-19.96	-20.09	-7.94
Water use	kL H <sub>2</sub> O	1.65	0.00	0.71	0.71	2.36
Solid waste	tonnes	0.20	-0.99	-0.21	-1.19	-1.00

Network diagrams detailing key processes that influence the impact listed in Table 13 are shown in Figure 17 to Figure 24. For further information regarding interpretation of network diagrams, refer to Understanding Network Diagrams (Figure 1).

### Key assumptions

Table 14 describes the key processes and data sources used to determine the benefits and impacts associated with the collection, recycling and reprocessing of 1 tonne of steel scrap. The table also includes the products and processes avoided when 1 tonne of steel is recycled.

**Table 14: Inventory for recycling of steel waste from C&I and C&D source (1 tonne)**

Item	Flow	Unit	Comment
<b>Process flows (Figure 16 — left hand side)</b>			
Waste collection and transport to reprocessor	20	km	20km distance estimate based on a simplified transport analysis for Sydney. Refer appendices for discussion on transport. Emissions from transport based on a trucking model adapted from Ecolnvent and NGGI (2004), Truck backhaul ratio assumed to be 1:2.
Reprocessing into secondary steel	1	tonne	Recycling steel produce 5% less usable metal, so reprocessing 1 tonne of waste steel ends up with 0.95 tonne of reprocessed steel outputs. Emission data from the production of steel through electric arc furnace from NPI, input data fom Strezov (2006). Estimated electricity consumption: 1.05 kWh per tonne, 0.05 kg liquid oxygen per tonne, 0.05 kg of calcined lime per tonne and 0.014 kg of black coal per tonne.
<b>Avoided process (Figure 16 — right hand side)</b>			
Collection and transport of waste to landfill	20	km	Waste collection avoided by sending material to MRF above. Transport model for kerbside collection based on Grant (2001b); refer appendices for discussion on transport. Emission of the truck from Apelbaum (2001), NGGIC (1997) and other sources.
Treatment of steel waste in landfill	1	tonne	Emission factors for steel disposal from a personal communication with Sydney Water Residual Group, 1998, and Finnveden (1996) Operation to the landfill from a personal communication with S. Middleton, Pacific Waste, NSW, 1998
Primary production of steel	0.95	tonne	Recycling steel produce around 5% less usable metal. Therefore, for 1t reprocessed, 950kg of steel is produced thereby avoiding 950kg of virgin steel production. Input data from BHP (2000), and other sources Emission data from NGGIC (1995) and NPI (2002–2003)

### *Data quality table and comment*

Table 15 describes the key processes and data sources used to determine the benefits and impacts associated with the collection, recycling and reprocessing of 1 tonne of scrap steel. The table also includes the products and processes avoided when 1 tonne of scrap steel is recycled.

**Table 15: Data quality for life cycle inventory data modelled for recycling and landfilling of scrap steel, C&I and C&D source (1 tonne)**

	Primary data source	Geography	Data Age	Technology	Representativeness
Impact of transportation modes	Ecolnvent, NGGI	European data adapted to Australian conditions and Australian data	1997–2005	Average technology	Mixed data
Transportation distances	Estimate	Sydney	2009	Average	Estimate based on simple radial transport model
Recycling steel	ETH-ESU (1996), BHP (2000)	Australia	2000–2004	Average technology	Mixed data
Avoided virgin steel production	BHP (2000)	Australia	2004	Average technology	Data from a specific process and company
Avoided landfill impacts	Finnveden (1996)	Australia	1995–1999	Unspecified	Unspecified

