Environmental benefits of recycling

Appendix 5 – Glass

Glass containers,
sheet and laminated glass

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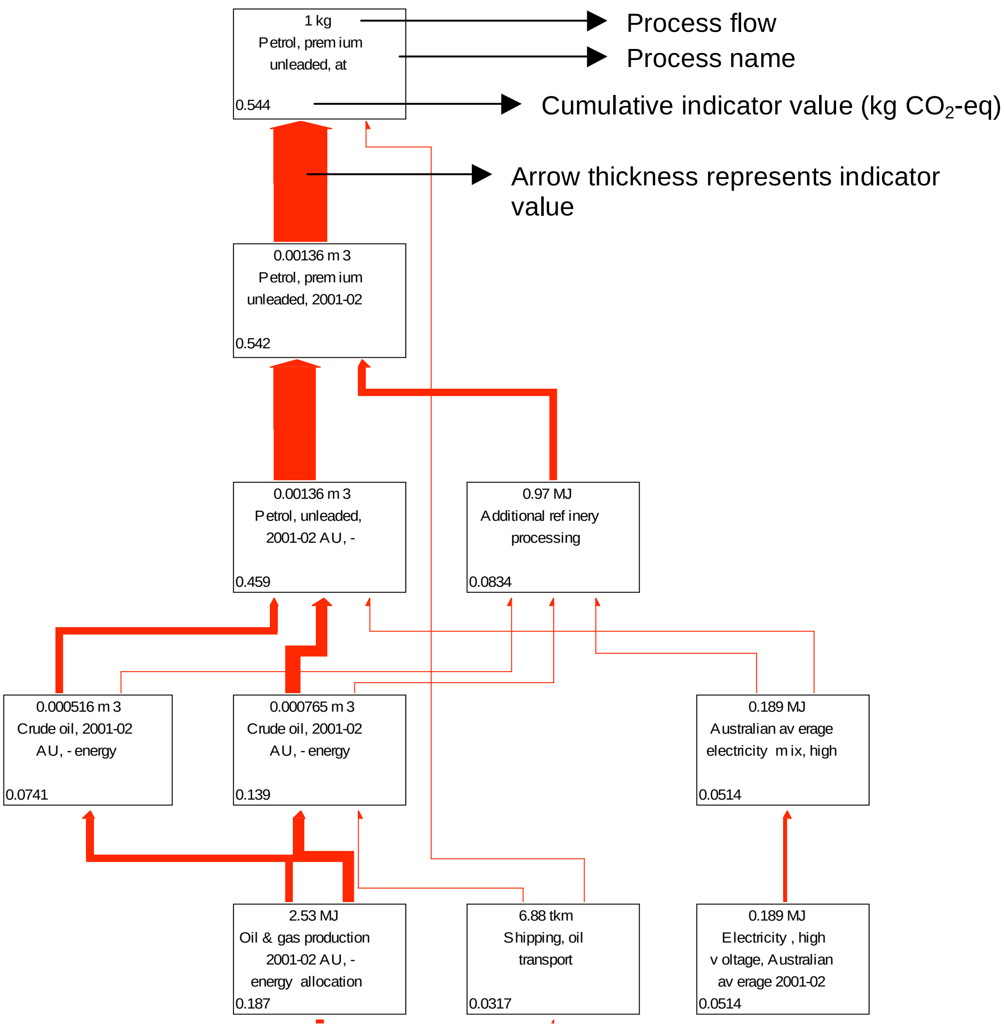
Understanding network diagrams

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_2 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.



Glass containers

Process description

Glass container production process can be considered as having three key stages. At the first stage, a batch-house holds and blends raw materials which are mainly silica. These materials are then sent to the second stage. In the second stage the materials are melted and formed to the desired shape (e.g. a bottle). In the third stage the formed container is inspected, packaged and dispatched for filling.

Reprocessing of glass requires a preliminary sorting of the material collected by colour. The glass is then crushed and the non recyclables (such as bottle caps, labels and other impurities) are removed from the stream. After this process, the crushed glass (cullet) is ready to be remelted in order to form new glass products.

Two collection systems for waste glass packaging were considered in the model:

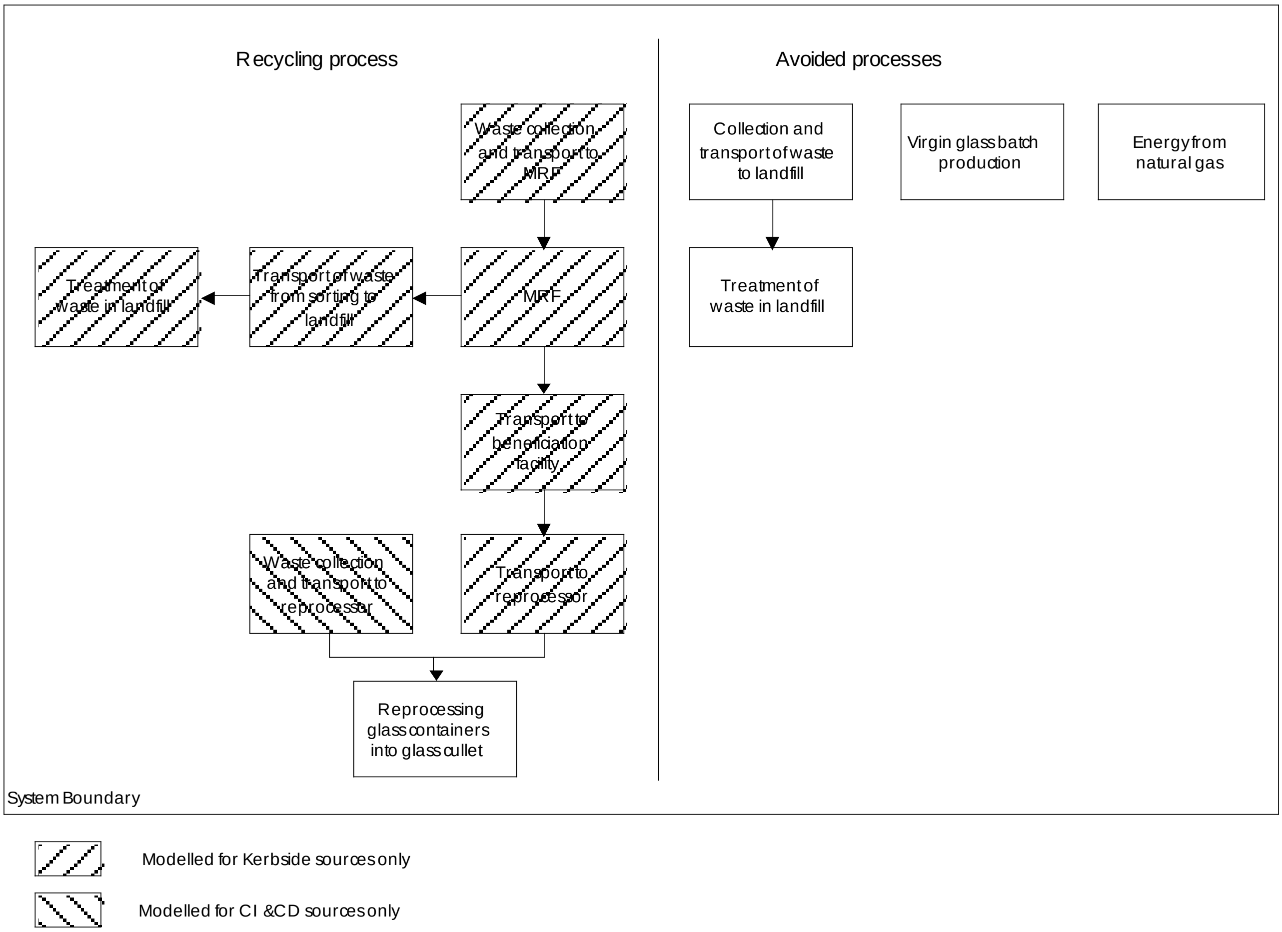
A) Kerbside collection — municipal collection from households, and processing through a Materials Recovery Facility

B) C&I, C&D collection — direct transfer from point of waste generation to a reprocessing facility

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

Figure 6 illustrates the processes considered in determining the overall impact of glass container recycling from kerbside and 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 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 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 melted glass cullet. Losses associated with this process are included in the analysis. The kerbside treatment system is illustrated in Figure 2 (processes unique to kerbside collection are shaded accordingly).

