# Life cycle comparison of crushed concrete aggregate with traditionally quarried stone aggregate

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# 1 Executive Summary

The aim of this project was to compare the potential environmental impacts of crushed concrete aggregate and quarried stone aggregate in road base applications, with a particular emphasis placed upon greenhouse gas emissions, solid waste and water use, as there is a high degree of awareness of these impacts in the building industry. The study considers a high volume crushed concrete aggregate product produced by Alex Fraser at their Laverton North concrete recycling plant which is compared directly to the equivalent traditional quarried stone product.

Life Cycle Assessment (LCA) has been used to determine and compare the potential environmental impacts of crushed concrete aggregate and quarried stone aggregate. LCA is an internationally accepted approach that provides detailed and independent environmental information on the lifecycle of products to stakeholders. LCA is also widely used as a basis for determining the consequential carbon dioxide emissions (that contribute to global warming) associated with the provision of a product or service.

The unit of comparison used in this study was equal to 1 tonne of aggregate (either crushed concrete or quarried stone) supplied to a construction site in urban Melbourne. The functional performance of crushed concrete aggregate is assumed to be equivalent to quarried aggregate in road base applications.

The production processes compared in the study are summarised in the system boundary diagram below (Figure 1). To the left of the vertical line in Figure 1 are shown those process units associated with quarried stone aggregate, and to the right are shown process units associated with crushed concrete aggregate. The diagram describes all of the processes that were included in the study (within the system boundary) and all those process steps excluded from the study (outside the system boundary). Where processes associated with quarried stone aggregate were excluded, potential impacts were assessed to ensure that beneficial processes were not being excluded that might disadvantage the quarried product in the comparison (refer Appendix B). In addition, the impact of electricity generation and supply, diesel refinement and water supply were also included in the study (excluded from the diagram to aid clarity). Capital infrastructure impacts were excluded from the study, with the exception of road infrastructure which was included. Capital infrastructure (crushers, machinery etc) was considered to be similar between systems, however transport infrastructure could have been potentially different between systems hence was included. Appendix C describes how capital impacts were tested.

Figure 1 also shows ‘Avoided’ processes within the system boundary (to the right of the diagram). Avoided processes are those processes that do not need to be undertaken as a consequence of undertaking a particular activity. In this study, avoided processes include steel making and land fill collection and processing, which do not need to be undertaken if concrete recycling occurs.

Currently, 51% of waste generated in Victoria is recovered and reprocessed in some form (Ecorecycle Victoria 2004). 42% of the total waste recovered is in the form of concrete, brick and asphalt, with significant opportunity to increase recovery rates.

Avoided processes typically generate environmental benefits because they avoid activities that generate impacts. For example, steel recovered during the crushed concrete aggregate process substitutes for steel that no longer needs to be extracted from the environment. The same is true for landfill, which is avoided if demolition waste is recycled (as part of the crushed concrete aggregate process).

In order to achieve avoided impacts it is often necessary to reprocess materials, such as steel. These reprocessing impacts are included in the study and are shown under the column 'Additional processes' in Figure 1. Avoided impacts associated with steel were considered in detail in Appendix A.

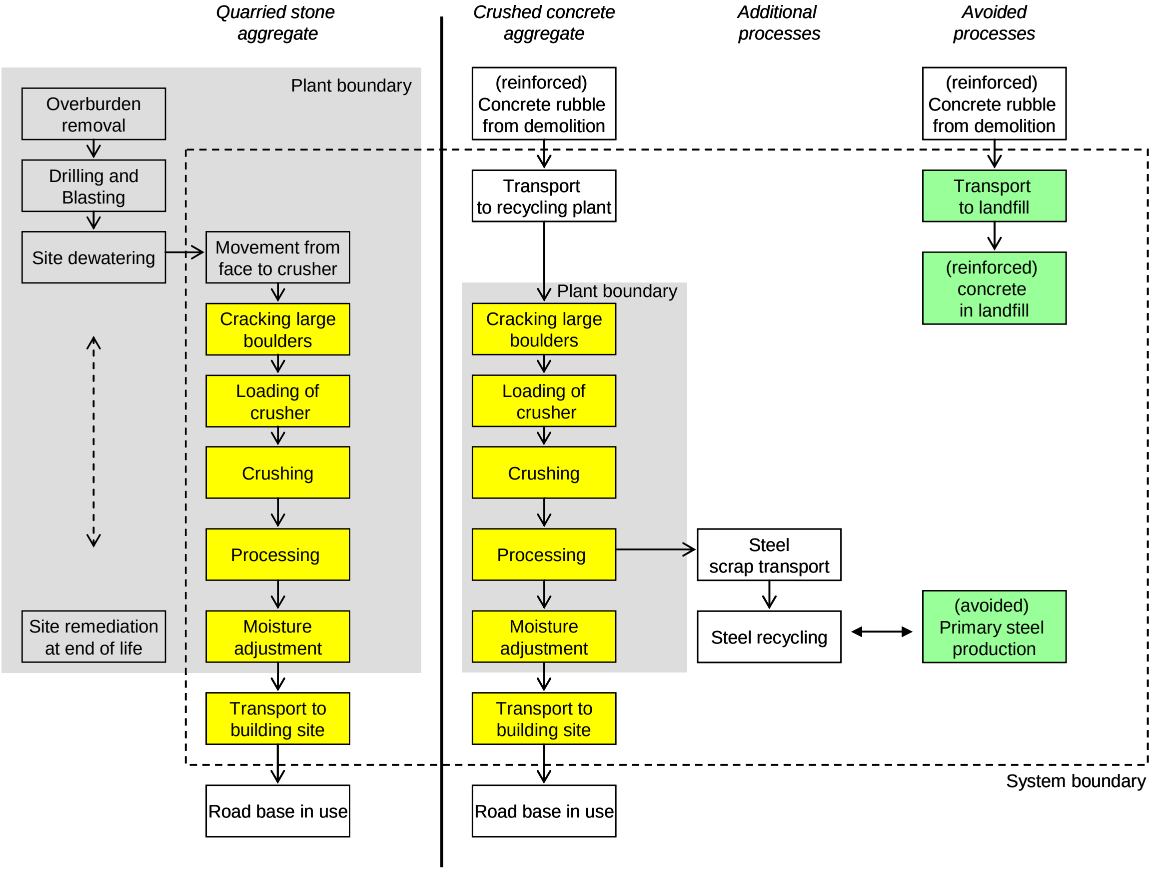


**Figure 1 System boundary diagram.**

Although somewhat hampered by a lack of detailed information regarding quarried stone aggregate production processes, strong similarities between the crushed concrete aggregate and quarried stone aggregate processes were able to be used to estimate process flows. Inventory data generated for the quarried stone aggregate processes were reviewed by a panel of experts at Alex Fraser, with a combined experience of over 50 years in quarrying and concrete recycling. Estimates were also compared to existing quarry data inventories, and 'best case' data used wherever contradictions arose. The inventory data comparisons are shown in Appendix D.

In order to undertake the study, an inventory of material and energy flows was constructed for each process unit within the system boundary described by Figure 1. Processes highlighted in yellow were assumed to have identical environmental impacts, whereas other process units were considered to be different between the stone and concrete products. The non-yellow process units are effectively what drive the differences in the life cycle impact of both products.

Key parameters used in the study are summarised in Table 1. Both systems consume diesel fuel to operate machinery on site, with most processes being very similar between crushed concrete aggregate and quarried stone aggregate. A key difference between the use of diesel fuel in machinery on-site is due to the need to move blasted rock from the rock face of a quarry to the crushing facility, which is typically undertaken by a dump truck. This is process step is not required in the crushed concrete aggregate process, hence the difference in fuel consumption used (quarried stone aggregate: 0.94 litres per tonne, crushed concrete aggregate: 0.78 litres per tonne).

**Table 1 Key differences between processes.**

| | Quarried stone aggregate | | Crushed concrete aggregate | |
|---|---|---|---|---|
| Transport of raw material to crushing plant | none | | 12 | km |
| Heavy vehicle fuel consumption within plant | Movement from face to crusher<br>Cracking large boulders<br>Loading of crusher<br>Water spreading<br>Other uses on site<br>0.94 | $l/t_{production}$ | Cracking large boulders<br>Loading of crusher<br>Water spreading<br>Other uses on site<br>0.78 | $l/t_{production}$ |
| Electricity use on site | 2.98 | $kWh/t_{production}$ | 2.98 | $kWh/t_{production}$ |
| Water use onsite | 153.00 | $l/t_{production}$ | 153.00 | $l/t_{production}$ |
| Waste generated by recycling process | none | | 200.00 | t/yr |
| Transport of waste to landfill | none | | 4 | km |
| Transport of aggregate to building site | 8 | km | 8 | km |
| Transport steel to recycling | none | | 20 | km |
| | | | | |
| Avoided products | | | | |
| Steel | none | | 8.07 | kg/t |
| Transport and landfill of demolition waste | none | | 1.01 | $t_{waste}/t_{production}$ |

## 1.1 Results

Table 2 illustrates the significant differences that were found to exist between the life cycle impacts of the aggregates considered. Although similarity existed between impacts associated with water use, differences existed in energy related indicators such as global warming, photochemical oxidation and fossil fuels.

Negative impacts – benefits - associated with the production of crushed concrete aggregate were largely driven by the allocation of avoided product impacts associated with the production of steel and the avoidance of demolition waste landfill.

**Table 2 Characterisation results summary (negative impacts indicate benefits).**

| **Impact category** | **Unit** | **Crushed concrete aggregate** | | | | **Quarried stone aggregate** | |
|---|---|---|---|---|---|---|---|
| | | Concrete recycling processes | Avoided steel manufacture | Avoided transport and landfill | **Total impact** | **Total impact** | **Difference (CCA less CSA)** |
| Global Warming | kg CO2 | 1.07E+01 | -1.32E+00 | -6.20E+00 | **3.14E+00** | **8.88E+00** | -5.73E+00 |
| Photochemical oxidation | kg C2H2 | 4.81E-02 | -1.86E-02 | -2.93E-02 | **5.09E-04** | **2.15E-02** | -2.10E-02 |
| Eutrophication | kg PO4--- eq | 7.44E-03 | -2.85E-03 | -5.15E-03 | **-5.54E-04** | **7.03E-03** | -7.59E-03 |
| Carcinogens | DALY | 8.07E-08 | -1.41E-08 | -5.30E-09 | **6.13E-08** | **8.52E-08** | -2.39E-08 |
| Land use | Ha a | 2.29E-05 | 3.60E-07 | -5.79E-09 | **2.32E-05** | **2.72E-05** | -3.98E-06 |
| Water Use | KL H2O | 1.33E-01 | 1.82E-02 | -3.27E-03 | **1.48E-01** | **1.36E-01** | 1.21E-02 |
| Solid waste | kg | 6.91E-02 | -1.77E+00 | -1.01E+03 | **-1.01E+03** | **6.70E-02** | -1.01E+03 |
| Fossil fuels | MJ surplus | 1.09E+01 | -4.31E+00 | -7.51E+00 | **-8.56E-01** | **8.29E+00** | -9.14E+00 |
| Minerals | MJ Surplus | 3.17E-02 | -3.29E-01 | -5.12E-06 | **-2.97E-01** | **3.80E-02** | -3.35E-01 |

* Focus indicators highlighted.

The study concluded that, in general, impacts associated with crushed concrete aggregate were driven by transport to and from the plant, machinery use within the plant, and electricity use. These impacts were found to be more than offset by benefits associated with steel recovery and landfill avoidance. With respect to quarried stone, impacts were driven by transport from the plant to the building site, machinery use within the plant, and electricity use.

In order to illustrate the process units that drive environmental impacts, the global warming indicator results (kg $CO_2$) are shown for each process unit or process group in Figure 2.

The diagram illustrates the significant global warming benefits associated with avoided products, and the similarities between the core process stages.

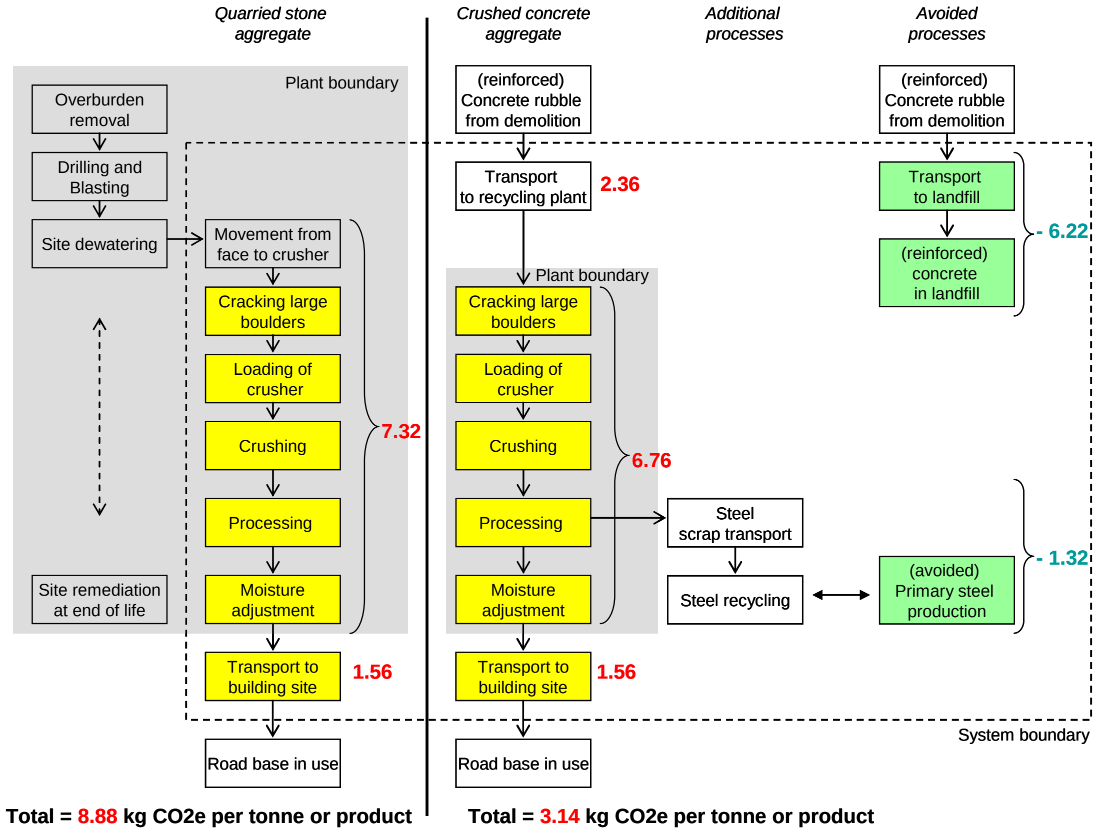


**Figure 2 Global warming results for crushed concrete aggregate and quarried stone aggregate summarised on the system boundary diagram.**

Sensitivity analysis was conducted to test the impacts of key study parameters. This analysis showed no change in study conclusions under the parameters considered, but did show that transport distances play a significant role in driving total environmental impacts. The goal of the study was to study Alex Fraser recycling operations in Melbourne, so distance variation applies mainly to various delivery locations within the city. The sensitivity study result suggested that the benefits of recycled concrete were substantial enough that even when quarry sites were closer to the building site, crushed concrete aggregate could still have a lower environmental impact. To maintain an even handed approach delivery distances were assumed to be identical between crushed concrete aggregate and quarried stone aggregate.

In addition, a comparison was done to an existing study by Grant and James (2005), that concluded greater benefits associated with crushed concrete aggregate versus quarried stone aggregate than were found in this study. A reconciliation of differences between the two studies showed that the differences were explainable, and that this study probably reflects a more conservative approach with better access to primary data.

Finally, the study has determined that crushed concrete aggregate has reduced impacts versus quarried stone aggregate under the assumptions described, in most indicators, with the exception of water use. This is not to suggest that either process cannot be further improved. Scope to employ low emission energy forms, energy efficiency, emissions reduction and other such initiatives exists in both processes.

# 2 Table of Contents

# 3 Introduction

Alex Fraser has pioneered the development of products derived from construction and demolition materials recycling in Victoria and Queensland. Products developed include crushed concrete and asphalt material that can be used in varied applications including pavement base, drainage aggregate, stabilised base course, light duty base, fill, capping and exposed car park toppings. Alex Fraser extracts reinforcing steel components from concrete composites, which is then made available for remelting.