## *References*

- Apelbaum Consulting Group (2001), Australian Transport facts 2001 Tables in Excel Format, Blackburn, Victoria.
- BHP Minerals (2000), LCA of steel and Electricity Production — ACARP Project C8049 — Case Studies B Summary of Inventory Values for Electricity Production, Newcastle
- DEH (2004), National Pollutant Inventory Data for year 2002, Department of Environment, Canberra.
- Finnveden, G., (1996), Solid waste treatment within the framework of life cycle assessment — metals in municipal solid waste landfills. *Int J LCA* 1, pp 74–78
- Frischknecht et al (1996), Öko-inventare von Energiesystemen, 3rd edition (german language only), ETH-ESU
- Grant, T., James, K.L., Lundie, S., Sonneveld, K., Beavis, P. (2001), Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in New South Wales, NSW Environment Protection Authority, Sydney
- Kraus, F.J., Tarulis, G.J. (1997), Cans, Steel, *The Wiley Encyclopedia of Packaging Technology*, A.L. Brody and K.S. Marsh, New York, Wiley and Sons: pp150
- National Greenhouse Gas Inventory Committee (1997), National Greenhouse Gas Inventory 1995 with Methodology Supplement, Environment Australia, Canberra Australia
- National Greenhouse Gas Inventory Committee (2004), National Greenhouse Gas Inventory, with methodology supplements, Australian Greenhouse Office.
- Nishtala, S., Solano-Mora, E., (1997), Description of the Material Recovery Facilities Process Model: Design, Cost, and Life-Cycle Inventory, Research Triangle Institute and North Carolina State University
- Strezov, L., Herbertson, J. (2006), A life cycle perspective on steel building materials. Sydney, Australian Steel Institute
- Swiss Centre for Life Cycle Inventories. (2004). "Ecolnvent Database version 1.01." from <http://www.ecoinvent.ch/en/index.htm>
- Wang, F. (1996). Solid Waste Integrated Management Model. PhD Thesis in the Department of Chemical and Metallurgical Engineering. Melbourne, RMIT.



**Figure 18: Recycling process network diagram — Cumulative energy demand indicator. Processes contributing less than 4% to total are not shown. Major processes from results table above are shown shaded.**