In order to determine the benefit or impact of recycling a material, it is also necessary to consider the processes avoided when recycling is undertaken. in Figure 2 also illustrates the processes that would be avoided when waste glass containers are recycled (shown to the right of the vertical line). Two main processes are considered, the collection and disposal to landfill of waste glass containers from the kerbside, and the primary manufacture of melted glass from virgin glass batch.

Results

Considering both the recycling process flows and the avoided process flows, described in 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 glass containers from kerbside sources (per 1 tonne of waste containers collected). Benefits are shown negative, impacts are shown positive.

Impact category	Unit	Recycling process impacts (Figure 90 - left side)	Avoided process impacts (Figure 90 - right side)			Net benefits of recycling
		Collection, sorting and reprocessing	Collection and landfill	Primary material production	Total avoided impacts	
Green house gases	t CO_2	0.09	-0.06	-0.59	-0.65	-0.56
Cumulative energy demand	GJ LHV	1.27	-0.85	-6.49	-7.33	-6.07
Water use	kL H_2O	0.02	-0.01	-2.32	-2.32	-2.30
Solid w aste	tonnes	0.09	-1.00	-0.03	-1.03	-0.94

Network diagrams detailing key processes that influence the impact 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 the collection, recycling and reprocessing of 1 tonne of glass containers. The table also includes the products and processes avoided when 1 tonne of glass containers is recycled.

Table 2: Inventory for glass containers, kerbside source (1 tonne)

Item	Flow	Unit	Comment
Process flows (Figure 2 — left hand side)			
Waste collection and transport to MRF	4.65	m^3	Based on whole glass packing density of 4.2 m^3/tonne plus 0.45 m^3 for collection of associated contaminants in recycling which are disposed at MRF. 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 glass at MRF	4.65	m^3	Based on whole glass packing density of 4.2 m^3/tonne plus 0.45 m^3 for collection of associated contaminants in recycling which are disposed at MRF. Energy inputs from Nishtala (1997) and estimated from equipment specifications
Transport to glass beneficiation facility	46.8	km	46.8 km transport from MRFs to Visy Glass Botany, assumption from Grant (2001a)
Transport to reprocessor	46.8	km	Transport from Botany to Penrith, assumption from Grant (2001a)
Reprocessing glass containers into glass cullet	950	kg	Data on energy consumption are estimated from the equipment specifications for glass breaker and conveyor and on Nishtala (1997) for the magnetic separator and trommel screen. 1.75 kWh of electricity consumed per tonne of waste reprocessed. Impacts from the production of electricity high voltage in Australia are based on ESAA, 2003 and other sources. Estimated diesel consumption for use of front end loader. 10.18 MJ of diesel consumed per tonne of waste reprocessed, emissions recorded by Pre Consultants, from Boeijink (1993). Data on diesel density from ABARE (2008) Assumption of 2 per cent losses from reprocessing, from Grant (2001b), so reprocessing 950 kg of glass waste ends up with 931 kg of reprocessed glass cullet output.
Transport of waste from MRF 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	During the sorting process, 5 per cent of glass assumed to be discarded at MRF, and treated in landfill
Avoided process (Figure 2 — right hand side)			
Collection and transport of waste to landfill	4.65	m^3	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.
Landfill of glass containers	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.
Virgin glass batch production	931	kg	For 950kg reprocessed 931kg of glass cullet is produced thereby avoiding 931kg of virgin glass cullet production. 0.698 MJ/tonne of electricity used for the production of virgin cullet. Input data from ACI (now Owens Illinois) Glass Packaging P/L, Hawthorn Vic 1997; energy use consistent with Tellus (1992)

Item	Flow	Unit	Comment
Energy from natural gas	1.05	GJ	Energy savings included as melting of reprocessed glass cullet necessit less energy than melting of a cullet from virgin resources. Based on assumption of 2.5 per cent energy savings per 10 per cent of cullet, from Grant (2001b). Current usage approximately 50 per cent gas energy. Emissions from NGGI (1998) and NPI (1999).

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 glass containers

	Primary data source	Geography	Data Age	Technology	Representativeness
Impacts of transportation modes	Apelbaum (2001), NGGIC (1997)	Australia	2005	Average technology	Mixed data
Cullet reprocessing	Unspecified	Unspecified	1999	Unspecified	Unspecified
Avoided virgin material production	Unspecified	Australia	1995–1999	Average technology	Average from a specific process
Avoided landfill impacts	Tellus Packaging Study, 1992	Australia	1999	Unspecified	Mixed Data

B) C&I and C&D

Processes considered

In the case of the C&I and C&D collection system, it has been assumed that waste collected from these sources is sent directly to the reprocessing site without any further 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 melted glass cullet. Losses associated with this process are included in the analysis. The system is described in Figure 2 (unique processes to C&I, C&D 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 glass containers from C&I and C&D sources (per 1 tonne of waste cans collected). Benefits are shown negative, impacts are shown positive.

Impact category	Unit	Recycling process impacts (Figure 90 - left side)	Avoided process impacts (Figure 90 - right side)			Net benefits of recycling
		Collection, sorting and reprocessing	Collection and landfill	Primary material production	Total avoided impacts	
Green house gases	t CO_2	0.00	-0.01	-0.62	-0.63	-0.62
Cumulative energy demand	GJ LHV	0.06	-0.13	-6.77	-6.90	-6.85
Water use	kL H_2O	0.00	0.00	-2.44	-2.44	-2.44
Solid w aste	tonnes	0.04	-1.00	-0.03	-1.03	-0.99

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.

Key assumptions

Table 5 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 glass containers. The table also includes the products and processes avoided when 1 tonne of glass containers are recycled.

Table 5: Inventory for recycling glass containers from C&I and C&D source (1 tonne)

Item	Flow	Unit	Comment
Process flows (Figure 2 — left hand side)			
Waste collection and transport to reprocessor	20	km	20km distance estimate based on a simplified transport analysis for Sydney. Refer appendices for transport discussion. 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 cullet, electricity high voltage use	1.75	kWh/tonne	1.75 kWh of electricity used per tonne of waste reprocessed. Data on energy consumption are estimated from the equipment specifications for glass breaker and conveyor and on Nishtala (1997) for the magnetic separator and trommel screen. Impacts from the production of electricity high voltage in Australia are based on ESAA, 2003 and other sources. Estimated diesel consumption of 10.2 MJ of diesel consumed per tonne of waste reprocessed, for use of front end loader. Amount of diesel used per MJ, and emissions from this used recorded by Pre Consultants from Boeijink (1993). Data on diesel density from ABARE (2008) Assumption of 2 per cent losses from reprocessing, from Grant (2001b), so reprocessing 1t of glass cullet waste ends up with 980kg of reprocessed glass cullet output.
Avoided process (Figure 2 — right hand side)			
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 glass containers	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.
Glass batch	0.98	tonne	Input data from ACI (now Owens Illinois) Glass Packaging P/L, Hawthorn Vic 1997; energy use consistent with Tellus (1992) 0.698 MJ/tonne of electricity used for the production of virgin cullet. For 1t reprocessed 980kg of glass cullet is produced thereby avoiding 980kg of virgin glass cullet production.
Energy, natural gas	1.05	GJ	Energy savings included as melting of reprocessed glass cullet necessit less energy than melting of a cullet from virgin resources. Based on assumption of 2.5 per cent energy savings per 10 per cent of cullet. Current usage approximately 50 per cent gas energy. Emissions from NGGI (1998) and NPI (1999).

Data quality table and comment

Table 1 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 1: Data quality for life cycle inventory data modelled for recycling and landfilling of glass containers from C&I and C&D sources

	Primary data source	Geography	Data Age	Technology	Representativeness
Impacts of transportation modes	Apelbaum (2001), NGGIC (1997)	Australia	2005	Average technology	Mixed data
Cullet reprocessing	Unspecified	Unspecified	1999	Unspecified	Unspecified
Avoided virgin material production	Unspecified	Australia	1995–1999	Average technology	Average from a specific process
Avoided landfill impacts	Tellus Packaging Study, 1992	Australia	1999	Unspecified	Mixed Data

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Network diagrams — Kerbside collection

Figure 3: Recycling process network diagram — Green house gases indicator. Processes contributing less than 2 per cent to total are not shown. Major processes from results table above are shown shaded.