By using salvaged material as the primary input to the manufacturing process and thereby diverting material destined for landfill, Alex Fraser believe they are producing aggregate product that is environmentally superior to a traditionally quarried product. To validate this belief and quantify the benefit (or otherwise), they have undertaken this Life Cycle Assessment (LCA) of their crushed concrete aggregate product versus a traditional quarried product.

LCA is an internationally accepted approach to provide detailed and independent environmental information on the lifecycle of products to customers and other stakeholders. LCA is able to help guide investments and decision making internally, so as to help improve future environmental performance of both individual product lines, and whole operations. LCA is also widely used as a basis for determining the consequential carbon dioxide emissions (that contribute to global warming) associated with the provision of a product or service.

# 4 Goal of the study

The aim of this project was to compare the potential environmental impacts between crushed concrete aggregate and quarried stone aggregate in road base applications, with a particular emphasis placed upon greenhouse gas emissions, solid waste and water use, as there is a high degree of awareness of these impacts in the building industry today.

The audience for the study was intended to be Alex Fraser management and employees who wish to better understand the environmental impacts associated with the crushed concrete aggregate product and the common alternative of quarried stone aggregate.

## 4.1 Peer review

The study has been peer reviewed and therefore is valid for wider communication of the results, in accordance with ISO 14040 series. The peer review comments raised and actions taken are described in Appendix G.

# 5 Scope of study

This project considers a high volume crushed concrete aggregate product produced by Alex Fraser at their Laverton North recycling plant which is compared directly to the equivalent traditional quarried stone product. Although Alex Fraser manufactures crushed concrete aggregate at three sites across metropolitan Melbourne, this approach was undertaken in order to maintain a clear connection between results derived and an actual production process (as opposed to a study based on average or aggregated data, which cannot be traced to a single manufacturing process).

A difference that may exist between Alex Fraser sites would be transport distance (both inbound and outbound), however because sites are located at roughly equivalent distances from the centre of Melbourne (20km approximately), within the city boundaries, it was felt that transport distances at each site could be considered to be equivalent. Nevertheless, differences in transport distances were considered in a sensitivity analysis undertaken in Section 10.

## 5.1 Reference unit

The reference unit used in this study is equal to 1 tonne of aggregate supplied to a construction site in urban Melbourne.

The functional performance of crushed concrete aggregate is assumed to be equivalent to quarried aggregate in road base applications.

## 5.2 System boundary

The system boundary (shown in Figure 3) of the study includes all flows to and from the environment to the unit processes involved in the creation and application of the crushed concrete aggregate and the traditional quarried aggregate. Consequential flows associated with energy sources such as diesel fuel and electricity are also included (electricity, diesel and water flows are excluded from the diagram for clarity).

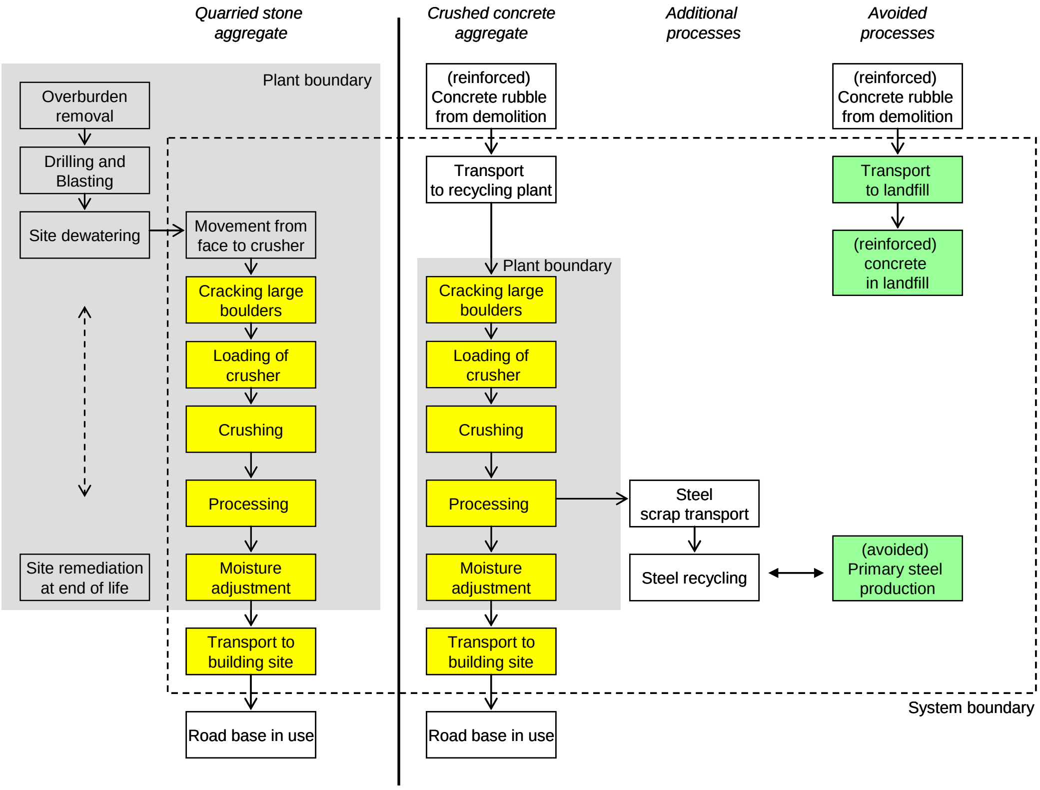


**Figure 3 System boundary (processes shown in green are avoided processes, processes shown in yellow are considered equivalent between quarried stone and crushed concrete).**

The processes that are undertaken after arrival of the aggregate at the building site are excluded from the system boundary in this study.  This exclusion is done because both products are expected to have similar impacts from this point forward.

‘Avoided’ processes are also included within the system boundary, under the column ‘Avoided processes’.  Avoided processes are those processes that do not need to be undertaken as a consequence of undertaking a particular activity.  In this study, avoided processes include steel making and land fill collection and generation, which do not need to be undertaken if concrete recycling occurs.  Avoided processes typically generate environmental benefits because they avoid activities that generate impacts.  In this case, steel recovered during the crushed concrete aggregate process does not need to be extracted from the environment.  The same is true for landfill, which is avoided if demolition waste is recycled (as part of the crushed concrete aggregate process).

In order to achieve avoided impacts it is often necessary to reprocess materials, such as steel.  These reprocessing impacts are included in the study and are shown under the column ‘Additional processes’

Some processes associated with the quarried stone aggregate production were excluded such as overburden removal, drilling and blasting, site dewatering and remediation.  These processes, although likely to generate environmental impacts, were excluded due to a lack of detailed industry average information.  Potential impacts were explored in more detail in Appendix B.

For the purposes of this study, the capital infrastructure directly involved in both the crushed concrete process and the quarried stone process is assumed to contribute minimally to both life cycles (impacts of capital tested in Appendix C and found to be minimal).  It is also assumed that infrastructure involved in both life cycles is relatively similar, so would be unlikely to differentiate the two processes.  For these reasons, infrastructure impacts have been excluded from the study, with the exception of road infrastructure, which has been included due to the significance of transportation in the systems compared.

In addition, administration overhead is excluded from the study as it is believed to reflect a small proportion of total impact, and would be expected to be similar for both the crushed concrete aggregate process and the quarried stone aggregate process.

## 5.3 Allocation procedures

Impacts directly and exclusively associated with unit processes are allocated directly to such processes.

### *5.3.1 Treatment of co-products*

Certain process impacts cannot be directly linked to a single product generated, as multiple co-products are produced through the same process.  An example of this in this study is the impact associated with operation of the processing plant at Laverton North.  As the plant produces multiple products, unrelated to the crushed concrete aggregate product, it is not possible to allocate its total impact to a single product. Instead the plant impacts are allocated to crushed concrete aggregate on a production tonnage basis. The production tonnage allocation method is described in Section 7.1, Table 6.

The plant manufactures products from asphalt, bricks, rock and concrete. The main share of production is crushed concrete and rock (approx 80%). The rock crushed is a harder material than the concrete, so is assumed to require greater energy (slightly) to process.

### *5.3.2 Treatment of subsequent life cycles*

Processes that generate benefits in other life cycles, such as the impact of landfill and the recycling of steel, are addressed by expanding the system boundary to incorporate these processes.

A number of methods were considered regarding the avoided impacts associated with recycled steel. Of these methods the method that most conservatively reflected the benefits was chosen (refer Appendix A).

A similar approach was taken for landfill. The system boundary is expanded to incorporate landfill operations associated with building waste. The avoided landfill impact is allocated directly to the crushed concrete aggregate life cycle. The corresponding implication is that landfill processes are avoided as a consequence of recycling concrete.

## 5.4 Assessment method

This study utilises the Australian Impact Method, developed by the Centre for Design, to interpret LCA inventory results. The method translates emissions, resource extraction and other measurables into defined environmental indicators. A listing of the factors used in the assessment method is attached in Appendix E.

The Australian Impact Method is based on a database developed by Centre for Design in conjunction with the Cooperative Research Centre (CRC) for Waste Management and Pollution Control as part of an Australian Inventory data project. The data from this project have been progressively updated particularly the data for metals production, energy, transport, and paper and board production. New data have been added for waste management from EcoRecycle projects in Victoria, agricultural inputs and fuel production from the comparison of transport fuels undertaken for the Australian Greenhouse Office (AGO) and data on Copper from published work from CSIRO (Terry Norgate).

Indicators of particular interest in this project are:

Global Warming
Solid Waste
Water Use

All indicators used in this study are shown in Table 3.

**Table 3: Environmental indicators**

| Indicators | Unit | Description |
|---|---|---|
| Global warming | kg $CO_2^{-eq}$ | Measurement of greenhouse gas emissions into the atmosphere, which cause absorption of infrared radiation that, would have otherwise escaped into space. Increased absorption of infrared radiation leads to an increase in the average temperatures of the Earth. The main greenhouse gases are water vapour, carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$). This indicator is represented as $CO_2$ equivalent units. |
| Photochemical oxidation | kg $C_2H_6$---eq | 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. |
| Eutrophication | kg $PO_4^{-3}$ eq | The release of nutrients (mainly phosphorous and nitrogen) into land and water systems, which may alter biota, and potentially increase algal growth and related toxic effects. |
| Carcinogens | DALY | Total damage caused by carcinogenic emissions measured in disability adjusted life years (DALY), a rate of mortality and morbidity that ranks years of life lost with years of disease and disability. |
| Land use | Ha.years | Total exclusive use of land for a given period of time for occupation by the built environment, forestry production and agricultural production processes. Measured in hectares per year. |
| Water use | kL $H_2O$ | Net water use including potable, process and cooling water which may impact on water quality, water depletion, and biodiversity |
| Solid waste | kg | The release of solid wastes from production and reprocessing to landfill. Impacts depend on the character of the waste. |
| Depletion of mineral resources & fossil fuels | MJ surplus | Measurement of the additional energy required to extract lower quality mineral and fossil resources, due to depletion of higher quality, easily extracted reserves. |

## 5.5 Limitations

A limitation of the study is the lack of primary data available for quarried aggregate processes. For this reason, wherever reasonable, estimates for quarrying process impacts have been used that reflect the lower end of the possible impact range. In addition, similar process impacts have been used for those processes considered similar in both product systems.

Transportation impact differences represent a significant challenge to determine between the two processes. For this reason the study assumes identical distances for delivery of product to the building site. In addition a sensitivity analysis has been undertaken that considers other transportation distances.

It should also be noted that the study is not intended to be a substitute for an environmental impact study. LCA is a useful tool for assessing the global impacts of processes however it does not readily address local impacts of processes. It is acknowledged that the product processes assessed in this study generate environmental impacts beyond those measured by the indicators selected (such as noise, dust, traffic congestion etc.). No comment is made by this study on these other impacts and it is left up to the user of the study to assess these other impacts when making decisions.

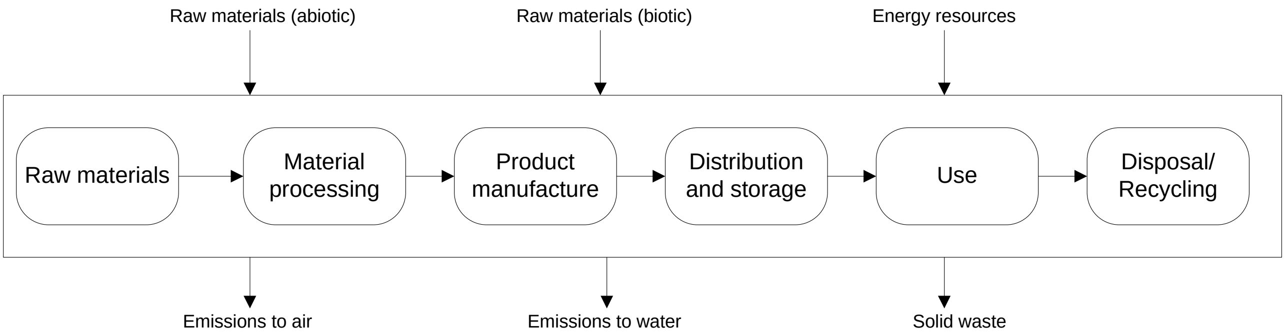
# 6 Methodology

This study utilises LCA to evaluate and compare the potential environmental impacts of crushed concrete aggregate and quarried stone aggregate. A description of the LCA process is provided in Section 6.1.

## 6.1 Life Cycle 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 4 illustrates the life cycle system concept of natural resources and energy entering the system with products, waste and emissions leaving the system.

**Figure 4: Life cycle system concept**



The International Standards Organisation (ISO) has defined LCA as (AS/NZS ISO 14041:1998):

> "a technique for assessing the environmental aspects and potential impacts associated with a product by:
>
> Compiling an inventory of relevant inputs and outputs of a product system; Evaluating the potential environmental impacts associated with those inputs and outputs; and Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study".

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 5.

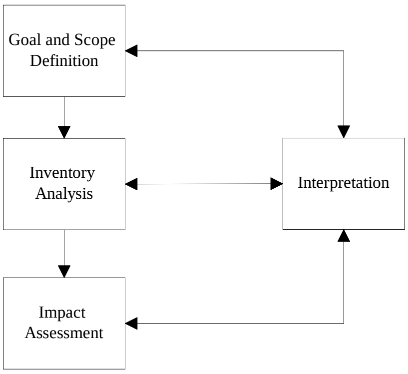


**Figure 5: The components of an LCA (AS/NZS 1998)**

### *6.1.1 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.

### *6.1.2 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 results include a process flow chart and a list of all environmental inventories (inventory table) that are associated with the product under study.

### *6.1.3 Impact assessment*

The primary aim of an impact assessment is to identify and establish a linkage 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.

### *6.1.4 Interpretation*

Interpretation is a systematic evaluation of the needs and opportunities to reduce the environmental burden, such as changes in product, process and service design, and reductions in raw material and/or energy usage.

## 6.2 Sima Pro®

The LCA comparison was undertaken using the Sima Pro® software package to create life cycle models of each product type which could then be analysed to determine various potential environmental impacts.

Sima Pro® is the most widely used Life Cycle Assessment software in the world. Introduced in 1990 in response to industry needs, the Sima Pro® product family facilitates the application of LCA using transparent analysis tools (process trees, graphs and inventory tables).

# 7 Life Cycle Inventory

The following sections summarise the information used to calculate environmental flows associated with both the crushed concrete aggregate process and the quarried stone aggregate process. In most cases, tables describe environmental flows per reference unit.

Key elements of background data used to undertake the study include life cycle inventories for diesel, electricity supply and mains water supply.

> Diesel – Impacts are based on a Swiss model of excavation machinery. It assumes that all diesel used in this inventory is burned in heavy machinery, therefore attracts all associated impacts including extraction, refining, supply, combustion and machinery related impacts (Ecoinvent 2.0, 2007).
>
> Electricity – Impacts are based an the inventory of impacts for Victorian high voltage electricity supply. Impacts incorporate the mix of supply sources and distribution losses. Data is based on Electricity Supply Association of Victoria information, Australian Greenhouse Office information and National Pollutant Inventory data (Australian Data Inventory, 2004). Refer Figure 6 for global warming breakdown of electricity supply.