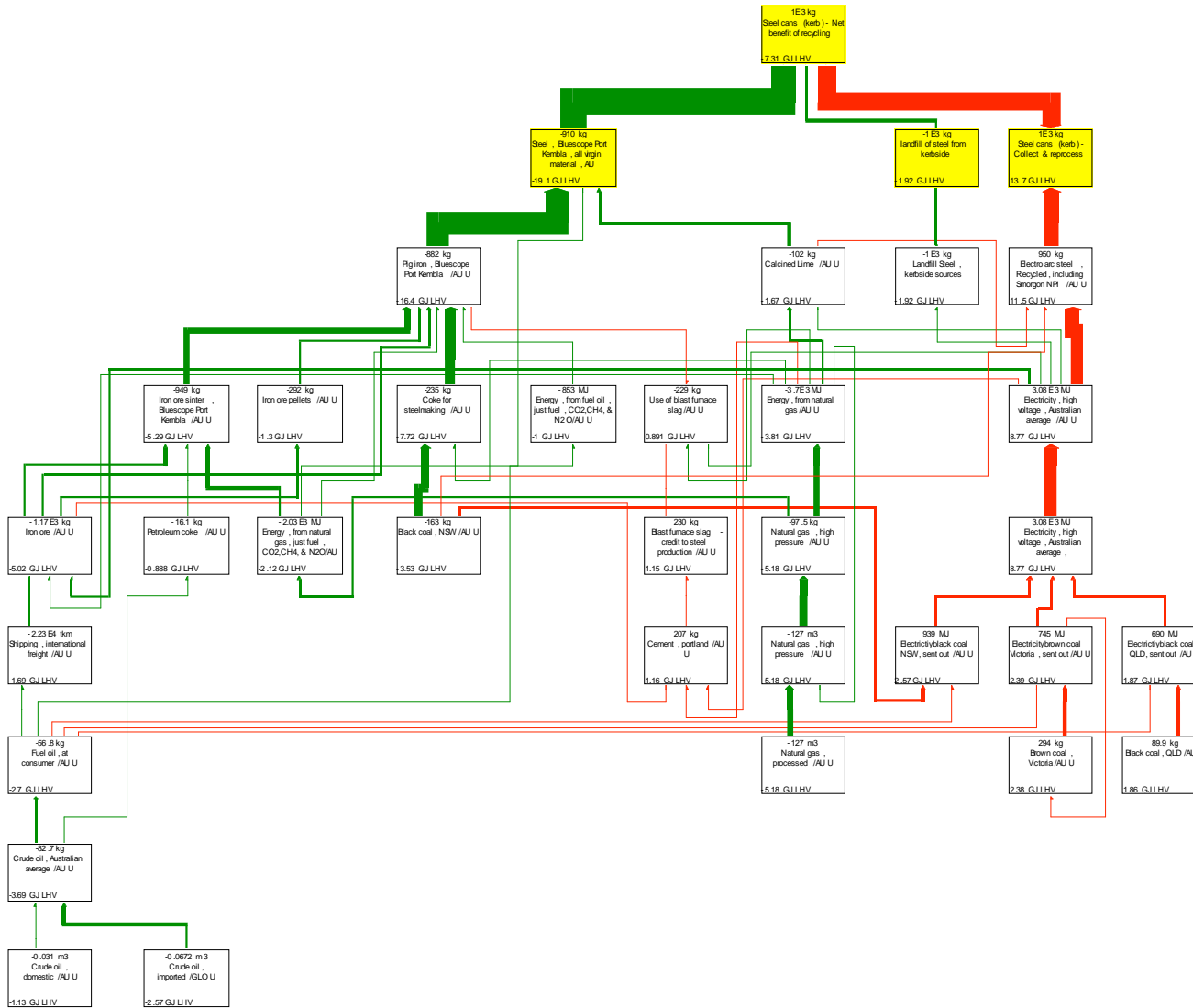
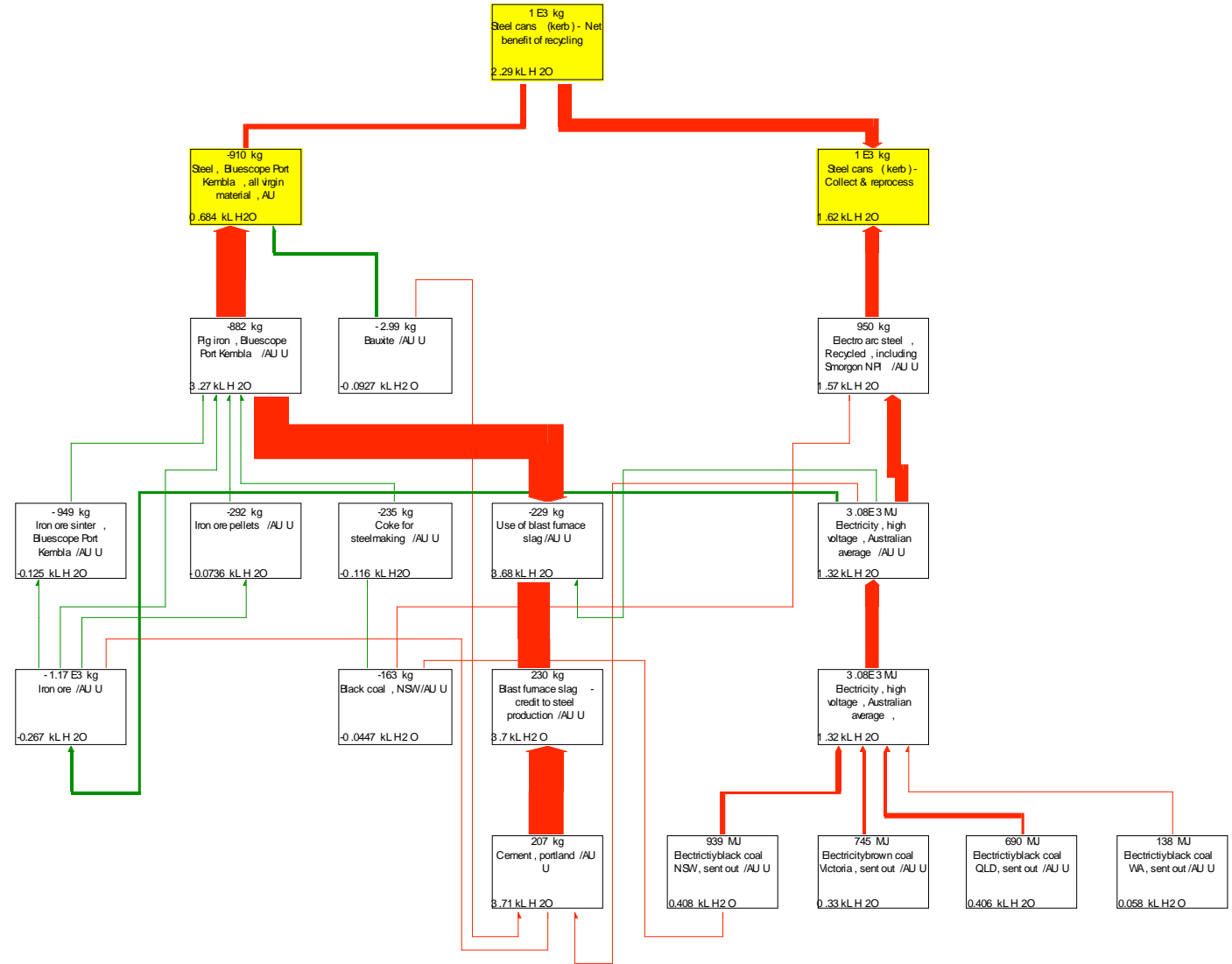