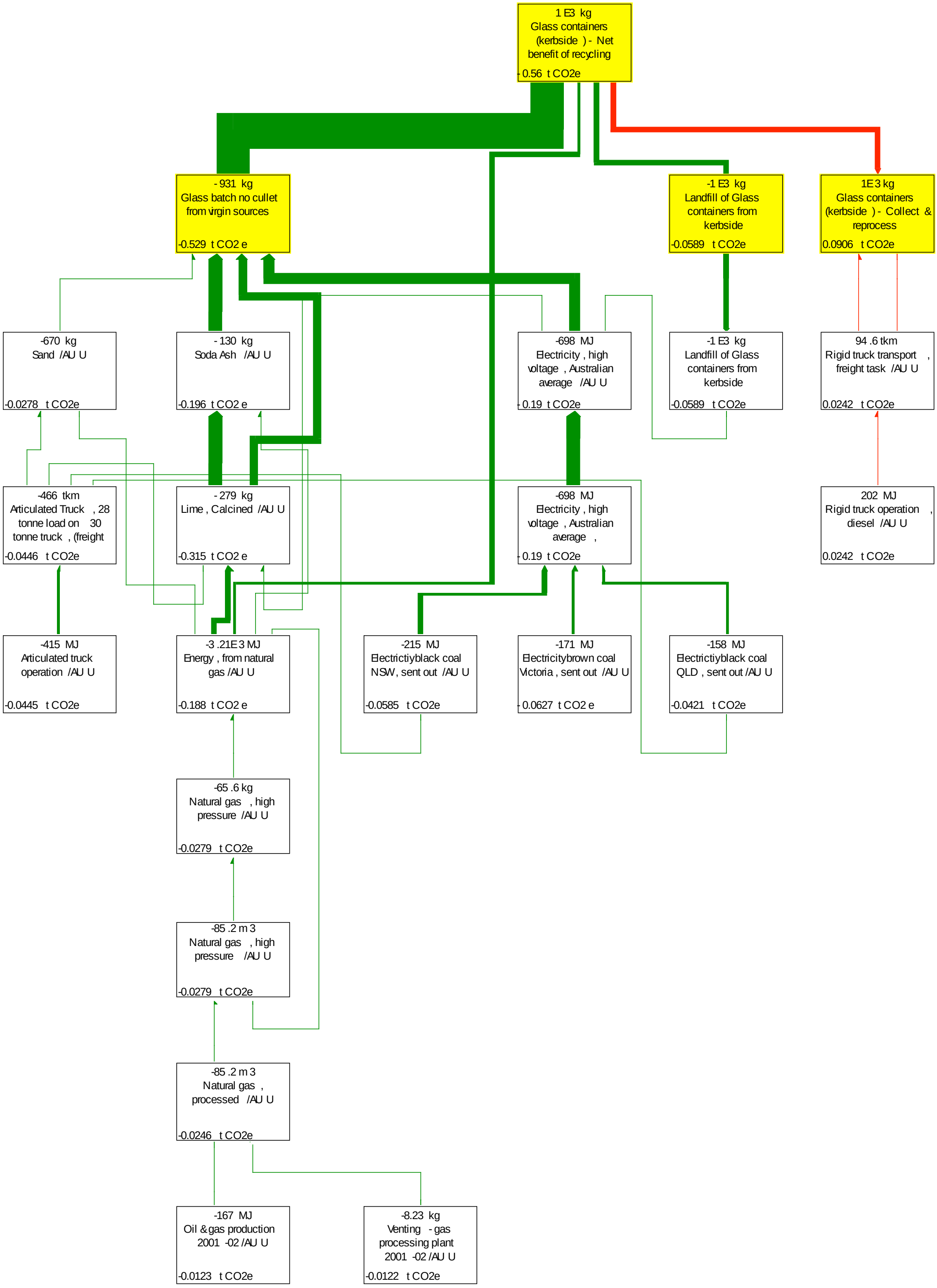


Figure 4: Recycling process network diagram — Cumulative energy demand indicator. Processes contributing less than 5 per cent to total are not shown. Major processes from results table above are shown shaded.

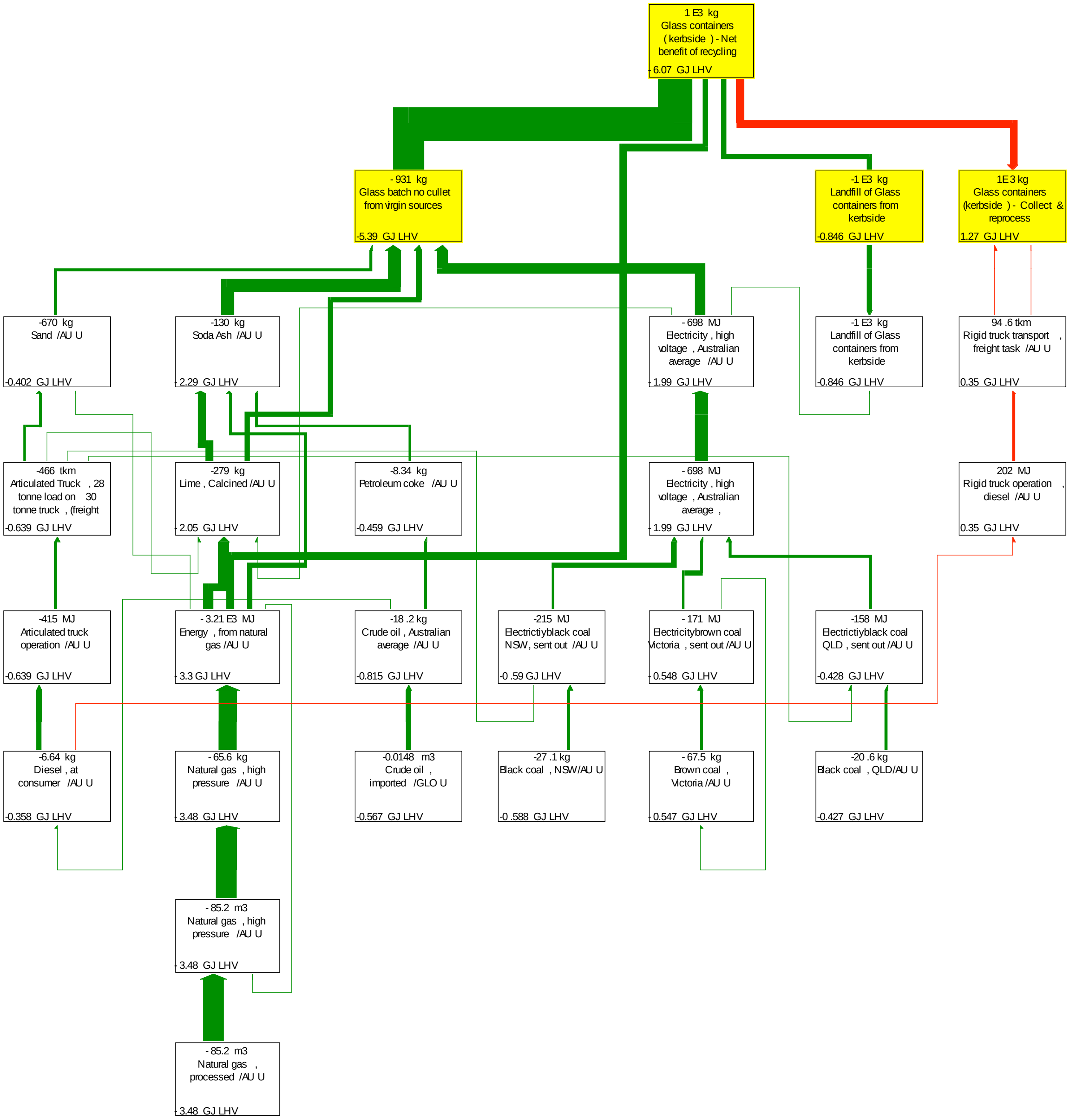


Figure 5: Recycling process network diagram — Water indicator. Processes contributing less than 1 per cent to total are not shown. Major processes from results table above are shown shaded.