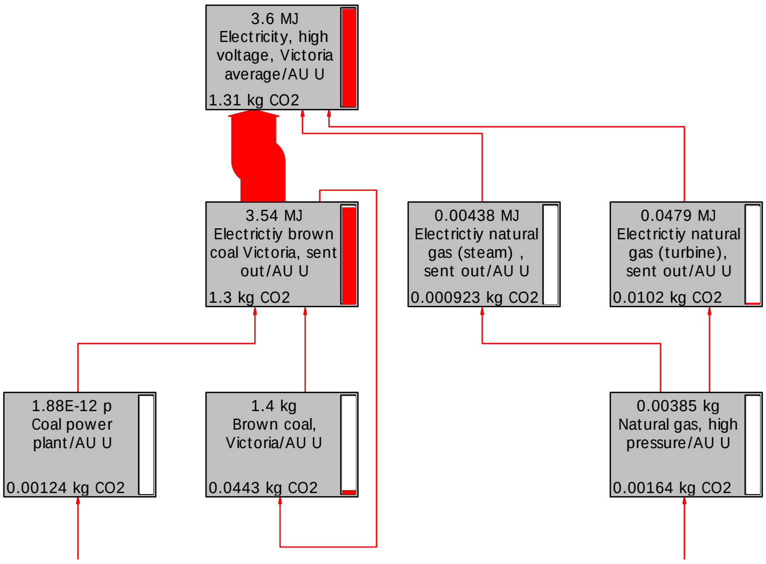


**Figure 6 Global warming impacts for 1 kWh (3.6 megajoules) of electricity supplied in Victoria, Australia*.**

*Network diagrams - Each box on the chart represents a process involved in land spread scenario. At the lower left corner of each process box is the relative contribution to the total global warming impact that the respective process provides. The arrows in the chart reflect resulting flow of contribution from each process and their thickness reflects the relative importance (proportionate to the contribution percentage in the lower left corner of each box). Note that in this figure negative impacts are shown in red and offsetting positive impacts in green.

> Mains water – Impacts based on water supply inventories generated by the Centre for Design based on experience undertaking LCA's associated with water infrastructure and operation (Australian Data Inventory,1999)

## 7.1 Crushed concrete aggregate

Crushed concrete aggregate is manufactured by Alex Fraser at three locations across Melbourne. The Laverton North manufacturing facility is used as the basis for the inventory, and is considered representative of the process in general.

The crushed concrete aggregate manufacturing process considered in this study is based upon the production processes used to produce class 2 and 3 crushed concrete and class 4 pavement base. The crushed concrete aggregate manufacturing process is described in Figure 3 (right of vertical line).

The study assumes at that 1.011t of demolition waste is required to generate 1.0t of crushed concrete aggregate. This figure was developed using the mass balance described in Figure 7.

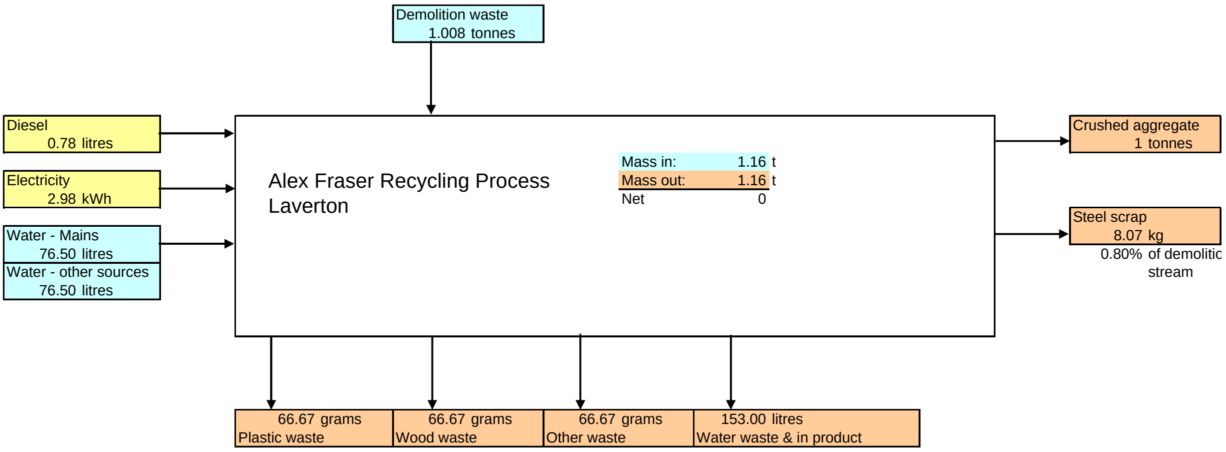


**Figure 7 Mass balance of crushed concrete aggregate process.**

Having been loaded onto a 30t articulated truck, the concrete is transported from the demolition site to the processing plant at Laverton North. Distance estimates assume that demolition waste disposal operators will only drop off waste concrete at the recycling plant if it is within a 24km radius (average 12 km) of the demolition site. Experience at Alex Fraser suggests that at greater distances, waste will be disposed of at landfill sites.

Trucking environmental impacts have been determined using a trucking inventory developed by the Centre for Design, based on Australian national averages. It is assumed that trucks carry loads in one direction only, thus are empty on the return journey. Foreground data used in this study to address transport from the demolition site to the processing plant are summarised in Table 4.

**Table 4 Transport to processing plant at Laverton North.**

| **Transport to recycling site** | | | **Source:** |
|---|---|---|---|
| 30 tonne articulated truck | | | |
| Model based on CFD LCA study of an articulated truck in Australian conditions (Australian average data). | | | |
| Utilisation to destination | 100% | | Estimate |
| Capacity return | 0% | | Estimate |
| Distance | 12 | km | Alex Fraser |
| Demolition waste (per t prod) | 1.008 | t(waste)/t(prod) | Mass balance |
| Transport (per tonne prod) | **12.10** | t.km/t(prod) | |

By consuming demolition waste, the crushed concrete process avoids the need to dispose of demolition waste in landfill. To account for this, both the impacts of trucking demolition waste to landfill and landfill processing impacts are subtracted from the crushed concrete process impact, in accordance with the allocation procedures described in Section 5.3.

Although there is some evidence to suggest that concrete recycling plants are closer to many building sites than landfill sites, this could not be proven. In the interests of conservatism, the distance from a demolition site to landfill was assumed to be the same as the distance to a recycling plant (12km). More generally, the three recycling plants associated with Alex Fraser's operations are all located approximately 20km from the Melbourne Central Business District (CBD). This location means that they are likely to be convenient to demolition activities in many cases, but not necessarily all. Landfills in Melbourne tend to be located at greater distances from the CBD, potentially making distances to demolition sites greater, however this will not be true in all cases. For the purposes of this study it was felt that no distance advantage should be allocated to the recycling process, as it could not be proven in all cases without undertaking a detailed transport study.

Demolition waste degradation in landfill was modelled using existing data from Ecoinvent 2.0 and processing operations were based on Australian industry datasets.

**Table 5 Transport and landfill of demolition waste.**

| **Transport and landfill of waste from building site** | | | **Source:** |
|---|---|---|---|
| 30 tonne articulated truck | | | |
| Model based on CFD LCA study of an articulated truck in Australian conditions (Australian average data). | | | |
| Utilisation to destination | 100% | | Estimate |
| Capacity return | 0% | | Estimate |
| Distance | 12 | km | Alex Fraser |
| Amount | 1.008 | t/t (prod) | |
| Transport (per tonne prod) | **12.10** | t.km/t(prod) | |
| Landfill operations are assumed to consume fuel as follows: | | | |
| Diesel to operate landfill | 1 | l/t (waste) | Australian database |
| Electricity to operate landfill | 0.8 | kWh/t (waste) | Australian database |
| Diesel and electricity use collected from landfill in NSW (Pacific Waste) in 1998. | | | |

The numerous processes that are undertaken within the site boundary at the Laverton North processing plant (as described by grey box titled 'plant boundary' on Figure 3) make it difficult to allocate impacts to individual processes. Instead, it was necessary to assess the total impact of the plant then allocate impacts to products on a production tonnage basis, in accordance with the allocation procedures described in Section 5.3.

Annual production at the Laverton North plant is described by Table 6. Impacts associated with water use on site, electricity use on site and diesel consumption on site are allocated proportionally to crushed concrete aggregate according to this production split. The implied assumption being that all products produced within the plant require similar quantities of resources and energy to produce. Given that the predominant co-product of the plant is crushed stone which is harder than concrete and therefore requires more energy to produce, this would represent a worst case assumption for crushed concrete aggregate (hardness of crushed concrete aggregate typically 80 megapascals, hardness of crushed stone typically 100 megapascals).

**Table 6 Production impact allocation basis.**

| **Product** | **Annual output (tonnes)** | **Annual output (%)** |
|---|---|---|
| Crushed concrete aggregate | 168,956 | 43% |
| Crushed stone products | 139,052 | 35% |
| Other products | 89,286 | 22% |
| Total production | 397,294 | 100% |

Water consumed in the processing plant is used to minimise dust on roads and to adjust moisture content in certain grades of product. Water is sourced from mains water (50%) and from other sources (50%) such as bores, stormwater and recycled water (Western Treatment Plant). Impacts associated with water supply are based on Centre for Design experience in assessing the life cycle impacts of water supply systems.

Foreground data used in this study to address water consumption within the processing plant are summarised in Table 7.

**Table 7 Water consumption within processing plant.**

| **Water usage on site** | | | **Source:** |
|---|---|---|---|
| Water is used primarily to suppress dust on site, | | | |
| and to correct moisture levels in outgoing product. | | | |
| Water used comes from 4 sources as follows: | | | |
| Mains water | 50% | | Alex Fraser |
| Recycled, storm, bore | 50% | | Alex Fraser |
| Total water consumption is allocated to aggregate on a | | | |
| production volume basis. | | | |
| On average 10% of a finished wet tonne is moisture | | | |
| Approx 4% of total moisture is already in concrete | | | |
| Therefore Alex Fraser add 6% = 60kg/ tonne | | | |
| Dust suppression is 3Meg/mnth/ 36,000t = 93kg/tonne | | | |
| 60kg + 93kg = 153kg/ tonne production | | | Alex Fraser |
| Water cons (per tonne prod) | **153.00** | l/t (prod) | Alex Fraser |
| 50% Mains water | **76.50** | l/t (prod) | Aust Data |
| 50% Recycled, storm, bore | **76.50** | l/t (prod) | Estimate |

Foreground data used in this study to address electricity consumption within the processing plant are summarised in Table 8. Electricity consumption is based electricity consumption of the recycling plant production processes which are separately metered.

**Table 8 Electricity consumption with processing plant.**

| **Electricity usage on site** | | | **Source:** |
|---|---|---|---|
| Electricity is used to provide a number of services | | | |
| across the Alex Fraser site, that include: | | | |
| Crushing processes | | | |
| Conveyor belt systems | | | |
| Pug mill (moisture adjustment) | | | |
| Laboratory functions | | | |
| Total electricity consumption is allocated to aggregate on a | | | |
| production volume basis. | | | |
| Electricity use total: | 1182831 | kWh/yr | Alex Fraser |
| Production volume total: | 397294 | t/year | Alex Fraser |
| Elec consumed (per tonne prod) | **2.98** | kWh/t (prod) | |

Heavy machinery is used across the site to perform various processes. Fuel used by this machinery (and that used to collect recycled water) is summarised in Table 9. Fuel usage data is colleted by Alex Fraser who accurately record fuel usage information at an ‘in plant’ fuel bowser.

Total diesel impacts are based on a Swiss model of excavation machinery (described at the start of Section 7). The adapted model assumes that all diesel used is burned in heavy machinery, therefore attracts all associated impacts including extraction, refining, supply, combustion and machinery related impacts such as oil use.

**Table 9 Diesel used within the processing plant.**

| **Diesel equipment usage on site** | | | **Source:** |
|---|---|---|---|
| Diesel vehicles are used across the Alex Fraser site to undertake activities as follows: | | | |
| Cracking large boulders | | | |
| Loading of crusher | | | |
| Water spreading - by truck | | | |
| Other tasks on site | | | |
| All vehicle impacts have been summarised based on known fuel consumption per annum. | | | |
| Total fuel consumption allocated to aggregate on a production volume basis. | | | |
| Fuel consumption total: | 308117 | l/year | Alex Fraser |
| Production volume total: | 397294 | t/year | Alex Fraser |
| Fuel consumed (per tonne prod) | **0.78** | l/t (prod) | |

In processing demolition waste into crushed concrete aggregate, wastes and co-products are generated. With the exception of steel, it is assumed that all waste products generated on site are allocable on a production basis. Steel is considered an exception to this rule because it enters the processing plant solely within reinforced concrete so is extracted solely by the crushed concrete aggregate process.

In addition, throughout the process dust is generated by machinery and road traffic. For the purpose of this LCA, dust emissions are assumed to be managed within legal minimum requirements, and were excluded from the impact assessment.

By-products generated are summarised in Table 10.

**Table 10 By-products from production.**

| **By-products from production** | | | **Source:** |
|---|---|---|---|
| Mixed waste to landfill | **200** | g/t (prod) | Alex Fraser |
| Assume even mix between plastic, wood and other | | | |
| Plastics to landfill | 66.67 | g/t (prod) | Alex Fraser |
| Wood to landfill | 66.67 | g/t (prod) | Alex Fraser |
| Other waste to landfill | 66.67 | g/t (prod) | Alex Fraser |
| Steel generated | 0.80% | of demo waste | Alex Fraser |
| Steel generated (per tonne prod) | **8.07** | kg/t (prod) | |

Material leaving the processing plant consists of crushed concrete aggregate product, steel for recycling, and waste materials for landfill.

Crushed concrete aggregate is delivered to the building site using 30t articulated trucks. Distance to the building site is estimated to be 8km on average, based on the known preference of construction groups to source materials within an approximate radius of 15km.

Environmental impacts from trucking have been determined using a trucking inventory developed by the Centre for Design, based on Australian national averages. It is assumed that trucks carry loads in one direction and are empty on the return journey. Foreground data used in this study to address transport from the processing plant to the building site are summarised in Table 11.

**Table 11 Outbound transport to the building site.**

| **Transport aggregate to building site** | | | **Source:** |
|---|---|---|---|
| 30 tonne articulated truck | | | |
| Model based on CFD LCA study of an articulated truck | | | |
| in Australian conditions (Australian average data). | | | |
| Utilisation to destination | 100% | | Estimate |
| Capacity return | 0% | | Estimate |
| Distance | 8 | km | Alex Fraser |
| Amount | 1 | t/t (prod) | |
| Transport (per tonne prod) | **8.00** | t.km/t(prod) | |

Waste materials generated by the production process are transported to landfill. Waste degradation in landfill was modelled for each of the materials deposited using existing data inventories as described in Table 12. Primary impacts of landfill disposal are associated with transport, landfill management processes and space occupied in the landfill.

**Table 12 Waste disposal in landfill.**

| **Impacts of waste disposal to landfill** | | | **Source:** |
|---|---|---|---|
| Mixed waste to landfill | **200** | g/t (prod) | Alex Fraser |
| Assume even mix between plastic, wood and other | | | |
| Plastics to landfill | 66.67 | g/t (prod) | Alex Fraser |
| Assumed typical Australian landfill management practice | | | Australian Database |
| Applied polypropylene breakdown in landfill | | | based on Ecoinvent 2.0 |
| Wood to landfill | 66.67 | g/t (prod) | Alex Fraser |
| Assumed typical Australian landfill management practice | | | Australian Database |
| Applied timber breakdown in landfill | | | based on Ecoinvent 2.0 |
| Other waste to landfill | 66.67 | g/t (prod) | Alex Fraser |
| Assumed typical Australian landfill management practice | | | Australian Database |
| Applied inert waste breakdown in landfill | | | based on Ecoinvent 2.0 |

Foreground data used in this study to address transport from the processing plant to the landfill are summarised in Table 13. Transport distance was based on known distance to landfill from the Laverton North recycling plant.

**Table 13 Transport of waste materials to landfill.**

| **Transport waste to landfill from Laverton plant** | | | **Source:** |
|---|---|---|---|
| 30 tonne articulated truck | | | |
| Model based on CFD LCA study of an articulated truck | | | |
| in Australian conditions (Australian average data). | | | |
| Utilisation to destination | 100% | | Estimate |
| Capacity return | 0% | | Estimate |
| Distance | 4 | km | Alex Fraser |
| Amount | 2.00E-04 | t/t (prod) | |
| Transport (per tonne prod) | **0.00** | t.km/t(prod) | |

Steel extracted from the processing plant is trucked to a local steel recycling facility. Trucking data assumed are summarised in Table 14.