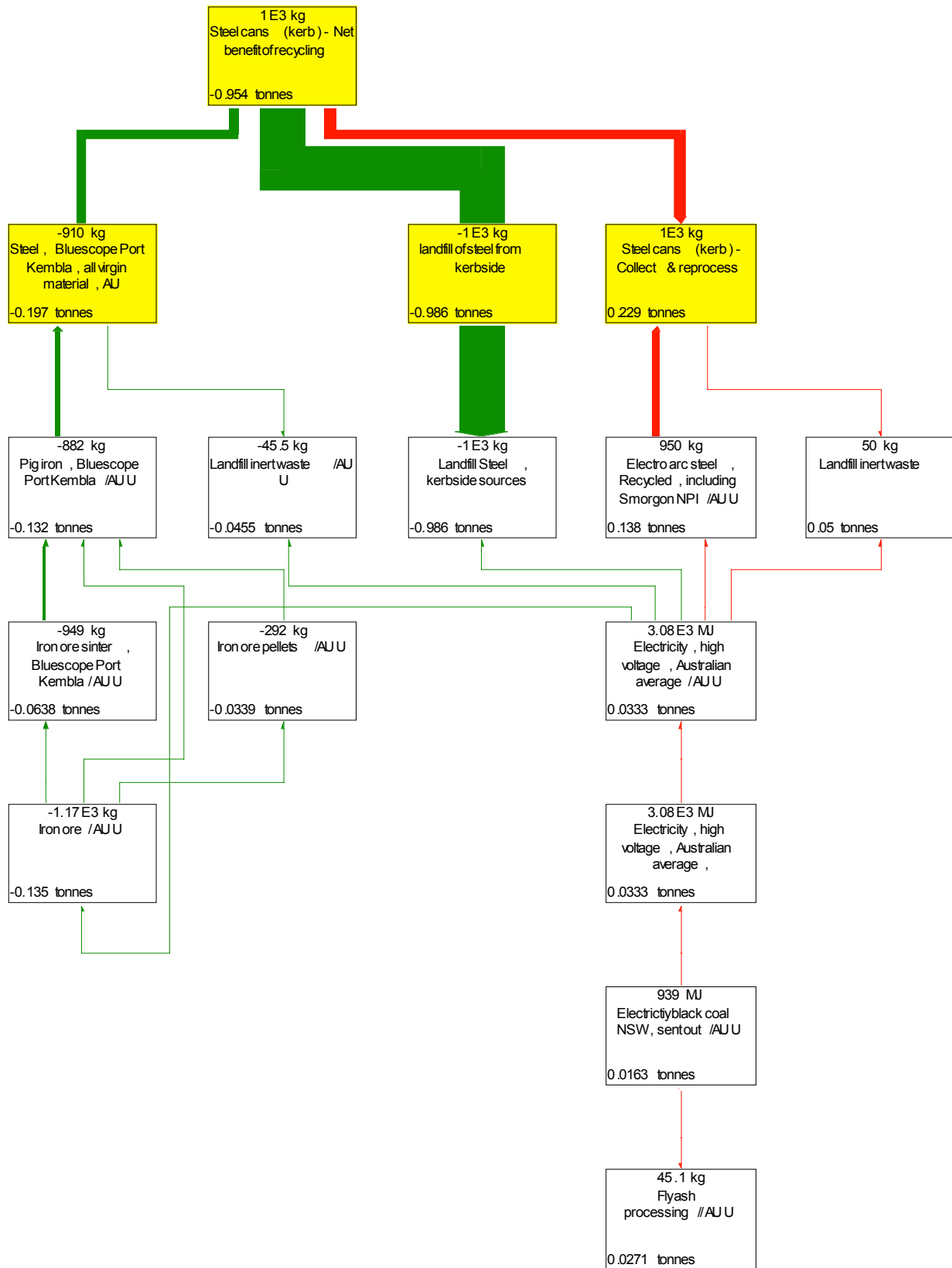