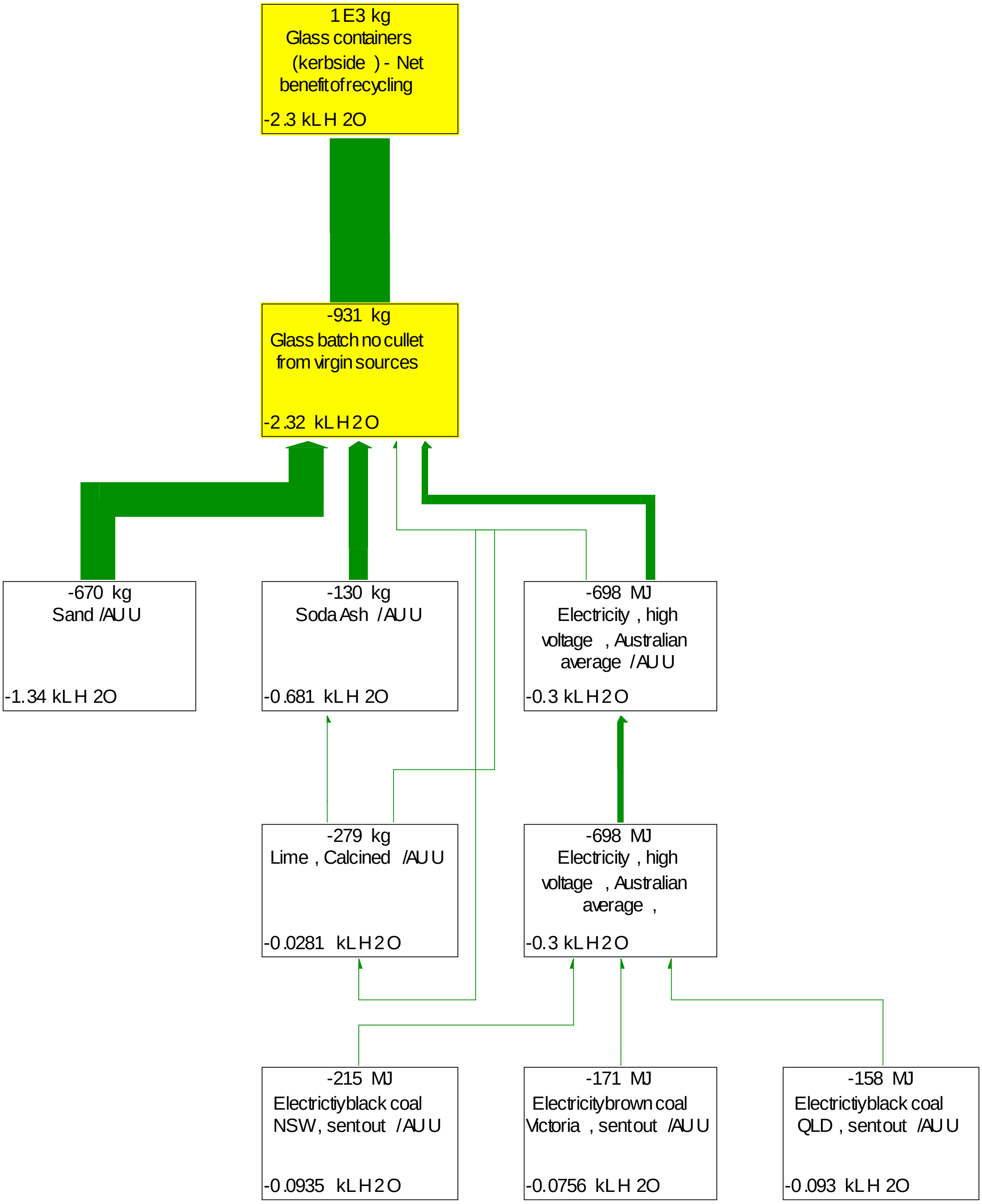
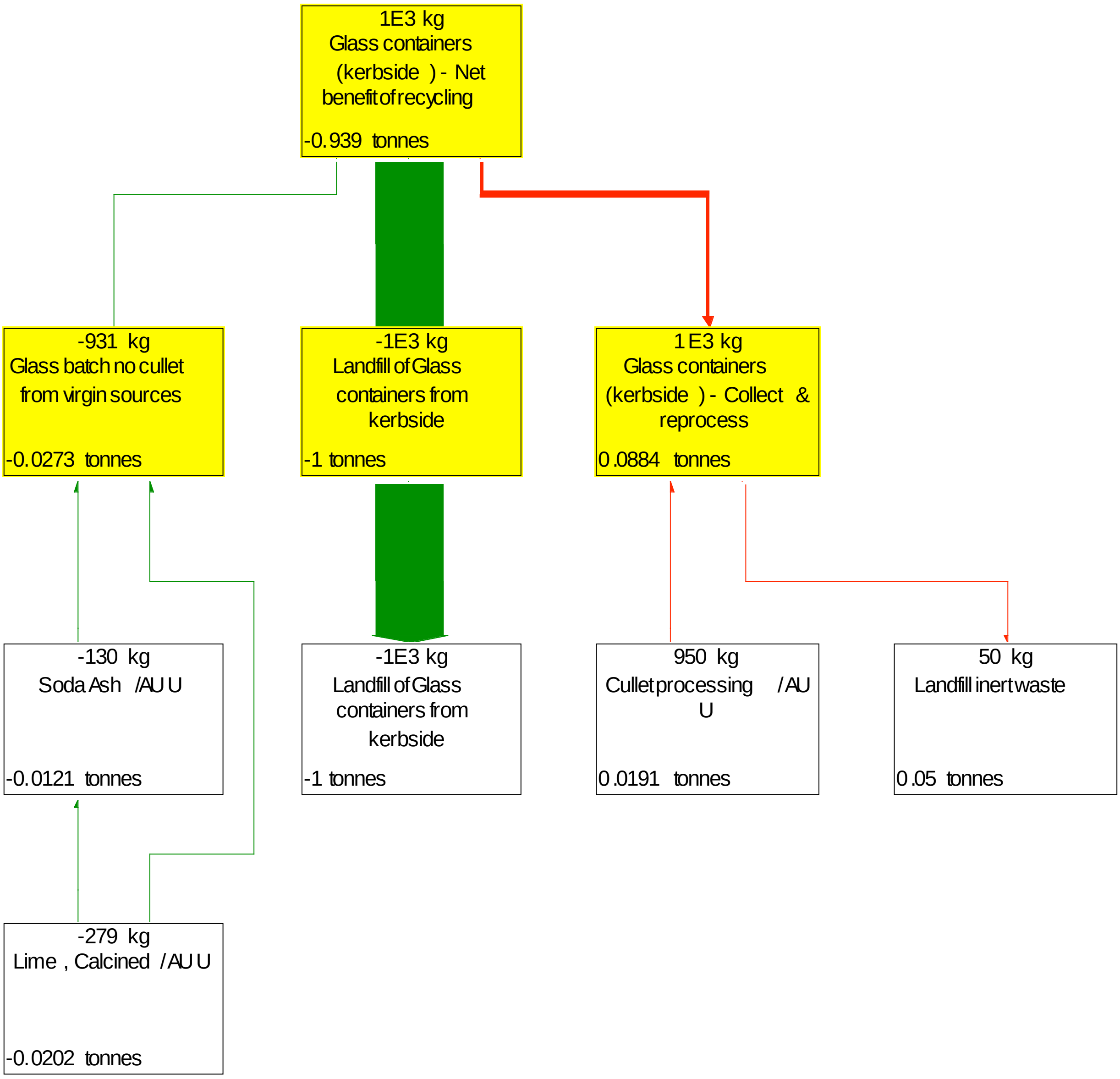


Figure 6: Recycling process network diagram — Solid waste indicator. Processes contributing less than 1 per cent to total are not shown. Major processes from results table above are shown shaded.



Network diagrams — C&I and C&D collection

Figure 7: Recycling process network diagram — Green house gases indicator. Processes contributing less than 2 per cent to total are not shown. Major processes from results table above are shown shaded.