**Table 14 Transport of steel to recycling plant.**

| **Transport steel to recycle** | | | **Source:** |
|---|---|---|---|
| 30 tonne articulated truck | | | |
| Model based on CFD LCA study of an articulated truck | | | |
| in Australian conditions (Australian average data). | | | |
| Utilisation to destination | 100% | | Estimate |
| Capacity return | 0% | | Estimate |
| Distance | 20 | km | Alex Fraser |
| Amount | 0.008 | t/t (prod) | |
| Transport (per tonne prod) | **0.16** | t.km/t(prod) | |

Steel generated is assumed to be reprocessed into structural grade steel. Reprocessing is assumed to involve washing of steel scrap then re-melting of scrap in an Electro Arc Furnace (EAF). The inventory of impacts associated with these processes is based on National Pollutant Inventory data associated with a typical steel recycling process.

Once reprocessing impacts have been assessed, a unit of structural steel generated is assumed to avoid a proportion of a unit of structural steel produced in Australia in accordance with the Method C described in Appendix A.

## 7.2 Quarried stone aggregate

Quarried stone aggregate is manufactured at numerous sites across metropolitan Melbourne. Many of the processes used are similar to the processes used to produce crushed concrete aggregate.

The key elements of the quarried stone aggregate process are summarised in Figure 3 (left of the vertical line). For the sake of comparison, the process has been presented with equivalent processes lined up beside each other (highlighted yellow in Figure 3).

Development of the inventory associated with quarrying processes was undertaken using expertise within Alex Fraser that involved an assumption review process involving reviewers with combined experience in quarrying and concrete recycling of over 50 years. It also endeavoured to select the ‘best case’ assumptions where alternative views existed as to quarry process impacts.

Development of the inventory also involved comparison to other inventories developed in the existing body of literature. Again, a principle of selecting ‘best case’ assumptions was applied. Appendix B describes the comparison.

Water is used on site to undertake similar tasks as for crushed concrete aggregate: dust suppression and product moisture adjustment. Although water sources would vary amongst quarries, it is assumed that water is supplied from similar sources as those used to supply the Laverton North crushed concrete process. It was also acknowledged that some quarries would be mining from faces that are heavy in water, whereas others may contain little moisture. Overall, it was not possible to confidently draw a distinction between water use in the processes, so it was assumed to be the same between crushed concrete aggregate and quarried stone aggregate. Ultimately, this assumption makes it difficult to conclude a difference between crushed concrete aggregate and quarried stone aggregate when it comes to water use. The measure in retained in the study to give the reader a sense of water use to be expected through both processes, and cannot be used to differentiate the processes.

Electricity is primarily used in production to crush quarried stone in accordance with sizing requirements and it is assumed that energy required to crush stone is similar to that required to crush concrete. Electricity consumption per tonne is therefore assumed to be the same as that assumed for crushed concrete aggregate production. This assumption is considered to be a ‘best case’ assumption as stone is typically harder than concrete so requires more energy to crush (crushed concrete aggregate typically has a hardness of 80 megapascals whereas crushed stone typically has a hardness of 100 megapascals).

Diesel consumption is treated somewhat differently to that of the recycled concrete process. For the most part, the processes that consume diesel in a stone quarry are similar to those undertaken in the concrete recycling plant. For this reason, fuel consumption is assumed to be identical per tonne of concrete produced, with the exception of one process “Movement from rock face to crusher”. This process is assumed to be incremental to the processes required under a crushed concrete production process. For this reason an incremental fuel requirement is incorporated that covers the movement of rock from the rock face to the crusher, as described in Table 15 (a sensitivity to variation in this assumption is calculated in Section 10.3).

**Table 15 Diesel equipment usage on site (quarried stone aggregate)**

| **Diesel equipment usage on site (quarried aggregate)** | | | **Source:** |
|---|---|---|---|
| Diesel vehicles are used across a quarry site | | | |
| to undertake activities as follows: | | | |
| Cracking large boulders | | | |
| Loading of crusher | | | |
| Water spreading - by truck | | | |
| Other tasks on site | | | |
| General vehicle impacts are assumed to identical to the concrete | | | |
| recycling process, which consumes: | | | |
| Fuel consumed (per tonne prod) | 0.78 | l/t (prod) | Alex Fraser |
| In addition to the above processes, it is assumed that a traditional | | | |
| quarry also consumes fuel to move rock from the blasting face | | | |
| to the crusher. This ADDITIONAL process is assumed to require | | | |
| fuel as follows: | | | |
| 50 tonne dump truck hauling rock from face | | | |
| to crusher: | | | |
| Fuel cons of truck | 55 | l/hr | Alex Fraser |
| Haulage time assumed | 10 | minutes | Estimate |
| Fuel used | 9.17 | l | |
| Fuel consumed (per tonne prod) | 0.17 | l/t (prod) | |
| Total fuel consumption (per tonne prod) | **0.94** | l/t (prod) | Estimate |

Unlike the crushed concrete aggregate process, the quarried stone aggregate process does not generate waste products or by-products so no impacts are assumed for these activities.

Dust generated is assumed to be similar to that generated as part of the crushed concrete aggregate process and is assumed to be managed within legal requirements.

Transport of quarried stone aggregate to the building site is estimated to be identical that assumed for crushed concrete aggregate (8km). Foreground data used to estimate transport impacts are summarised in Table 16.

**Table 16 Outbound transport to building site.**

| **Transport quarried aggregate to building site** | | | **Source:** |
|---|---|---|---|
| 30 tonne articulated truck | | | |
| Model based on CFD LCA study of an articulated truck | | | |
| in Australian conditions (Australian average data). | | | |
| Utilisation to destination | 100% | | Estimate |
| Capacity return | 0% | | Estimate |
| Distance | 8 | km | Alex Fraser |
| Amount | 1 | t/t (prod) | |
| Transport (per tonne prod) | **8.00** | t.km/t(prod) | |

In order to further explore potential differences in transport distances a sensitivity analysis has been conducted, which will be discussed in Section 10.

## 7.3 Key process similarities and differences

Similarities exist between the processes modelled that can be difficult to visualise in when reviewing separate inventories. For this reason a table comparing key assumptions used in both processes is shown in Table 17.

**Table 17 Key differences between processes.**

| | **Quarried stone aggregate** | | **Crushed concrete aggregate** | |
|---|---|---|---|---|
| Transport of raw material to crushing plant | none | | 12 | km |
| | Movement from face to crusher<br>Cracking large boulders<br>Loading of crusher<br>Water spreading<br>Other uses on site | | Cracking large boulders<br>Loading of crusher<br>Water spreading<br>Other uses on site | |
| Heavy vehicle fuel consumption within plant | 0.94 | l/t | 0.78 | l/t |
| Electricity use on site | 2.98 | kWh/t | 2.98 | kWh/t |
| Water use onsite | 153.00 | l/t | 153.00 | l/t |
| Waste generated by recycling process | none | | 200.00 | t/yr |
| Transport of waste to landfill | none | | 4 | km |
| Transport of aggregate to building site | 8 | km | 8 | km |
| Transport steel to recycling | none | | 20 | km |
| | | | | |
| Avoided products | | | | |
| Steel | none | | 8.07 | kg/t |
| Transport and landfill of demolition waste | none | | 1.01 | t |

# 8 Results

LCA results were calculated over the life of the aggregate products considered as described by the system boundary (Section 5.2).

Results have been presented in two forms: i) characterised results, and ii) normalised results.

## 8.1 Results Characterisation

The Life Cycle Characterisation applies the Assessment Method (refer Section 5.4) to the inventory developed in order to determine absolute environmental impacts per reference unit (1 tonne of aggregate at the building site). All impacts identified in the Life Cycle Inventory (Section 7) are added and interpreted using the Assessment Method to give the impact per reference unit (Section 5.1).

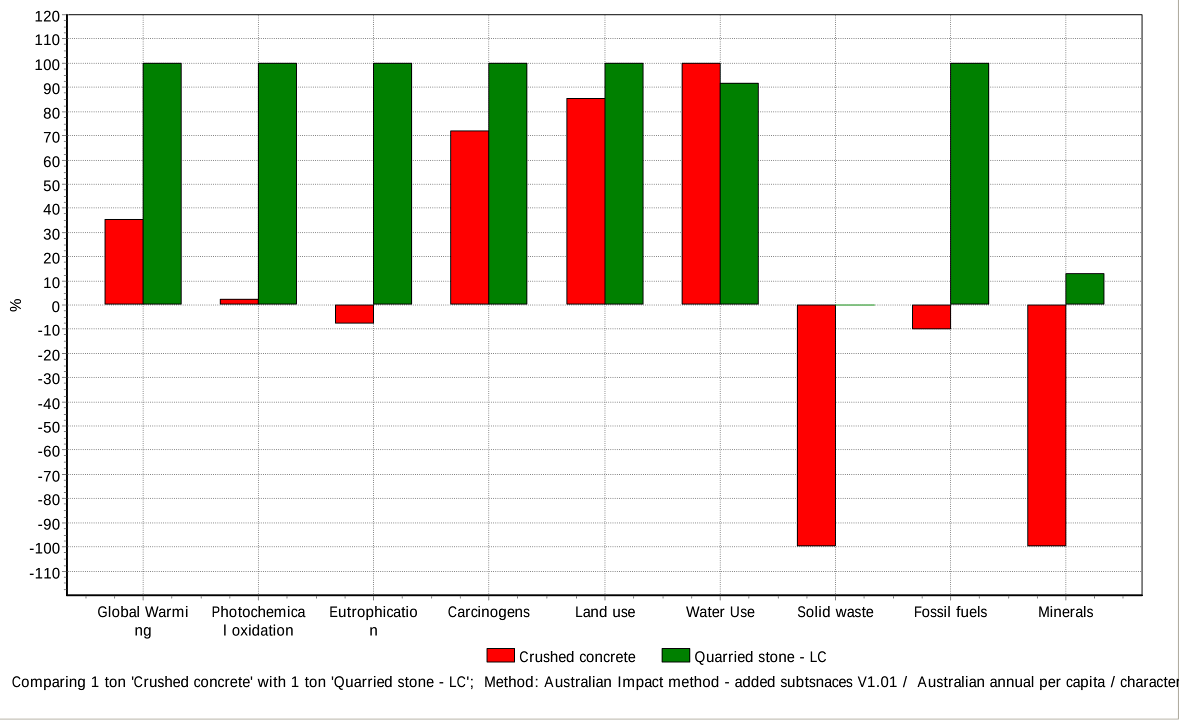


Figure 8 Comparison of life cycle impacts of aggregate (negative values reflect benefits).

**Table 18 Characterisation of life cycle impacts of aggregate (per tonne produced) - typical units.**

| **Impact category** | **Unit** | **Crushed concrete aggregate** | | | | **Quarried stone aggregate** | |
|---|---|---|---|---|---|---|---|
| | | Concrete recycling processes | Avoided steel manufacture | Avoided transport and landfill | **Total impact** | **Total impact** | **Difference (CCA less CSA)** |
| Global Warming | kg CO2 | 1.07E+01 | -1.32E+00 | -6.20E+00 | **3.14E+00** | **8.88E+00** | -5.73E+00 |
| Photochemical oxidation | kg C2H2 | 4.81E-02 | -1.86E-02 | -2.93E-02 | **5.09E-04** | **2.15E-02** | -2.10E-02 |
| Eutrophication | kg PO4--- eq | 7.44E-03 | -2.85E-03 | -5.15E-03 | **-5.54E-04** | **7.03E-03** | -7.59E-03 |
| Carcinogens | DALY | 8.07E-08 | -1.41E-08 | -5.30E-09 | **6.13E-08** | **8.52E-08** | -2.39E-08 |
| Land use | Ha a | 2.29E-05 | 3.60E-07 | -5.79E-09 | **2.32E-05** | **2.72E-05** | -3.98E-06 |
| Water Use | KL H2O | 1.33E-01 | 1.82E-02 | -3.27E-03 | **1.48E-01** | **1.36E-01** | 1.21E-02 |
| Solid waste | kg | 6.91E-02 | -1.77E+00 | -1.01E+03 | **-1.01E+03** | **6.70E-02** | -1.01E+03 |
| Fossil fuels | MJ surplus | 1.09E+01 | -4.31E+00 | -7.51E+00 | **-8.56E-01** | **8.29E+00** | -9.14E+00 |
| Minerals | MJ Surplus | 3.17E-02 | -3.29E-01 | -5.12E-06 | **-2.97E-01** | **3.80E-02** | -3.35E-01 |

* Focus indicators highlighted.

Factors used to undertake the characterisation are provided as part of the Australian Impact Assessment Method, and are described in Appendix E.

### *8.1.1 Results Characterisation – equivalent units for reference only*

In an attempt to make interpretation of results more meaningful, the characterisation presented in Table 18 is recalculated in terms of alternative units and shown in Table 19.

**Table 19 Characterisation of life cycle impacts of aggregate (per tonne produced) - equivalent units.**

| **Impact category** | **Unit** | **Crushed concrete aggregate** | | | | **Quarried stone aggregate** | |
|---|---|---|---|---|---|---|---|
| | | Concrete recycling processes | Avoided steel manufacture | Avoided transport and landfill | **Total impact** | **Total impact** | **Difference (CCA less CSA)** |
| Global Warming | Balloons | 2.12E+02 | -2.64E+01 | -1.24E+02 | **6.20E+01** | **1.77E+02** | -1.15E+02 |
| Minerals & fuel | House E days | 5.40E-02 | -1.97E-02 | -3.89E-02 | **-4.61E-03** | **4.96E-02** | -5.42E-02 |
| Photochemical oxidation | km car trave | 5.76E+01 | -2.23E+01 | -3.51E+01 | **6.10E-01** | **2.57E+01** | -2.51E+01 |
| Eutrophication | L grey water | 5.97E+02 | -2.29E+02 | -4.13E+02 | **-4.45E+01** | **5.65E+02** | -6.09E+02 |
| Carcinogens | kg Arsenic | 6.11E-06 | -1.07E-06 | -4.01E-07 | **4.65E-06** | **6.46E-06** | -1.81E-06 |
| Land use | Footy fields | 1.10E-06 | 1.75E-07 | -2.85E-09 | **1.27E-06** | **1.23E-06** | 4.51E-08 |
| Water Use | 10l Buckets | 1.32E+01 | 1.82E+00 | -3.27E-01 | **1.47E+01** | **1.35E+01** | 1.23E+00 |
| Solid waste | kg rubbish | 6.91E-02 | -1.77E+00 | -1.01E+03 | **-1.01E+03** | **6.69E-02** | -1.01E+03 |
| Cumulative energy demand | House E days | 7.41E-01 | -1.43E-01 | -4.84E-01 | **1.14E-01** | **6.90E-01** | -5.76E-01 |

* Focus indicators highlighted.

Description of alternative units:

- Global warming (number of black balloons (50g)) source: www.saveenergy.vic.gov.au
- Cumulative energy demand - (daily household energy use - 51.4GJ/hh p.a. average /365 = 141MJ per hh per day) Source: Wilkenfeld, G., 1998, Household Energy Use in Australia,www.energyrating.gov.au
- Depletion of mineral resources and fossil fuels (daily household energy use - 51.4GJ/hh p.a. average /365 = 141MJ per hh per day) Source: Wilkenfeld, G., 1998, Household Energy Use in Australia,www.energyrating.gov.au
- Photo-oxidation (number of kilometers of typical Australian passenger verhicle opeartion)
- Eutrophication (number of litres household grey water (untreated)) - Untreated houseold grey water (TP 3.46mg/L) (calculated: 3.46E-6*3.6=1.25E-5 PO4 eq (P basis)) Source: Sustainability of Alternative Water Servicing Options, 2004
- Carcinogens (kg of Arsenic released to soil (1.32E-2 Daly)) - based on assessment Australian Impact Method

- Land use (number of MCG football areas (20290m2, 2.029Ha a) taken up by activities such as farming, powergeneration facilities) source: www.mcg.org.au
- Water use (buckets * based upon 10 litre volume)
- Solid waste (kg of rubbish).

## 8.2 Normalised results

Normalised results alter the characterisation results to give an indication of the relative significance of the indicators to each other. Comparison of indicators with quite different units of measure is achieved by dividing the characterisation results by the per-capita environmental impact of an average Australian. The normalised results should not be interpreted as describing which indicators are most important, rather they should be viewed as describing environmental impacts relative to a known baseline impact (good bad or indifferent).