Figure 19: Recycling process network diagram — Water indicator. Processes contributing less than 1% to total are not shown. Major processes from results table above are shown shaded.



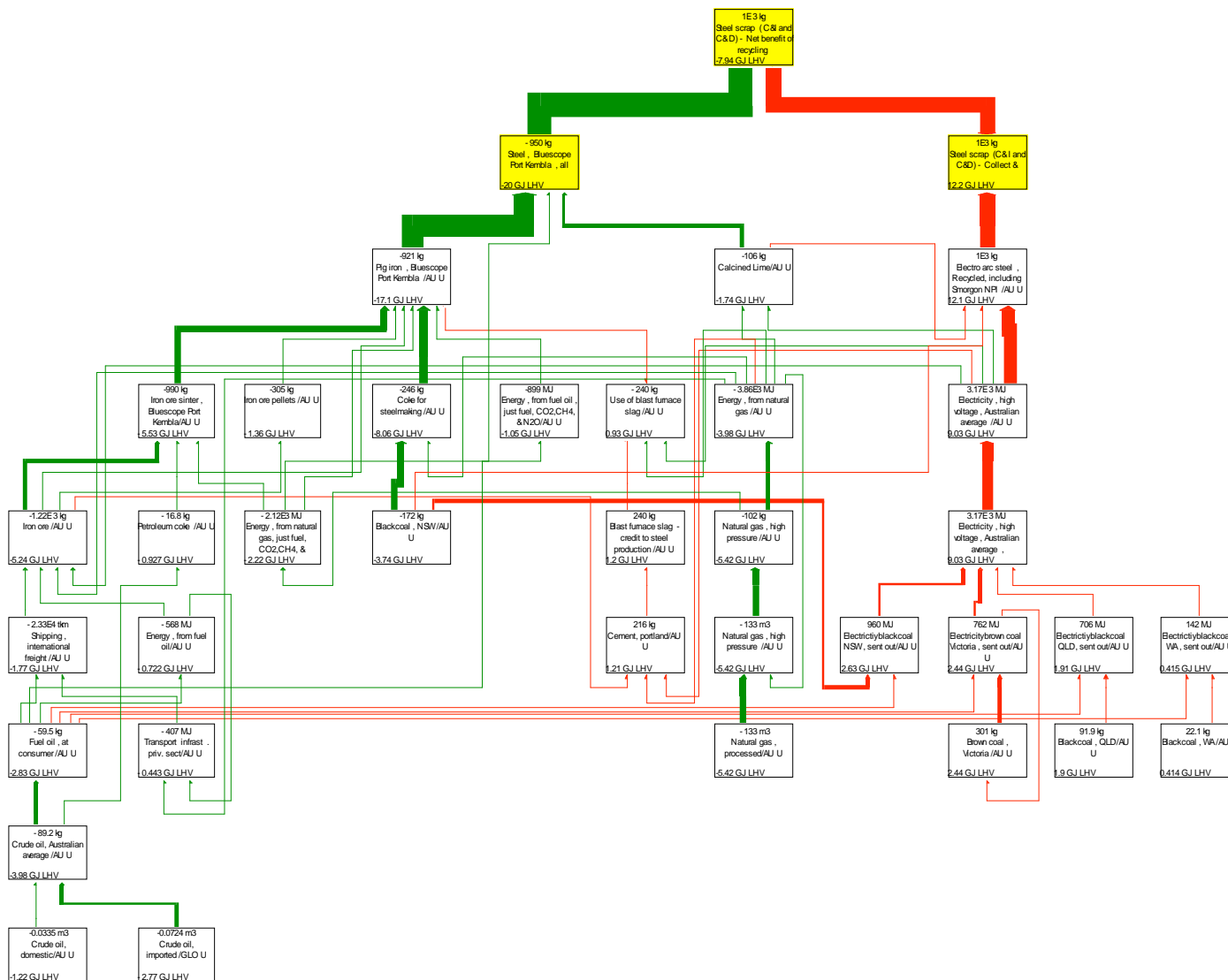


**Figure 20: Recycling process network diagram — Solid waste indicator. Processes contributing less than 1% to total are not shown. Major processes from results table above are shown shaded.**