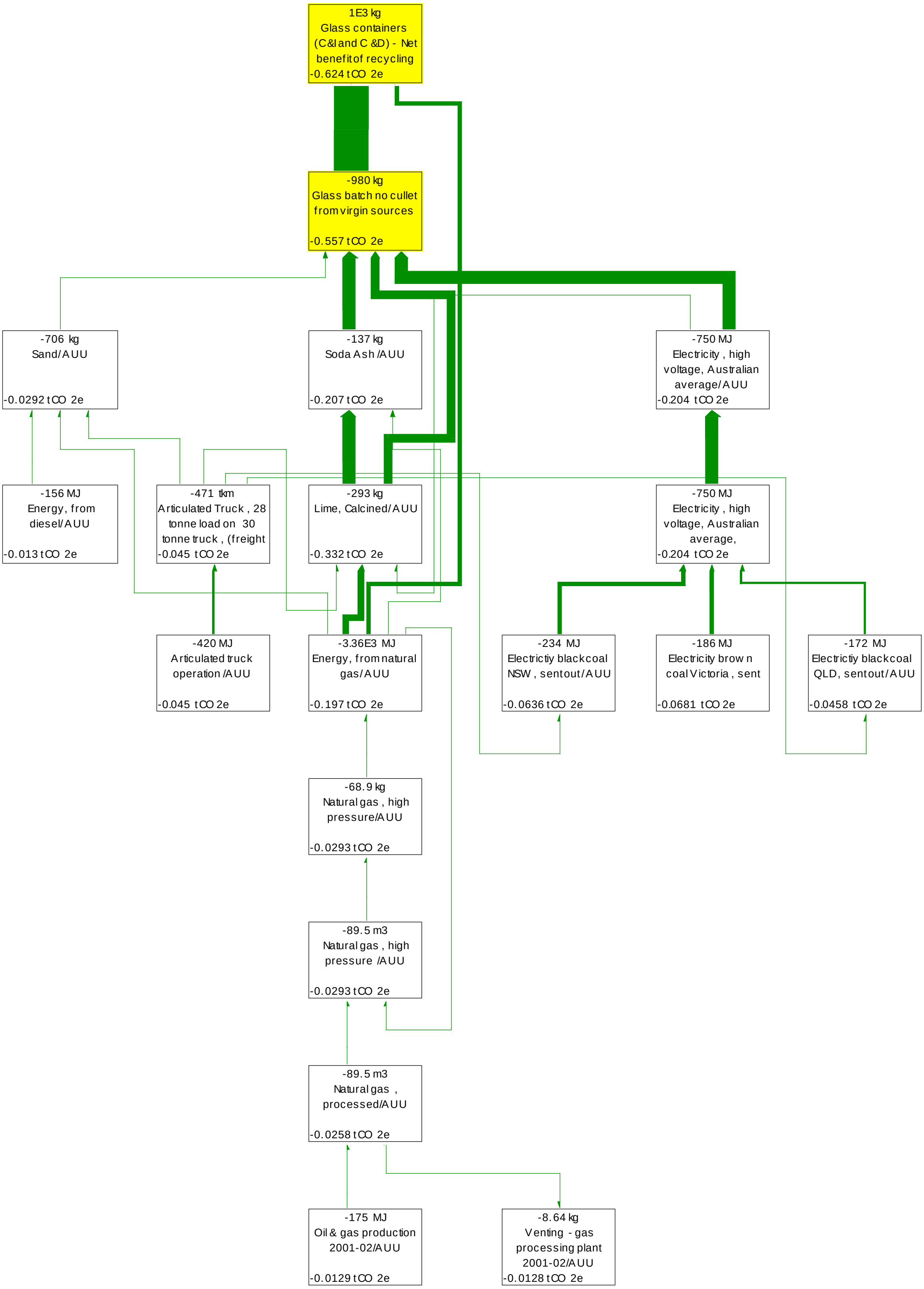


Figure 8: Recycling process network diagram — Cumulative energy demand indicator. Processes contributing less than 4 per cent to total are not shown. Major processes from results table above are shown shaded.

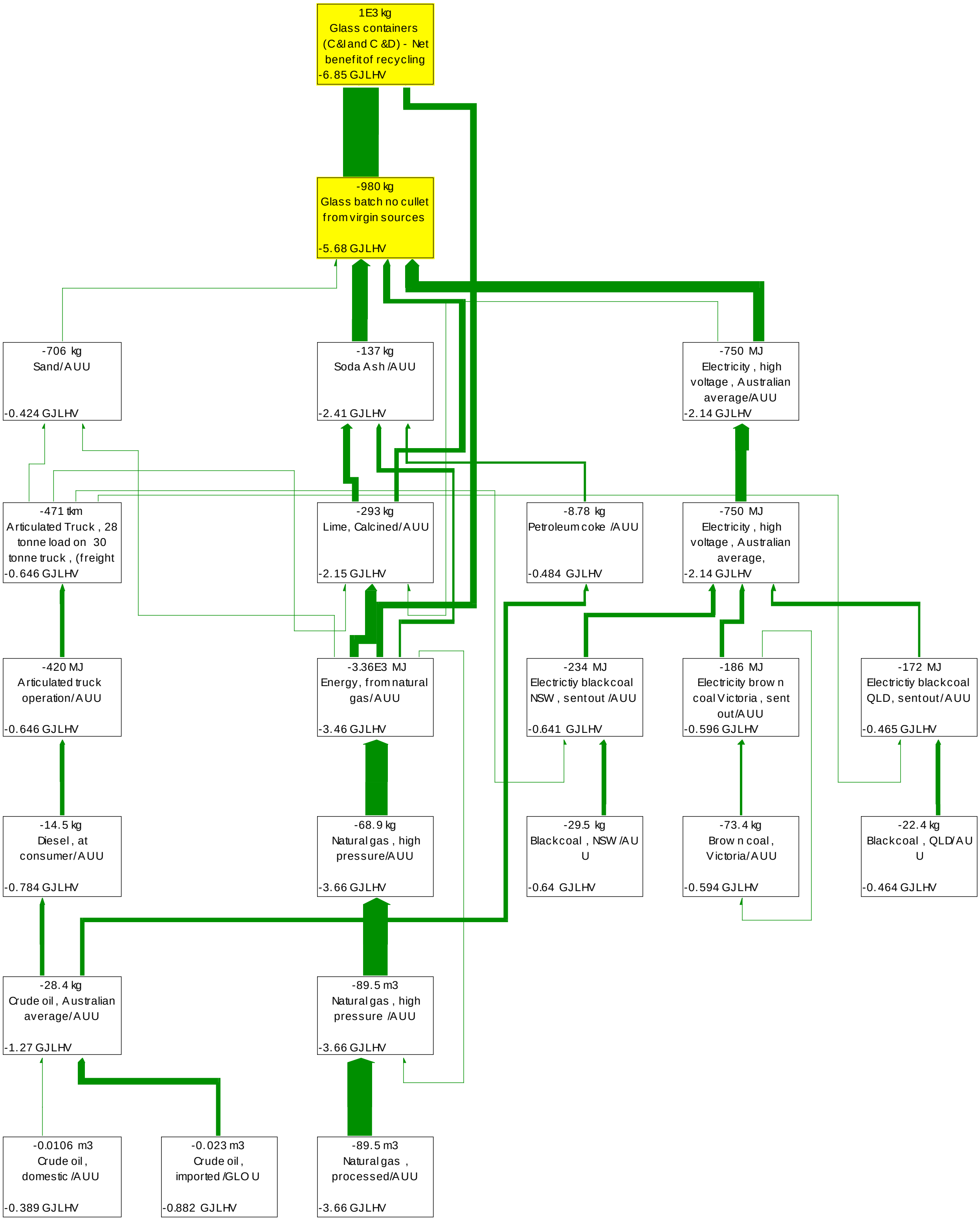


Figure 9: Recycling process network diagram — Water indicator. Processes contributing less than 1 per cent to total are not shown. Major processes from results table above are shown shaded.