Normalisation was undertaken using the factors provided for under the Australian Impact Assessment method, and are described in Appendix E.

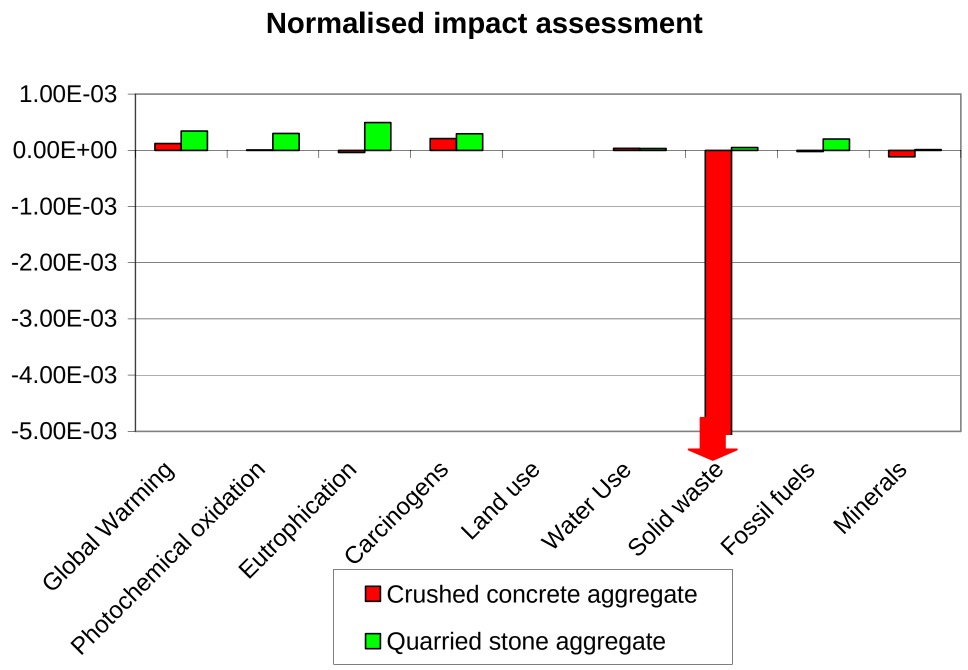


**Figure 9 Comparison of normalised (unitless) life cycle impacts of aggregate (normalised results - Australian per capita). Negative results indicate benefits.**

# 9 Discussion

Significant differences were found to exist between the life cycle impacts of the aggregates considered. Although similarity existed between impacts associated with water use, large differences existed in energy related indicators such as global warming, photochemical oxidation and fossil fuels. Negative impacts (benefits) associated with the production of crushed concrete aggregate are largely driven by the allocation of avoided product impacts associated with the production of steel and avoided landfill operations and transport.

The normalised results suggest that the Australian per capita impact is most influenced by the solid waste impacts that occur under the quarried stone aggregate process associated with the avoided landfilling of building waste.

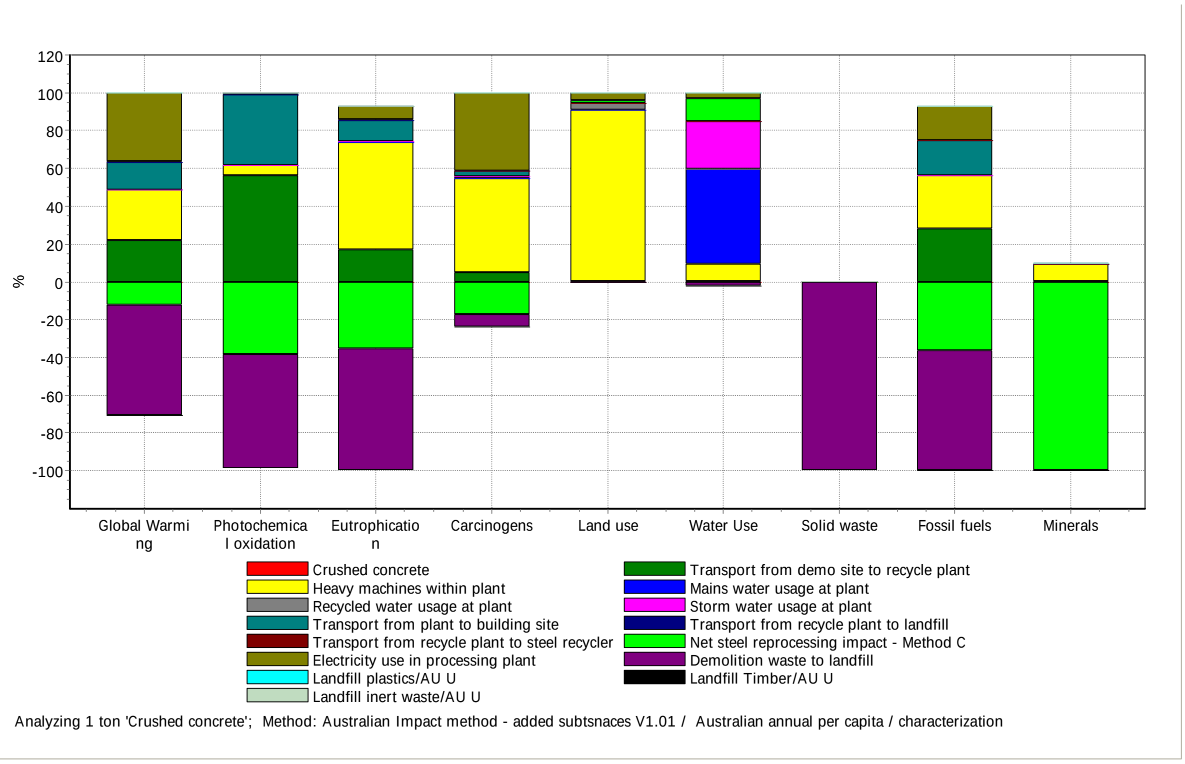
In addition, the normalised results suggest that impact categories of land use and water use represent small overall contributions to national per-capita impacts.

## 9.1 Drivers of environmental impact - crushed concrete aggregate

Figure 10 identifies those processes that contribute to the impacts described by each indicator for crushed concrete aggregate.

Impacts associated with the crushed concrete process are driven primarily by i) transport from the demolition site to the processing plant, ii)heavy machine usage within the plant and by ii) transport from the plant to the building site.

Substantial negative impacts (benefits) are associated with avoided steel production in most indicators, and landfill avoidance, including avoided transport to landfill.



Analyzing 1 ton 'Crushed concrete'; Method: Australian Impact method - added subtsnaces V1.01 / Australian annual per capita / characterization

**Figure 10 Drivers of environmental impacts – Crushed concrete aggregate (positive values are impacts, negative values are benefits associated with avoided impacts).**

Considering the global warming indicator in isolation, impacts are driven by processes as shown in Table 20. These global warming impacts are shown diagrammatically in the network diagram shown in Figure 11. In general the figures show that primary global warming impacts are driven by transport to and from the plant, machinery use within the plant, and electricity use. These impacts are substantially offset by benefits associated with steel recovery and landfill avoidance (including transport).

**Table 20 Global warming contribution by process for 1 tonne of crushed concrete aggregate (negative values indicate avoided impacts).**

| | Global warming impact (kgCO2) |
|---|---:|
| Transport from demo site to recycle plant | 2.36 |
| Heavy machines within plant | 2.83 |
| Mains water usage at plant | 0.01 |
| Recycled water usage at plant | 0.00 |
| Storm water usage at plant | 0.00 |
| Transport from plant to building site | 1.56 |
| Transport from recycle plant to landfill | 0.00 |
| Transport from recycle plant to steel recycler | 0.03 |
| Net steel reprocessing impact | -1.32 |
| Electricity use in processing plant | 3.90 |
| Demolition waste to landfill | -6.22 |
| Landfill plastics | 0.00 |
| Landfill Timber | 0.00 |
| Landfill other | 0.00 |
| Total | **3.14** |

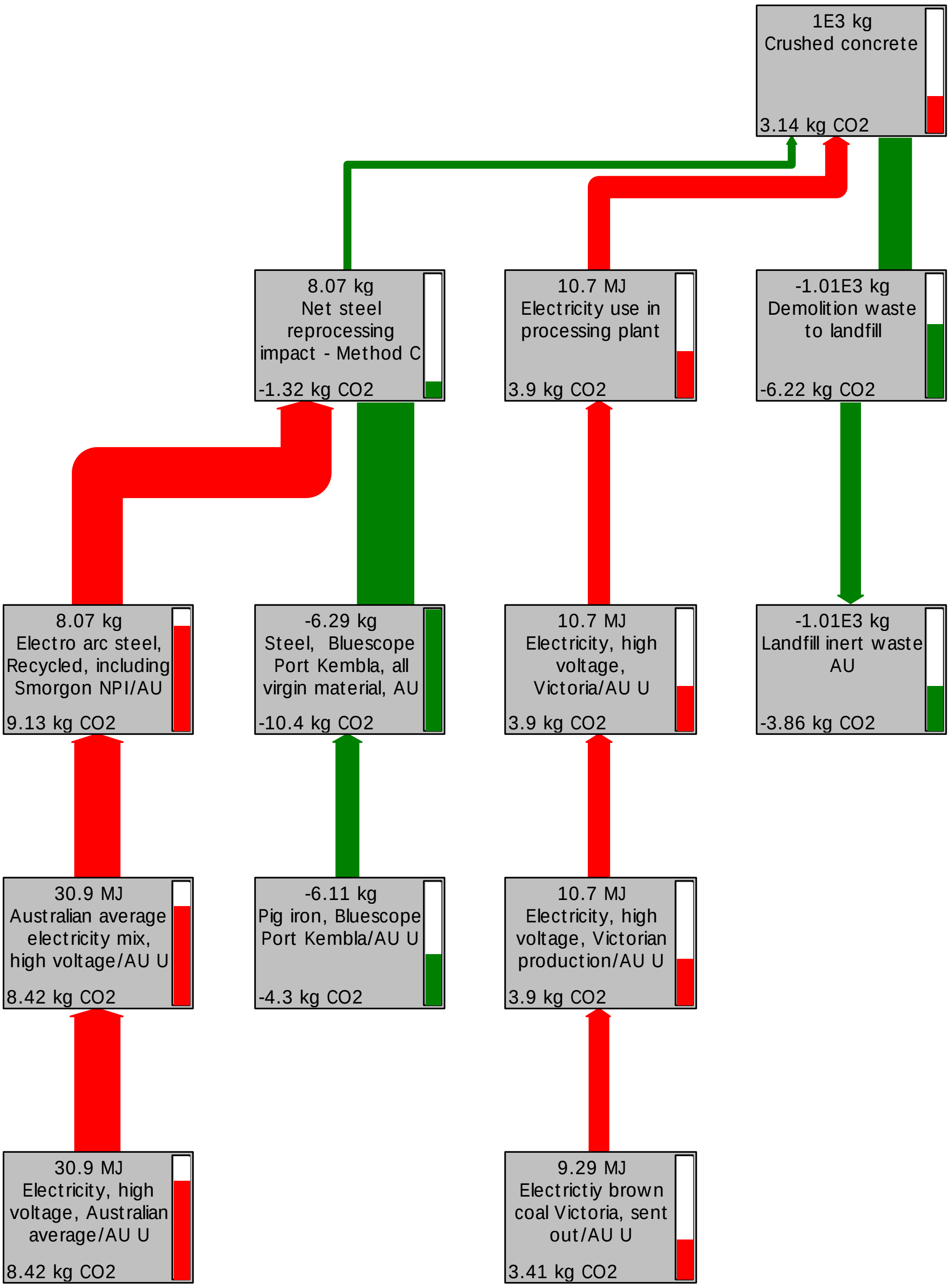


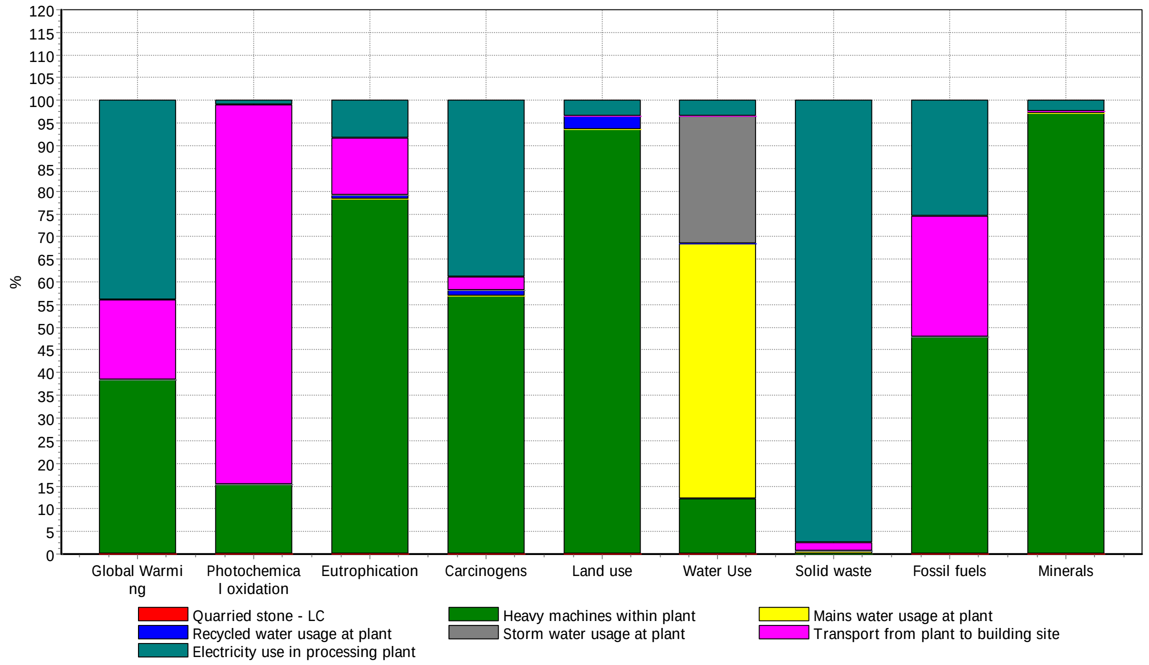
**Figure 11 Network diagram* illustrating drivers of global warming impacts for crushed concrete aggregate (30% contribution or greater shown).**

*Network diagrams - Each box on the chart represents a process involved in land spread scenario. At the lower left corner of each process box is the relative contribution to the total global warming impact that the respective process provides. The arrows in the chart reflect resulting flow of contribution from each process and their thickness reflects the relative importance (proportionate to the contribution percentage in the lower left corner of each box). Note that in this figure negative impacts are shown in red and offsetting positive impacts in green.

## 9.2 Drivers of environmental impact – quarried stone aggregate

Quarried stone aggregate's impact assessment is different to that of crushed concrete aggregate in that it contains no avoided product allocation benefits (such as steel or landfill avoidance). This means that each process impact is positive which simplifies interpretation.

Figure 12 identifies the processes that contribute the impacts associated with quarried stone aggregate. Significant impacts are associated with delivery of aggregate to the building site, consumption of diesel in heavy machinery on site and electricity use.



Analyzing 1 ton 'Quarried stone - LC'; Method: Australian Impact method - added subtsnaces V1.01 / Australian annual per capita / characterization

**Figure 12 Drivers of environmental impacts - Quarried stone aggregate.**

Considering the global warming indicator in isolation, impacts are driven by processes as shown in Table 21. These global warming impacts are shown diagrammatically in the network diagram shown in Figure 13. In general the figures show that primary global warming impacts are driven by transport from the plant to the building site, machinery use within the plant, and electricity use.