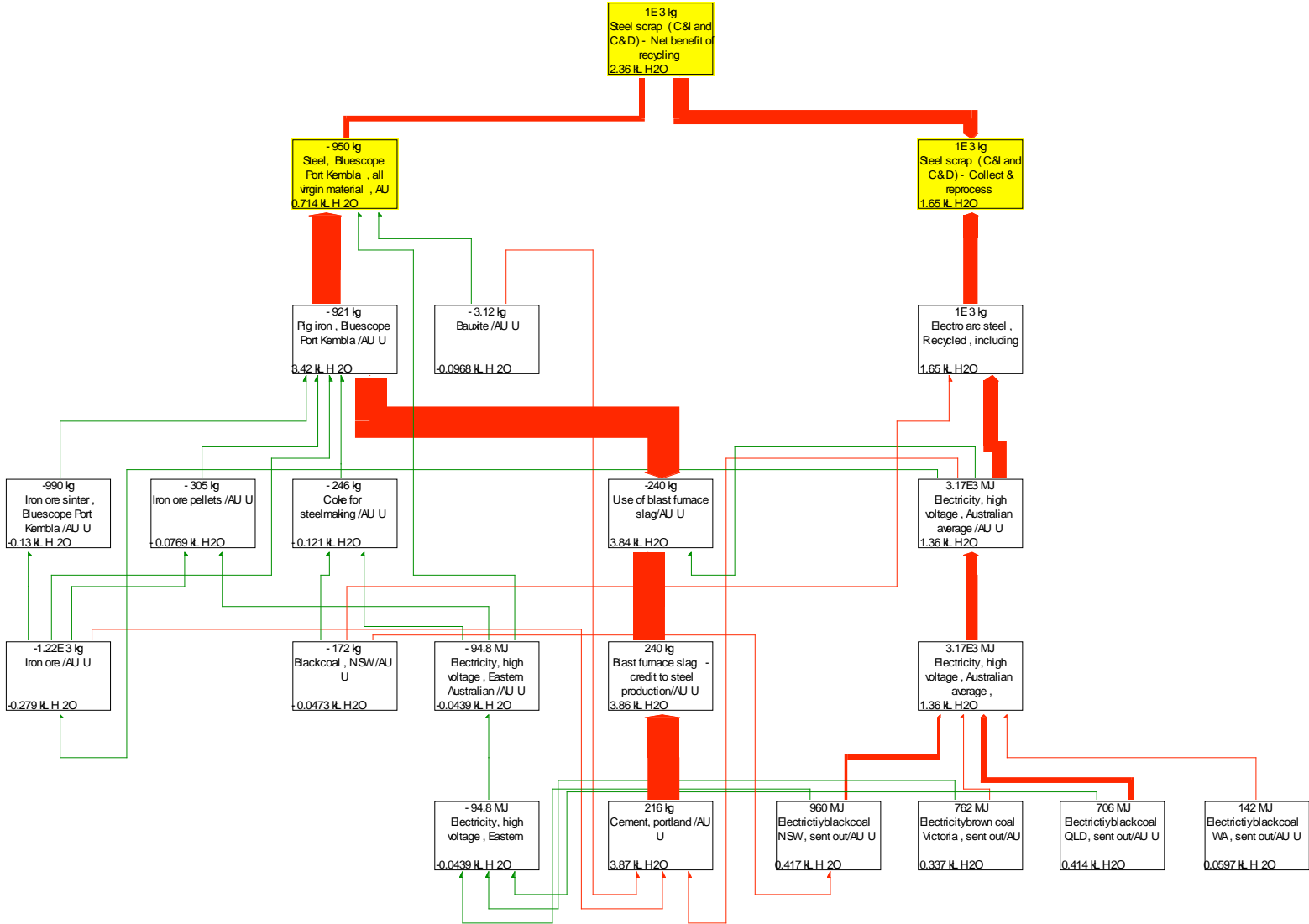




**Figure 22: Recycling process network diagram — Cumulative energy demand indicator. Processes contributing less than 2% to total are not shown. Major processes from results table above are shown shaded.**



**Figure 23: Recycling process network diagram — Water indicator. Processes contributing less than 1% to total are not shown. Major processes from results table above are shown shaded.**



**Figure 24: Recycling process network diagram — Solid waste indicator. Processes contributing less than 1% to total are not shown. Major processes from results table above are shown shaded.**