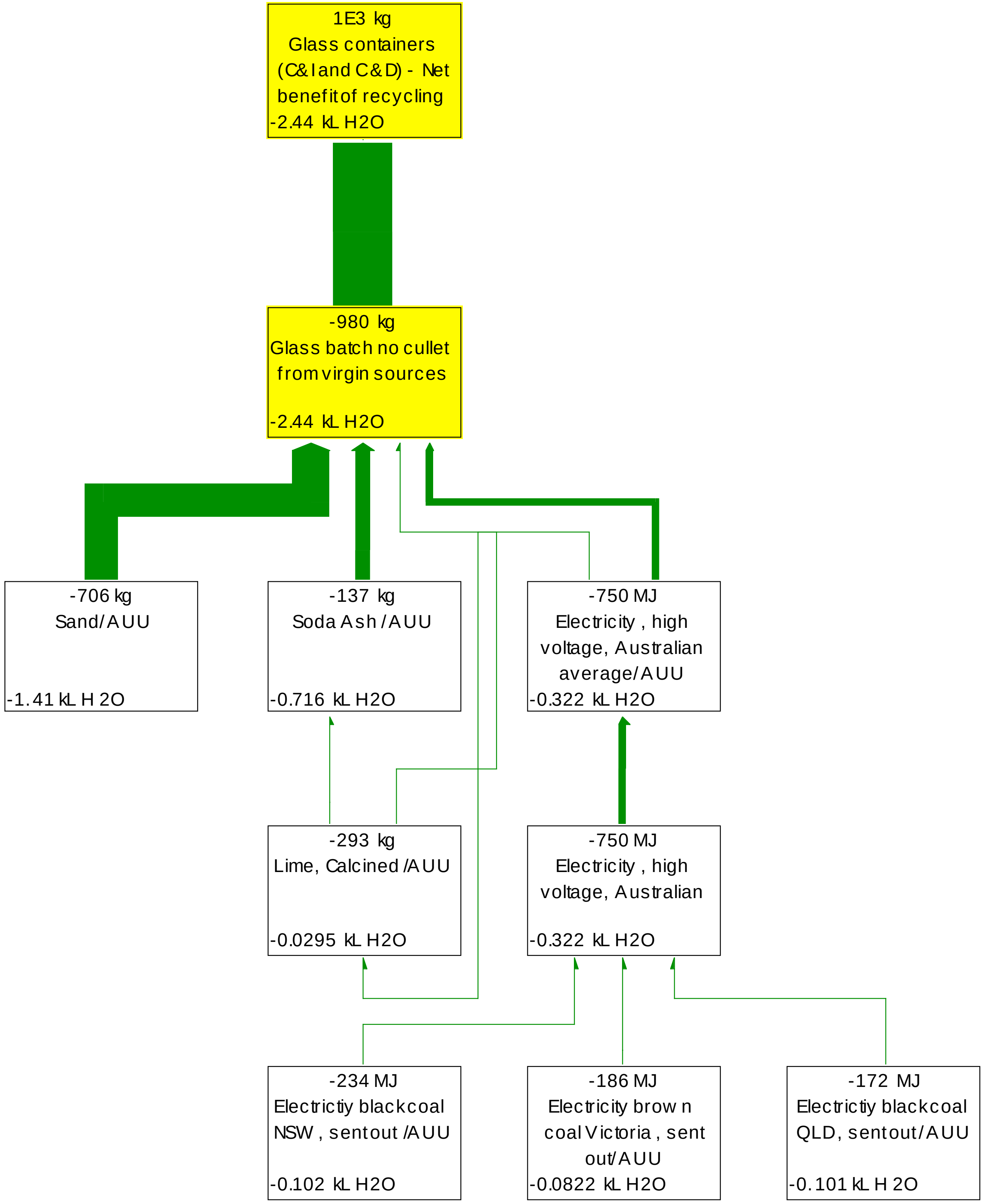
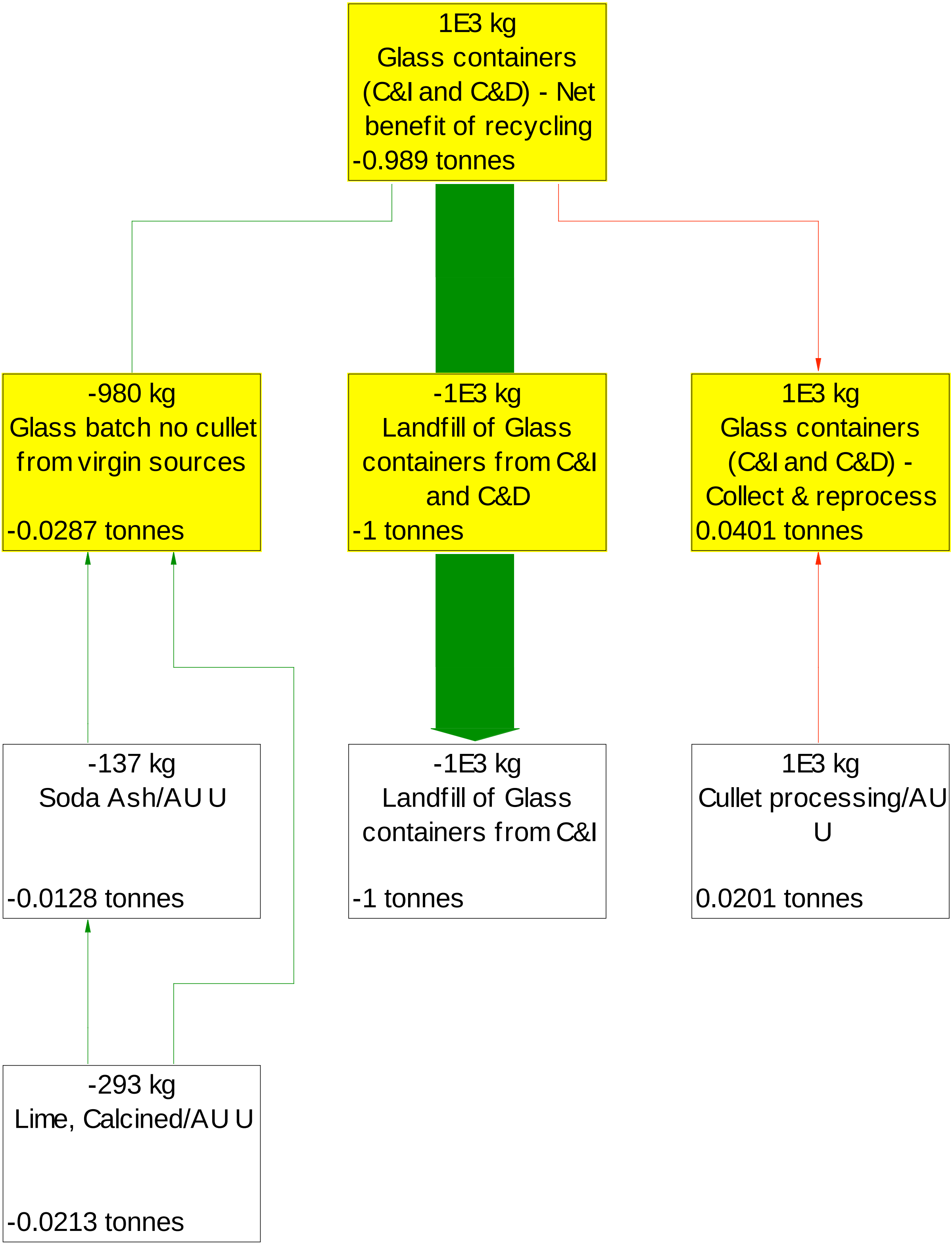


Figure 10: Recycling process network diagram — Solid waste indicator. Processes contributing less than 1 per cent to total are not shown. Major processes from results table above are shown shaded.