**Table 21 Global warming contribution by process for 1 tonne of quarried stone aggregate.**

| | Global warming impact (kgCO2) |
|---|---:|
| Heavy machines within plant | 3.41 |
| Mains water usage at plant | 0.01 |
| Recycled water usage at plant | 0.00 |
| Storm water usage at plant | 0.00 |
| Transport from plant to building site | 1.56 |
| Electricity use in processing plant | 3.90 |
| Total | **8.88** |

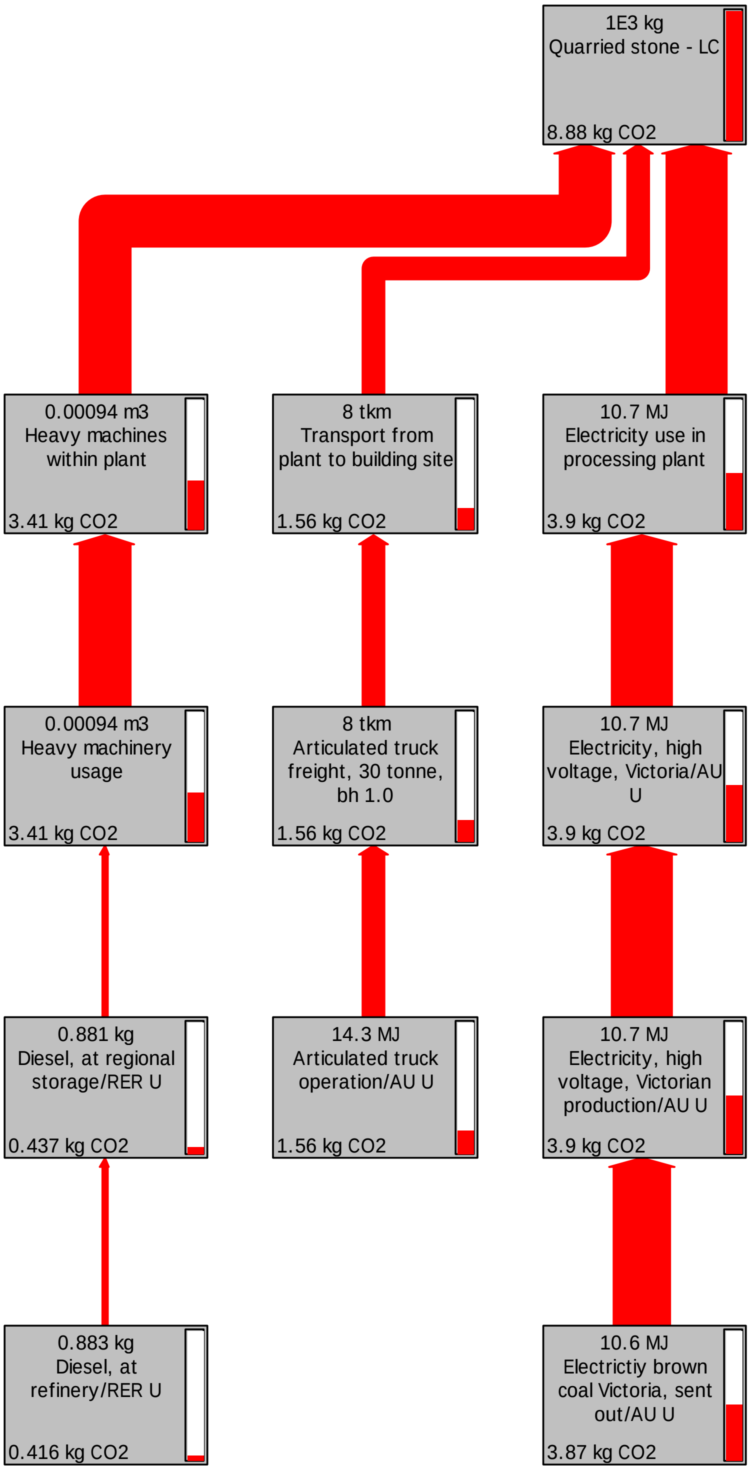


**Figure 13 Network diagram* illustrating drivers of global warming impacts for quarried stone aggregate (5% contribution or greater shown).**

*Network diagrams - Each box on the chart represents a process involved in land spread scenario. At the lower left corner of each process box is the relative contribution to the total global warming impact that the respective process provides. The arrows in the chart reflect resulting flow of contribution from each process and their thickness reflects the relative importance (proportionate to the contribution percentage in the lower left corner of each box). Note that in this figure negative impacts are shown in red and offsetting positive impacts in green.

## 9.3 Crushed concrete aggregate and quarried stone aggregate results summarised for the global warming indicator

The results presented above can be summarised on the system boundary diagram.

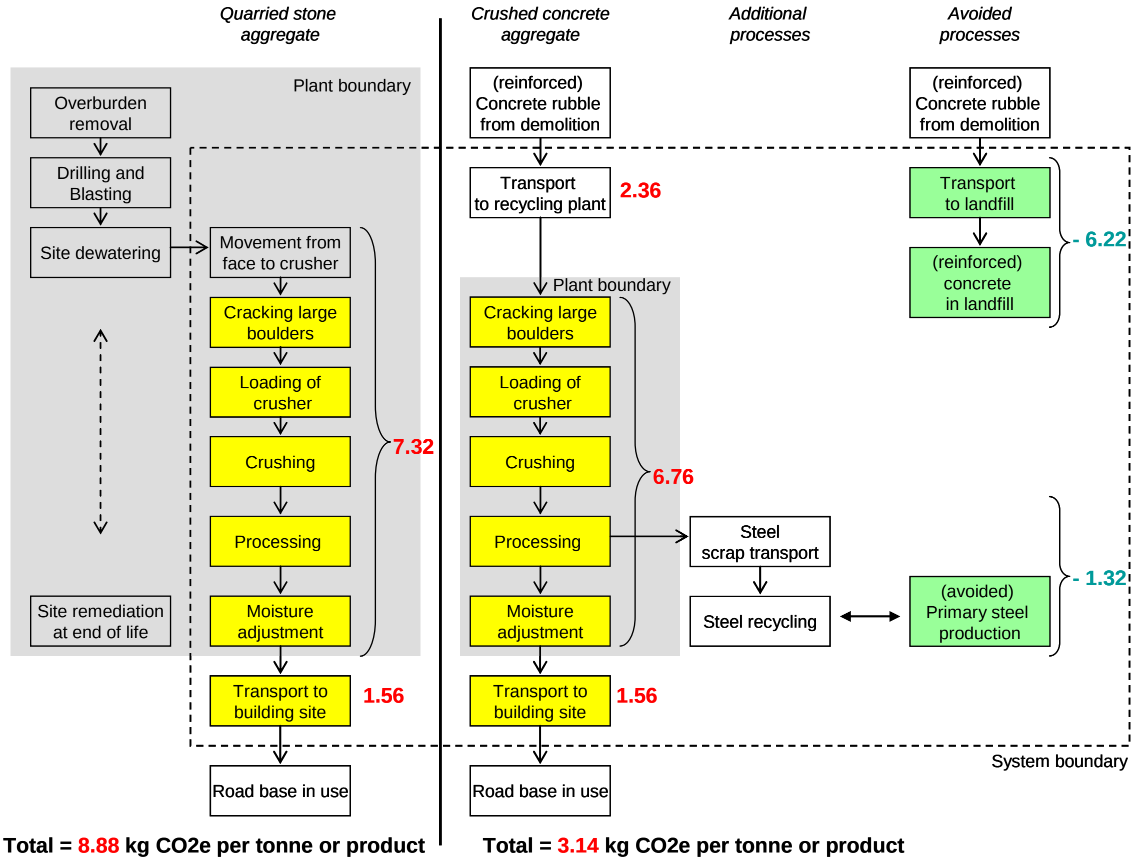


**Figure 14 Global warming results for crushed concrete aggregate and quarried stone aggregate summarised on the system boundary diagram.**

Figure 14 places the results for global warming on the system boundary diagram – impacts are shown in red, and benefits (negative impacts) are shown in blue.

# 10 Sensitivity analysis

A number of sensitivity analyses were undertaken in order to address areas of data uncertainty and in order to better understand process relationships.

## 10.1 Transport distance to building site

Transport distances from the quarry/processing plant to the building site were considered to be identical between the aggregates analysed. This sensitivity study was undertaken to assess the impact of changed distances to the building site as described in Table 22.

**Table 22 Sensitivity scenarios to assess distance from quarry to building site.**

| | Case A: Study baseline | Case B: South East Melbourne | Case C: Quarry closer |
|---|---|---|---|
| Crushed concrete aggregate | 8km | 8km | 8km |
| Quarried stone aggregate | 8km | 20km | 4km |

The global warming impact was assessed for both product processes at the various distances described in Table 22. The result shown in Figure 15 suggests that distance to building site has a significant impact on the total global warming result for quarried stone aggregate, however even at half the delivery distance (Case C) impacts are not reduced below those of crushed concrete aggregate.

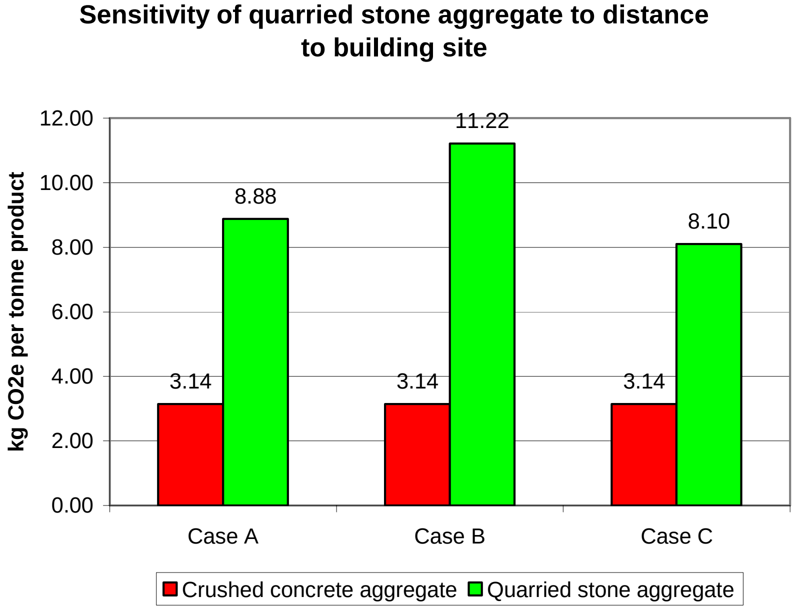


**Figure 15 Sensitivity of quarried stone aggregate to changes in distance to building site.**

### *10.1.1 The impact of material transport*

Figure 15 shows the significant impact material haulage has on overall process impacts.  To demonstrate this in detail, the global warming transport impacts alone to move one tonne of material one kilometre were assessed in isolation, as follows:

> **184 grams of $CO_2$e are emitted per tonne-kilometre of transport movement** (assumes 30 tonne articulated truck, fully loaded in one direction and empty on the return journey)

For example, if the transport distance at any phase of the process can be reduced by 5 km, then the reduction in global warming potential will be approximately 5x0.184=**0.92**kg $CO_2$e per tonne moved.

## 10.2 Avoided steel production

Avoided steel production is certainly a benefit of producing crushed concrete aggregate in preference to producing quarried stone aggregate.  However, it may be useful to understand the differences in product impacts without the allocation of avoided steel product.

This sensitivity study assumed that benefits associated with the avoidance of steel production under the crushed concrete aggregate process were ignored, as shown in Table 23.

**Table 23 Sensitivity scenarios to assess avoided steel production impacts.**

| | Case D: Study baseline | Case E: No avoided steel |
|---|---|---|
| Crushed concrete aggregate | Avoided steel production | No avoided steel production |
| Quarried stone aggregate | No avoided products | No avoided products |

The global warming impact was assessed for both product processes under the avoidance assumptions described in Table 23.  The result shown in Figure 16 suggests that although avoided steel production has an impact on the total global warming result for crushed concrete aggregate, ignoring it does not increase impacts above those of quarried stone aggregate.  This is primarily due to avoided landfill operations associated with crushed concrete aggregate.

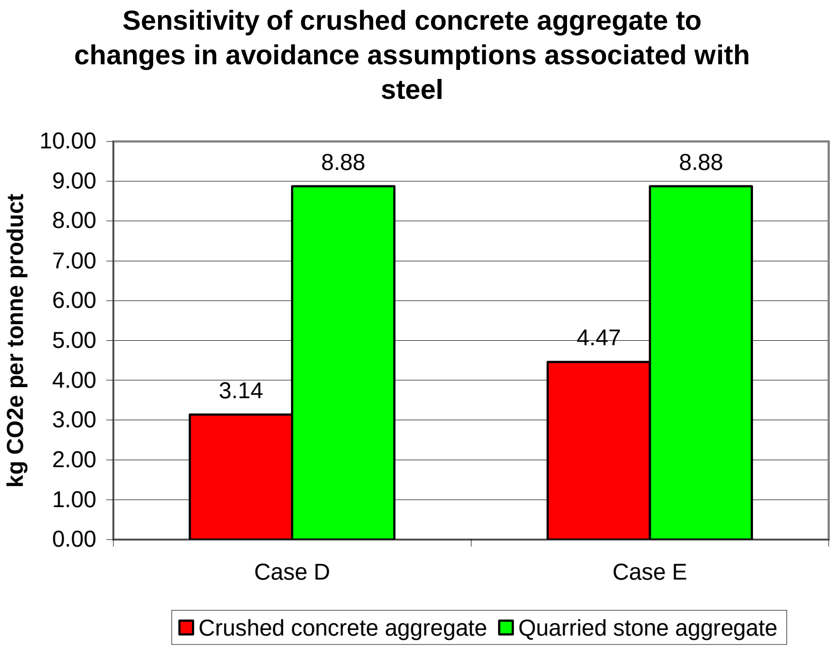


**Figure 16** Sensitivity of crushed concrete aggregate to changes in avoidance assumptions.

## 10.3 Variations in dump-truck fuel efficiency in the quarried stone aggregate process

In Section 7.2, it was stated that an additional machinery process was required when producing quarried stone aggregate versus crushed concrete aggregate. This process involved movement of blasted ore from the quarry rock face to the crushing facility. Diesel consumption during this addition process was estimated in Table 15 as being equal to 0.17 litres of diesel per tonne of aggregate produced. The estimate was based on fuel consumption figures taken from the Specifications and Applications Handbook (Komatsu 2006) over a 10 minute usage period.

To test the fuel consumption estimate, a sensitivity analysis was undertaken at alternative fuel consumption levels as shown in Table 24.

**Table 24** Sensitivity scenarios analysed to investigate variations in fuel consumption to move rock from the quarry face to the crusher.

| | Case F: Study baseline | Case G: Low fuel consumption | Case H: High fuel consumption |
|---|---|---|---|
| Fuel consumption to rate selected for dump truck (HD465-7) | Medium | Low | High |
| **Crushed concrete aggregate** | | | |
| Consumption rate: | NA | NA | NA |
| Time: | NA | NA | NA |
| Loading: | NA | NA | NA |
| Total face to crush: | NA | NA | NA |
| Total all plant operations: | 0.78 l/tonne | 0.78 l/tonne | 0.78 l/tonne |
| **Quarried stone aggregate** | | | |
| Consumption rate: | 55 l/hr | 28 l/hr | 76 l/hr |
| Time: | 10min | 10min | 10min |
| Loading: | 50 tonnes | 50 tonnes | 50 tonnes |
| Total face to crush: | 0.17 l/tonne | 0.09 l/tonne | 0.25 l/tonne |
| Total all plant operations: | 0.94 l/tonne | 0.87 l/tonne | 1.03 l/tonne |

The above consumption figures are associated with off-highway dump trucks. The usage cycles of low, medium and high are defined as shown in Table 28 for a Komatsu HD465-7 truck with a 61 tonne capacity.

**Table 25 Load range definitions (Komatsu 2006).**

Low: High ratio of loading time to cycle time, good haul road conditions. Low truck job efficiency.
Medium: Medium ratio of travelling time to cycle time, medium load factor of truck, and medium haul road conditions and grade. Total resistance; Over 2% through 10%.
High: High ratio of travelling time to cycle time, tough load factor of truck, severe haul road conditions and grade. Total resistance; 10% and above.

Although a 'low' fuel consumption level was tested, the high loading assumed (50 tonnes) may make this scenario somewhat unrealistic (low fuel consumption contradicts are high loading scenario).

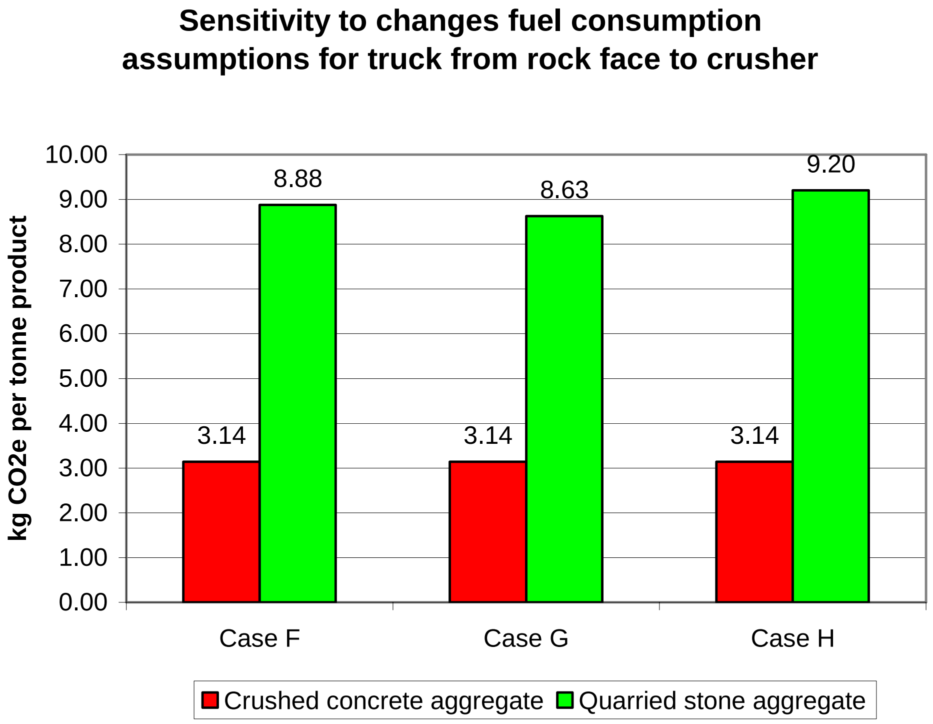


**Figure 17** **Sensitivity to changes in fuel consumption assumptions for truck from rock face to crusher.**

Figure 20 shows that altering fuel consumption assumptions for trucking rock from the face to the crusher in the quarried stone aggregate process has a minimal impact on overall impacts for quarried stone aggregate, and that study conclusions are unaltered at all efficiencies considered.

## 10.4 Sensitivity to changes in avoidance assumptions associated with landfill

The base analysis assumes that a tonne of demolition waste that is recycled avoids a tonne of demolition waste going to landfill. Although this assumption is likely to be true in the current environment, where minimal recycling capacity exists, it may not always be the case. In future, more recycling capacity is likely to be put in place that will gradually reduce the amount of material going to landfill, and ultimately displace it altogether. This sensitivity explores the impact of increased recycling capacity on the impacts associated with crushed concrete aggregate.

The scenario makes the assumption, that as recycling capacity increases, each incremental tonne of demolition waste that is recycled at a particular recycling facility, will partly deprive a competing recycling facility from receiving a unit of demolition waste, and will partly avoid landfill. The scenario assumes that recycling capacity has increased to the point where 51% of demolition rubble is being recycled and 49% is going to landfill (the same ratio as reported by EcoRecycle (2004) for general waste).

**Table 26 Sensitivity scenarios to assess changes in avoided landfill assumptions.**

| | Case D:<br>Study baseline | Case E:<br>Partial displacement of existing recycling activity |
|---|---|---|
| Crushed concrete aggregate | 100% avoidance of landfill | 49% avoidance of landfill<br>51% displacement of existing recycling activity |
| Quarried stone aggregate | No avoided products | No avoided products |

The results of the analysis are shown in Figure 18.

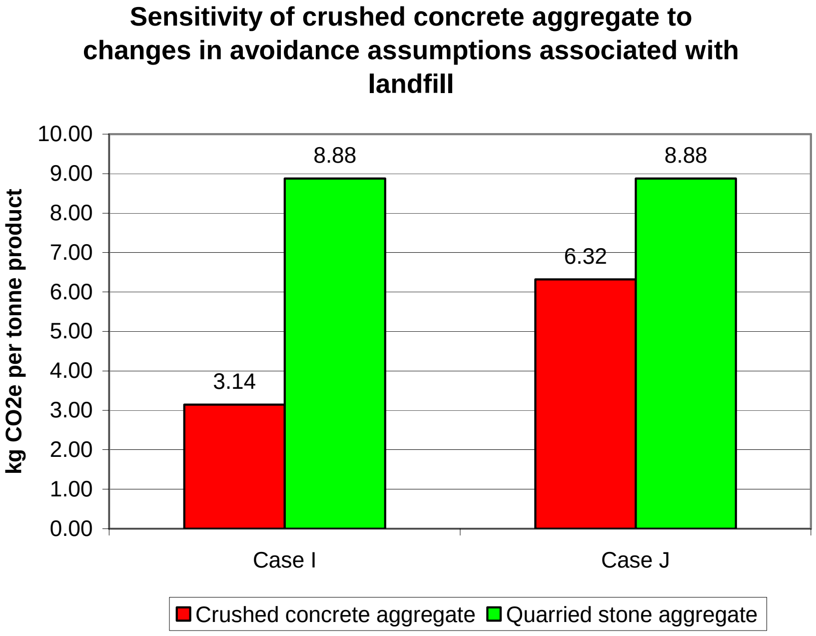


**Figure 18 Sensitivity of crushed concrete aggregate to changes in avoidance assumptions associated with landfill.**

Figure 18 shows that the impacts associated with crushed concrete aggregate are increased under the scenario where demolition waste is only partly diverted from landfill (Case J). This increase in impacts is brought about by the reduction in ‘benefit’ associated with landfill avoidance. The scenario illustrates the incremental impact a purchaser of recycled concrete aggregate might have on the environment in a market of recycling operators.

Although the incremental (or marginal) benefit of purchasing a unit of recycled aggregate diminishes as more recycling capacity is brought online, this result does not affect the inherent benefit of recycling versus landfilling.  Rather it suggests that once landfilling no longer takes place (a happy situation), the incremental benefits of recycling are reduced.

# 11 Other studies

In an effort to further cross-check the outcomes above, the study was compared to an earlier study of waste disposal and recycling practices undertaken in Victoria, Australia:

> Grant, T. and K. James (2005). Life Cycle Impact Data for Resource Recovery from Commercial and Industrial and Construction and Demolition Waste in Victoria. Melbourne, Centre For Design at RMIT.

Although the study was undertaken by the same research centre (The Centre for Design at RMIT), it was undertaken by different authors and used different assumptions.

A section of the Grant report (2005), focussed on comparing the benefits of recycling concrete aggregate versus using traditional quarried aggregates. Grant concluded that recycling concrete generated a net benefit of 29kg CO2e per tonne recycled. This is on contrast to a benefit of 5.73kg CO2e per tonne recycled shown in this study (refer Table 18). To better understand the reasons for the difference, a reconciliation was undertaken that compared the assumptions and results of both studies. The results of this reconciliation are shown in Table 27.

**Table 27 Global warming reconciliation of this study and Grant and James (2005).**

| | Quarried stone aggregate | | Crushed concrete aggregate | | Variance between quarried and cushed concrete | | |
|---|---|---|---|---|---|---|---|
| | Grant (2005) (kgCO2) | This study (kgCO2) | Grant (2005) (kgCO2) | This study (kgCO2) | Grant (2005) (kgCO2) | This study (kgCO2) | Explanation of variance |
| *Recycle process impact (excl avoided steel)* | | | *5.50* | *10.66* | | | *Grant excludes electricity and uses on-site fuel consumption 30% below this study.* |
| *Steel avoidance impacts* | | | *-16.90* | *-1.32* | | | *Although recycled steel treatment is different between studies, the difference exists because the Grant study uses older data for emissions from pig iron production (1998), versus this study which uses 2007 data, and because this study applies value corrected substitution rather than 100% virgin offset.* |
| *Landfill avoidance impacts* | | | *-9.30* | *-6.20* | | | *Landfill impacts used in Grant include additional transportation impacts, possibly associated with municipal garbage collection. These are excluded from this study.* |
| *Unknown* | | | *0.50* | | | | *Unexplained variation* |
| *Total Impact* | *8.80* | *8.88* | *-20.20* | *3.14* | *-29.0* | *-5.73* | *Small variation in quarry impacts. Grant uses European quarrying data adjusted for Australian energy profile, whereas this study uses an independently developed estimate.* |

The result shown in Table 27 shows that the bulk of the difference between the two studies can be explained. In general, assumptions used in this study reduce the emissions differences between the two systems, so reflect a more conservative view of impact differences between systems.

The first major difference is that the Grant study does not include on-site electricity use when determining the impacts of crushed concrete aggregate, and states a lower fuel consumption figure than this study.

Another major difference is associated with the avoided impacts associated with steel recycling. The grant study shows substantially greater avoided impacts due in part to the use of older data for steel manufacture (more energy intensive) and in part due to a different approach to avoided impact allocation.

Both studies are consistent with respect to avoided impacts of landfill, and the impacts associated with manufacturing quarried stone aggregate.  Given that Grant used European data for quarried stone aggregate, the result supports the adequacy of the quarried stone data used in the study.

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# 12 Conclusions

The project aimed to undertake a LCA that compared the environmental impacts of crushed concrete aggregate and quarried stone aggregate in road base applications, with a particular emphasis placed upon environmental impacts associated with greenhouse gas emissions, solid waste and water use. In addressing this aim a comparison was drawn that considered crushed concrete aggregate impacts, including avoided impacts (such as steel production and landfill of demolition waste) relative to the impacts of quarried stone aggregate.

Although somewhat hampered by a lack of detailed information regarding quarried stone aggregate production processes, strong similarities between the crushed concrete aggregate and quarried stone aggregate processes were able to be used to estimate process flows. Inventory data generated for the quarried stone aggregate processes were reviewed by a panel of experts at Alex Fraser, with a combined experience of over 50 years in quarrying and concrete recycling. Estimates were also compared to existing quarry data inventories, and 'best case' data used wherever contradictions arose. The inventory data comparisons are shown in Appendix D.

**Table 28 Characterisation results summary (study focus areas highlighted).**

| **Impact category** | **Unit** | **Crushed concrete aggregate** | | | | **Quarried stone aggregate** | |
|---|---|---|---|---|---|---|---|
| | | Concrete recycling processes | Avoided steel manufacture | Avoided transport and landfill | **Total impact** | **Total impact** | **Difference (CCA less CSA)** |
| Global Warming | kg CO2 | 1.07E+01 | -1.32E+00 | -6.20E+00 | **3.14E+00** | **8.88E+00** | -5.73E+00 |
| Photochemical oxidation | kg C2H2 | 4.81E-02 | -1.86E-02 | -2.93E-02 | **5.09E-04** | **2.15E-02** | -2.10E-02 |
| Eutrophication | kg PO4--- eq | 7.44E-03 | -2.85E-03 | -5.15E-03 | **-5.54E-04** | **7.03E-03** | -7.59E-03 |
| Carcinogens | DALY | 8.07E-08 | -1.41E-08 | -5.30E-09 | **6.13E-08** | **8.52E-08** | -2.39E-08 |
| Land use | Ha a | 2.29E-05 | 3.60E-07 | -5.79E-09 | **2.32E-05** | **2.72E-05** | -3.98E-06 |
| Water Use | KL H2O | 1.33E-01 | 1.82E-02 | -3.27E-03 | **1.48E-01** | **1.36E-01** | 1.21E-02 |
| Solid waste | kg | 6.91E-02 | -1.77E+00 | -1.01E+03 | **-1.01E+03** | **6.70E-02** | -1.01E+03 |
| Fossil fuels | MJ surplus | 1.09E+01 | -4.31E+00 | -7.51E+00 | **-8.56E-01** | **8.29E+00** | -9.14E+00 |
| Minerals | MJ Surplus | 3.17E-02 | -3.29E-01 | -5.12E-06 | **-2.97E-01** | **3.80E-02** | -3.35E-01 |

Table 28 illustrates the significant differences that were found to exist between the life cycle impacts of the aggregates considered. Although similarity existed between impacts associated with water use, large differences existed in energy related indicators such as global warming, photochemical oxidation and fossil fuels. Negative impacts – benefits - associated with the production of crushed concrete aggregate were largely driven by the allocation of avoided product impacts associated with the production of steel (photochemical smog, solid waste, fossil fuels and minerals) and the avoidance of demolition waste landfill.

Water use for both processes was assumed to be similar in both in-plant processes, hence the life cycle result is also similar. A small increase in water consumed under the crushed concrete aggregate process is associated with the re-processing of steel. Therefore, conclusions with respect to water use, although relevant to the crushed concrete process, cannot be used to draw a distinction between the products.

In general, impacts associated with crushed concrete aggregate were driven by transport to and from the plant, machinery use within the plant, and electricity use. These impacts were found to be partially offset by benefits associated with steel recovery and landfill avoidance.

With respect to quarried stone, impacts were driven by transport from the plant to the building site, machinery use within the plant, and electricity use.

Sensitivity analysis was conducted to test the impacts of key study parameters. This analysis showed no change in study conclusions under the parameters considered, but did show that transport distances play a significant role in driving total environmental impacts. The goal of the study was to study Alex Fraser recycling operations in Melbourne, so distance variation applies mainly to various delivery locations within the city. The sensitivity study result suggested that the benefits of recycled concrete were substantial enough that even when quarry sites were closer to the building site, crushed concrete aggregate could still have a lower environmental impact. To maintain an even handed approach delivery distances were assumed to be identical between crushed concrete aggregate and quarried stone aggregate.

In addition to sensitivity analysis, a comparison was done to an existing study by Grant and James (2005), that concluded greater benefits associated with crushed concrete aggregate versus quarried stone aggregate than were found in this study. A reconciliation of differences between the two studies showed that the differences were explainable, and that this study probably reflects are more conservative approach with better access to primary data.

Finally, the study has determined that crushed concrete aggregate has reduced impacts versus quarried stone aggregate under the assumptions described in most indicators. This is not to suggest that either process cannot be further improved. Scope to employ low emission energy forms, energy efficiency, emissions reduction and other such initiatives exists in both processes.

# 13 References

## 13.1 Sima Pro® background databases utilised

| **Database name** | **Description** |
|---|---|
| Ecoinvent 2.0 | The Ecoinvent data v2.0 comprise LCI data covering energy (including oil, natural gas, hard coal, lignite,nuclear energy, hydro power, photovoltaics, solar heat, wind power, electricity mixes, biofuels),transport, building materials, wood (European and tropical wood), renewable fibres, metals (including precious metals), chemicals (including petrochemical solvents and detergents), electronics, mechanical engineering (metals treatment and compressed air), paper and pulp, plastics, waste treatment and agricultural products. Swiss Centre for Life Cycle Inventories (2007). |
| Australian Input/Output database | Database developed by the University of Sydney based on national account data for the years 1998-99. |
| Australian Data Inventory | Australian LCA database developed from 1998 up to 2008 by Centre for Design from data originally developed with the CRC for Waste Management and Pollution Control as part of an Australian Inventory data project. The data from this project has been progressively updated particularly the data for metals production, energy, transport and paper and board production. |

## 13.2 Literature references

Australian Steel Institute. (2008, 13/5/2008). "Sustainability." from www.steel.org.au.

Centre for Design at RMIT (1998). Life Cycle Inventory Data: production of Steel Tinplate in Australia, CRC for Waste Management and Pollution control.

Ecorecycle Victoria (2004). Annual survey of victorian recycling industries 2002-2003. Melbourne, Ecorecycle.

Grant, T. and K. James (2005). Life Cycle Impact Data for Resource Recovery from Commercial and Industrial and Construction and Demolition Waste in Victoria. Melbourne, Centre For Design at RMIT.

Komatsu (2006). Specifications and Application Handook. Japan.

MEPS Ltd. (2008). "MEPS World Carbon Steel Prices ($US per tonne)." Retrieved 26/5/08, 2008, from www.meps.co.uk.

ISO 14040:2006 “Environmental management – Life cycle assessment – Principles and framework”

ISO 14044:2006 “Environmental management – Life cycle assessment – Requirements and guidelines”

# 14 Appendix A – Avoided impacts from steel manufacture

A key challenge of the study has been to determine the avoided impacts (benefits) associated with recycling steel. Within the Life Cycle Assessment methodology a number of approaches can be undertaken

## 14.1 Steel method A: Avoided impacts of steel recycling in a market constrained by supply of scrap steel (material pool incorporating material degradation approach).

The allocation of avoided impacts associated with recycling steel can be determined by applying a ‘material pool’ approach. The approach assumes that steel produced from scrap is preferable to steel produced from iron ore using the Basic Oxygen Furnace (BOF) process if scrap prices are below a threshold amount, and that the supply of steel produced from scrap is constrained by the supply of scrap material, not a lack of EAF production capacity. The preference for steel manufacture from scrap is indicated by the fact that scrap steel has significant value, that is driven by its usefulness in the manufacture of steel product and the fact the EAF capacity exceeds scrap steel supply quantities.