Sheet and laminated glass

Process description

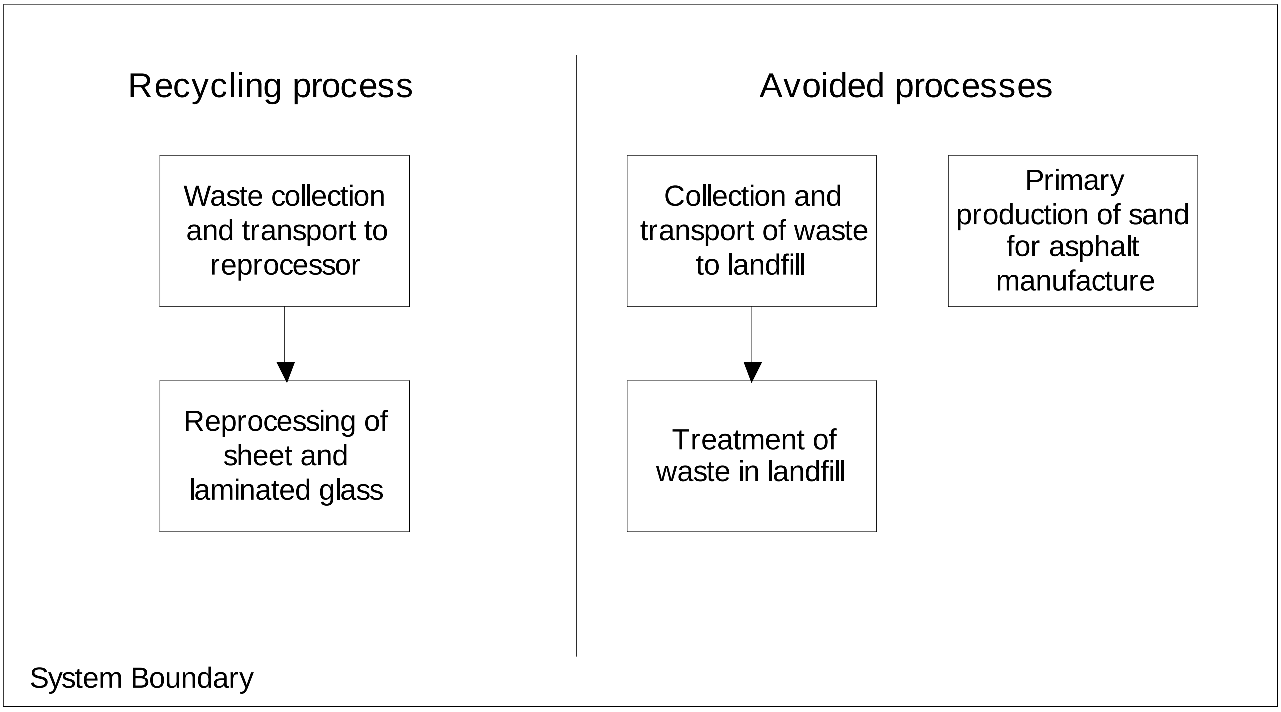
Glass is generally made of Silica melted with a mix of other chemicals, and then formed by the float glass process. Glass sheets are typically used for the manufacture of windows. Laminated glass can also be used as a safety glass (e.g. in a car's windshield). After collection for recycling and reprocessing, it can be used for asphalt manufacture as a substitute for fine aggregates such as sand.

Only one collection system for waste sheet glass was considered in the model:

> C&I, 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 a substitute to sand in asphalt manufacture. 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 impacts of the recycling, from C&I and C&D source (1 tonne)



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 of sheet and laminated glass from C&I and C&D sources (per tonne). Benefits are shown negative, impacts are shown positive.

Impact category	Unit	Recycling process impacts (Figure 99 - left hand side)	Avoided process impacts (Figure 99 - right hand side)			Net benefits of recycling
		Collection and reprocessing	Collection and landfill	Primary material production	Total avoided impacts	
Green house gases	t CO_2	0.00	-0.01	-0.02	-0.03	-0.02
Cumulative energy demand	GJ LHV	0.06	-0.13	-0.26	-0.39	-0.33
Water use	kL H_2O	0.00	0.00	-0.01	-0.01	-0.01
Solid w aste	tonnes	0.04	-1.00	-0.08	-1.08	-1.04

Network diagrams detailing key processes that influence the impact 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 sheet and laminated glass. The table also includes the products and processes avoided when 1 tonne of sheet and laminated glass is recycled.

Table 8: Inventory for recycling of sheet and laminated glass from C&I and C&D sources (1 tonne)

Item	Flow	Unit	Comment
Process flows (Figure 11— left hand side)			
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 of sheet and laminated glass, electricity high voltage use	1	tonne	Data on energy consumption are estimated from the equipments specifications for glass breaker and conveyor and on Nishtala (1997) for the magnetic separator and trammel screen. 1.75 kWh of electricity consumed per tonne of waste reprocessed. Impacts from the production of electricity high voltage in Australia are based on ESAA, 2003 and other sources. Estimated diesel consumption for use of front end loader. 10.18 MJ of diesel consumed per tonne of waste reprocessed, emissions recorded by Pre Consultants, from Boeijink (1993). Data on diesel density from ABARE (2008) Assumption of 2 per cent losses from reprocessing, from Grant (2001), so reprocessing 1t of glass cullet waste ends up with 980kg of reprocessed glass cullet output.
Avoided processes (Figure 11 — right hand side)			
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	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 sand for asphalt manufacture	0.98	tonne	Sand production impacts adapted for Australian conditions from IVAM database. Distance from quarries estimated from NPI emissions database (127km) For 1 tonne reprocessed 980kg of glass cullet is produced thereby avoiding 980kg of virgin sand production.

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 sheet and laminated glass from C&I and C&D sources (1 tonne)

	Primary data source	Geography	Data Age	Technology	Representativeness
Impact 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
Recycling sheet and laminated glass	Nishtala (1997), estimation from equipment specification	Australia	1997–1999	Unspecified	Mixed data
Avoided sand production	Adapted from IVAM	Australia	2000–2004	Average technology	Mixed data
Avoided landfill impacts	Tellus Packaging Study, 1992	Australia	2000–2004	Unspecified	Unspecified

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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 4 per cent to total are not shown. Major processes from results table above are shown shaded.

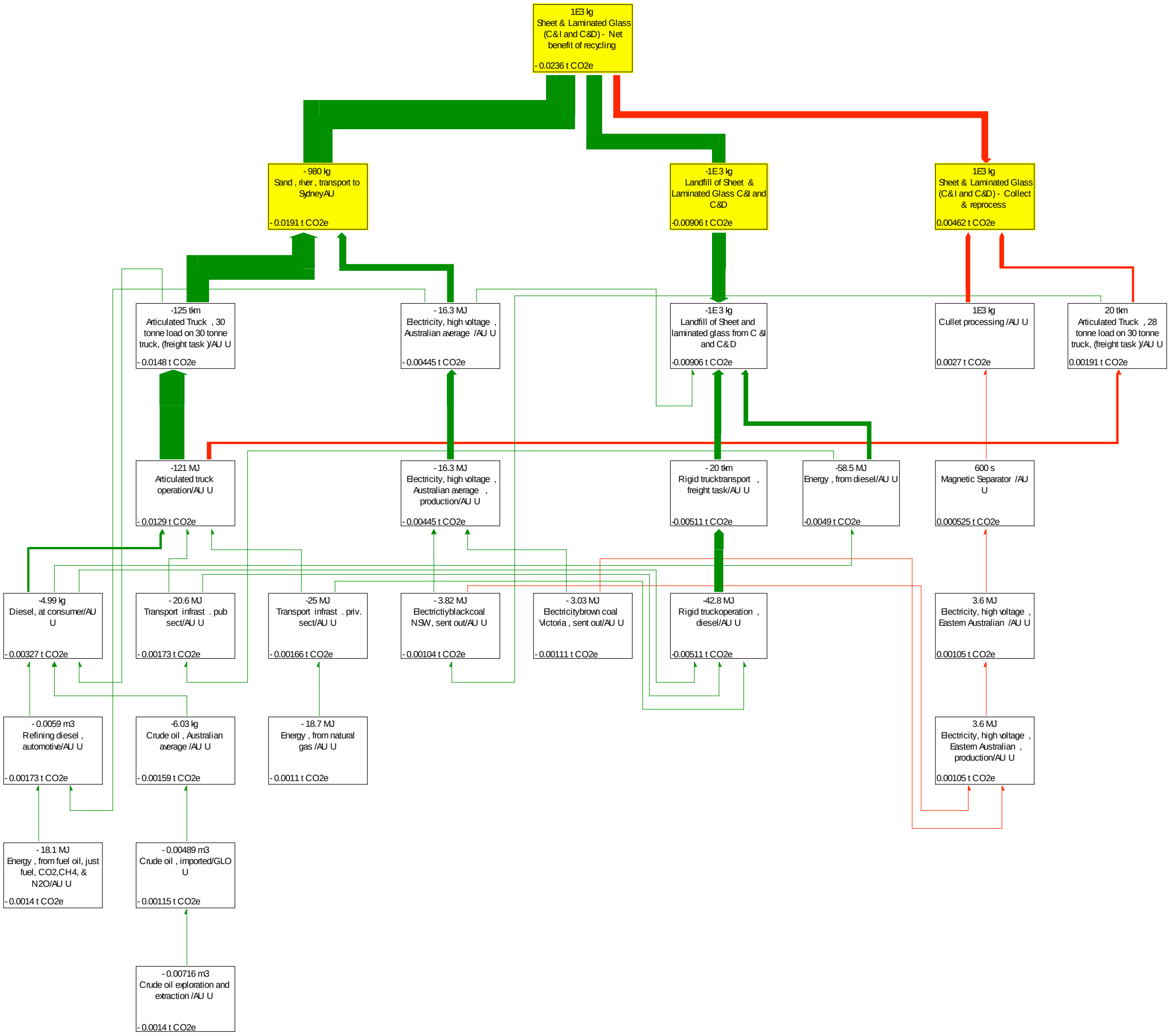

Figure 13: Recycling process network diagram — Cumulative energy demand indicator. Processes contributing less than 4 per cent to total are not shown. Major processes from results table above are shown shaded.

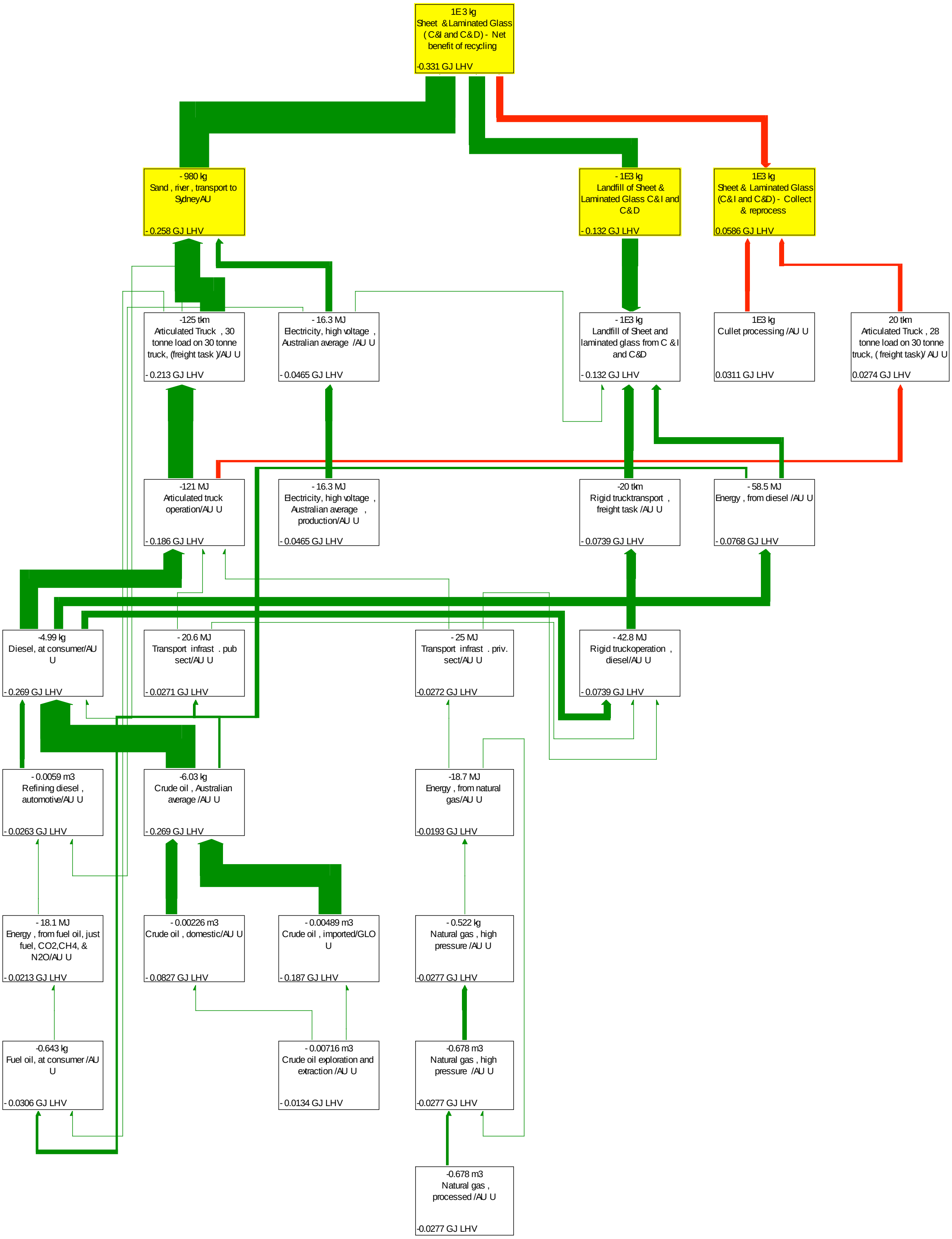

Figure 14: Recycling process network diagram — Water indicator. Processes contributing less than 7 per cent to total are not shown. Major processes from results table above are shown shaded.

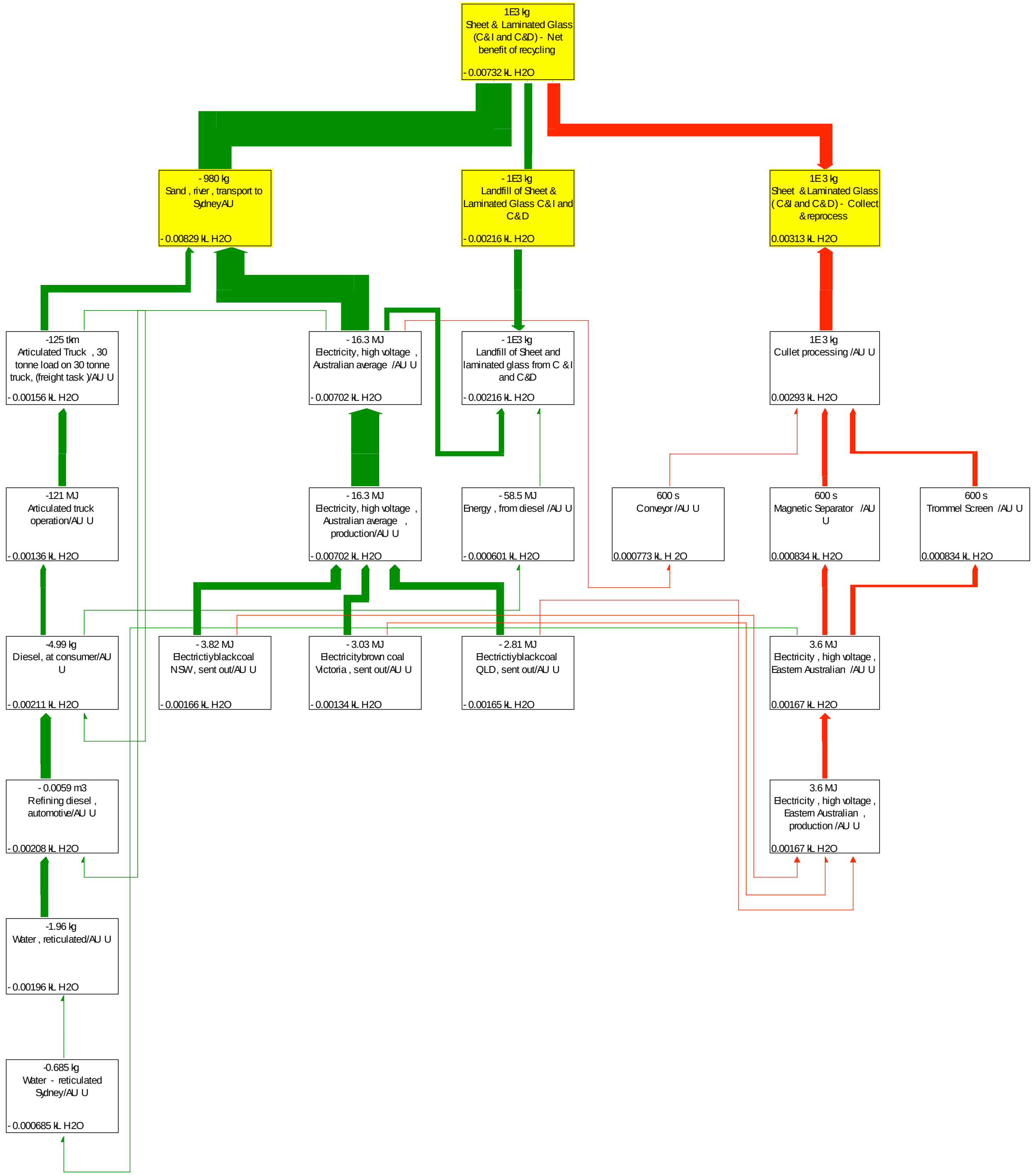

Figure 15: Recycling process network diagram — Solid waste indicator. Processes contributing less than 0.5 per cent to total are not shown. Major processes from results table above are shown shaded.