> “Although 82 percent of Australian steel is recycled and this proportion is continuing to grow, even if Australia achieved 100 percent recycling of the scrap arising and didn’t export any scrap, this recycled material could not cover most of the demand for steel. As a result, Australia’s steel industry currently needs to be predominantly structured around production from primary minerals – iron ore and coal.
> It is the global steel industry view that installing additional EAF capacity will do nothing to change the level of recycling of steel worldwide.” (Australian Steel Institute 2008)

Provided pricing of scrap is below certain thresholds, manufacturers will prefer to manufacture via the EAF process in many applications.

Injection of increased quantities of scrap steel into the steel material pool, will depress the price of scrap and therefore increase production of EAF steel versus BOF steel. Assuming no change in total demand for steel, the result is displacement of steel produced from virgin materials via the BOF process (refer Figure 19).

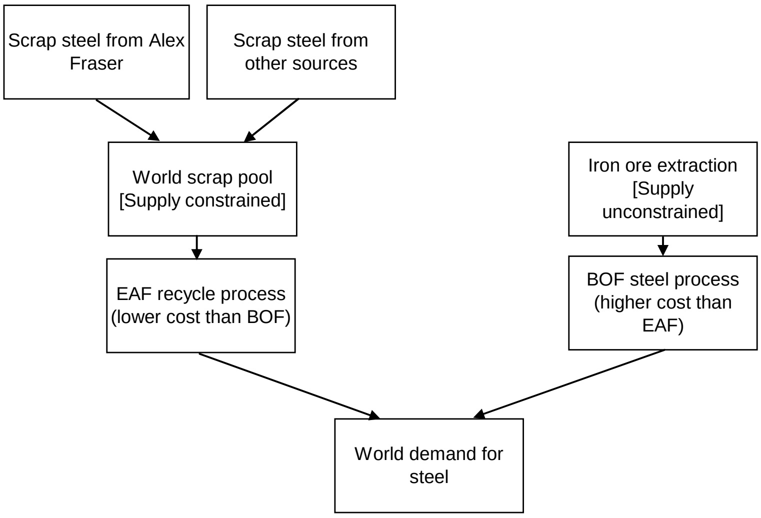


**Figure 19 Displacement of BOF steel from material pool**

Unlike many ‘closed loop’ recycling models, this model does not assume that recycled scrap steel has equivalent characteristics of virgin produced BOF steel. It therefore must be ‘topped up’ with an amount of virgin steel (from BOF process) to ensure metallurgy sufficient to for use in structural building applications (long products such as beams). In a prior study, an EAF plant in Sydney (BHP Billiton) was reviewed and found to top-up recycling steel with 14% iron in order to produce structural grade steel (Centre for Design at RMIT 1998).

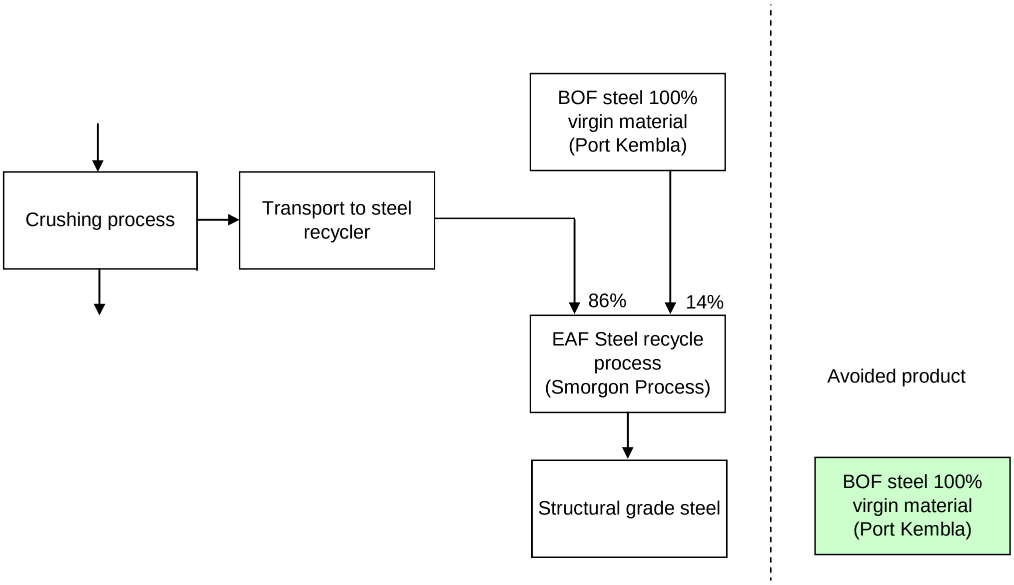


**Figure 20 Steel recycling process - structural grade products.**

As discussed above, the injection into the material pool of steel produced from EAF processes offsets production of steel via the BOF process. In this model, the avoided BOF process is based on steel production at Port Kembla, Australia.

## 14.2 Steel method B: Avoided impacts of steel recycling in a market constrained by supply of scrap steel (material pool without material degradation approach).

This approach is similar to that described in Section 14.1, with the exception that material is not assumed to degrade significantly. Recycled steel manufactured via the EAF process at the One Steel facility in Laverton (where much of Alex Fraser's steel is assumed to be consumed) is used to produce long products and rebar, without top-up of virgin steel. In this process recycled steel collected from Alex Fraser is added directly to the EAF furnace where metallurgical properties are adjusted, and the products produced.

Arguably, this process produces steel products that would otherwise have to be produced directly from BOF steel from virgin resources. This being true, then increasing the pool of scrap steel directly reduces the demand for BOF steel as described in Section 14.1. Figure 21 describes the process.

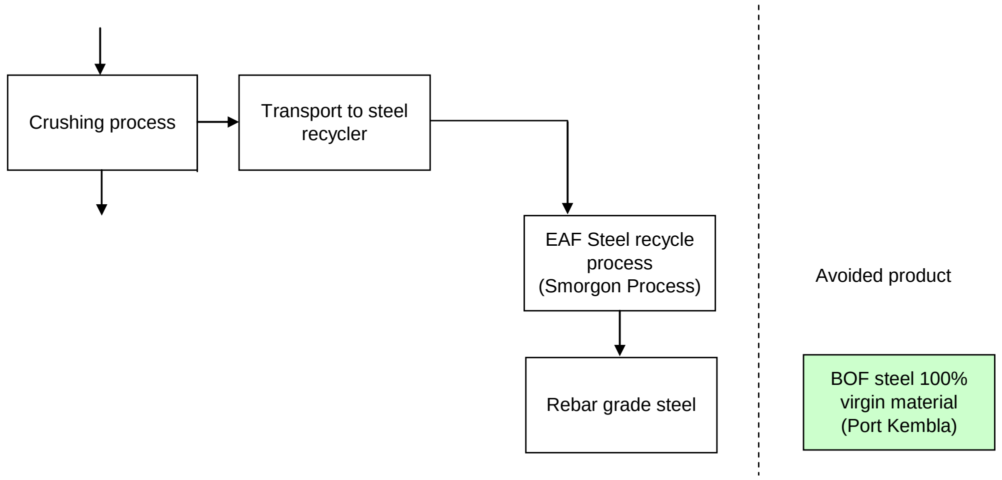


**Figure 21 Rebar grade steel produced through One Steel process.**

## 14.3 Steel method C: Avoided impacts of steel recycling determined by applying value corrected substitution.

A potential weakness of Method B is that it assumes that the EAF grade steel used to produce rebar is a perfect substitute for BOF grade steel which can be used in structural applications. Material degradation is not addressed in Method B, which may mean it overstates benefits associated with recycling. Apart from applying a virgin material 'top up' as described in Method A, a further change could be made to Method B to address this potential shortcoming. The change involves applying Value Corrected Substitution (VCS) to impacts determined in Method B. VCS is described in the draft Dutch standard NEN8006: 2004 "Guidelines for allocation".

The standard describes value corrected substitution as being applicable for determining avoided impacts in situations when a material can be recycled an unknown number of times and when a substitute material is used with a different functional performance to the secondary material being assessed. The standard describes the method to be applied as follows:

> "The value corrected substitution for the output flows consists of subtracting the product system (for the relevant material or product) to be substituted. The value correction is the ratio between the value of the secondary material ($p_s$) and the value of the material to be substituted ($p_{sub}$), namely: $p_s / p_{sub}$."
> NEN8006

Applying the standard to the crushed concrete aggregate process requires that prices of steel scrap and recycled steel product be known, and that an appropriate substitute material be identified. It also assumes that the value of steel entering the recycling system (embedded in concrete) is zero.

In this case prices at each boundary of the recycling process are assumed to be known and are based on published steel price data.

**Table 29 Steel pricing (MEPS Ltd. 2008)**

| | |
|---|---|
| Price of rebar (Feb 2008): | US$702 per tonne |
| Price of structural (Feb 2008): | US$905 per tonne |

The above data suggests that value corrected substitution ratio for steel reprocessing into rebar would be $702/$905 = 78% (calculated by: $p_s / p_{sub}$).

The substitute product is assumed to be structural grade steel (100% virgin) which is then adjusted according to the value correction factor (78%) to reduce the avoided impact to that that would be expected from a lower grade steel such as that used to manufacture rebar.

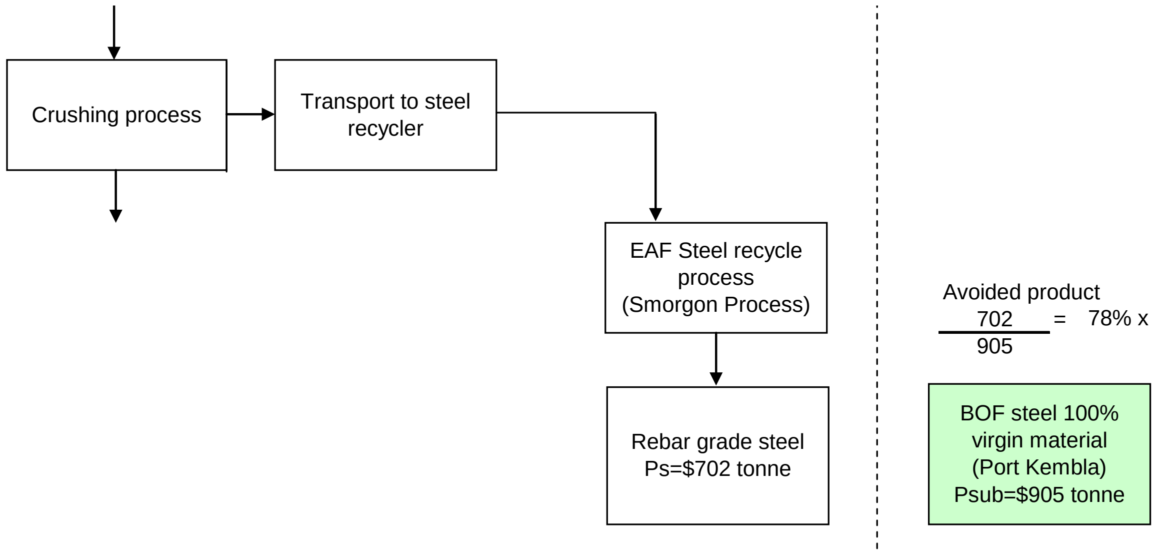


**Figure 22 Value corrected substitution.**

## 14.4 Comparison and conclusions

The life cycle impacts of each of the above approaches to steel recycling were calculated and are shown in Table 30.

**Table 30 Avoided impacts of steel reprocessing (8.07kg steel, as per recovery rate per tonne of crushed concrete aggregate produced)**

| **Impact category** | **Unit** | **Net impact of steel recycling** | | |
|---|---|---|---|---|
| | | Method A | Method B | Method C |
| Global Warming | kg CO2 | -2.78E+00 | -4.27E+00 | -1.32E+00 |
| Photochemical oxidation | kg C2H2 | -2.41E-02 | -2.44E-02 | -1.86E-02 |
| Eutrophication | kg PO4--- | -4.06E-03 | -4.62E-03 | -2.85E-03 |
| Carcinogens | DALY | -2.26E-08 | -2.88E-08 | -1.41E-08 |
| Land use | Ha a | 1.37E-07 | -3.05E-07 | 3.60E-07 |
| Water Use | KL H2O | 2.17E-02 | 1.96E-02 | 1.82E-02 |
| Solid waste | kg | -2.41E+00 | -2.60E+00 | -1.77E+00 |
| Fossil fuels | MJ surplus | -6.30E+00 | -7.34E+00 | -4.31E+00 |
| Minerals | MJ Surplus | -4.22E-01 | -4.22E-01 | -3.29E-01 |

Table 30 shows that of the methods reviewed Method C produces the smallest avoided impacts and Method B the largest avoided impacts.

Method B produces the most significant avoided impacts because recycled steel produced via the EAF process is assumed to fully substitute for virgin steel produced via the BOF process, which is far more resource intensive. Although a valid comparison, the method could potentially overstate the benefit of recycling, especially if virgin material must be added to the mix to allow the steel to be used in structural applications.

Method A addresses the shortcomings of method B by directly including the virgin material ‘top up’ required to produce a structural grade steel. This method arguably produces a steel that could be functionally compared directly to steel produced via the BOF process from virgin resources.

Method C uses an alternative method to address the comparability of the steel produced with the virgin steel substitute. Instead of increasing impacts associated with the recycling process, avoided impacts of the substitute (BOF) steel are reduced based on the difference in value between the two steel products (rebar grade, versus structural grade).

Selection of the most appropriate method is difficult and can be approached from a number of perspectives. Method B approaches the problem from a ‘finite material pool’ perspective that assumes that any steel recovered from waste streams, even if used to produce a low grade product such as rebar will ultimately offset a unit of steel production from virgin sources. Central to the argument is the belief that no substitutes exist for rebar in concrete applications, so failing to recover the steel from waste will lead to a necessary ‘upgrading’ of steel used in rebar manufacture if sufficient low grade steel is not available. It does not acknowledge that increasing supply of recycled steel will depress recycled steel prices and therefore displace other recycling activities, because of the large cost premium associated with steel from virgin sources, and the existing constrained supply of recycled steel to the market.  Significantly, Method B does not acknowledge that over time the closed pool of material will degrade and eventually become unusable in any application.  Arguably, this is a weakness in the method that in the long-run may overstate the benefits attainable through recycling.

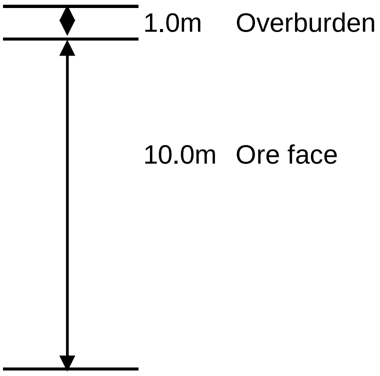
Method A and Method B, using differing techniques, downgrade the benefit of recycling by acknowledging a degradation of material quality over multiple building life cycles.  Method A uses a straightforward virgin material ‘top up’ to account for degradation and Method C uses VCS to approximate how the material has deteriorated versus the virgin product.  Each method has its merits and shortcomings.  Method A is a straightforward approach that models a particular process from waste stream back to useful material, where as Method C uses a more complex market based approach.

For the purposes of this study, it is difficult to distinguish between the methods outlined.  Taking a conservative. ‘worst case’ position would lead to the selection of Method C for determining avoided impacts from steel production, although any of the above methods could be convincingly argued.

# 15 Appendix B – Potential impacts of excluded quarry activities

In drawing the system boundary for the assessment of manufacturing quarried stone aggregate, certain activities have been excluded from the system boundary: Overburden removal, drilling and blasting, site dewatering and site remediation. In excluding these activities from the study it is important to consider whether any potential ‘benefits’ associated with quarrying activity may have been excluded, unfairly biasing the study.

To test the impact of these exclusions a fictitious quarrying scenario was developed, that could be representative of a quarry situation. The scenario is summarised in Figure 23.



| | | |
|---|---|---|
| Production: | 400000 | tonnes p.a |
| Lifetime production: | 20000000 | tonnes |
| Quarry life: | 50 | years |
| Density of ore: | 2 | tonnes/m3 |
| Area of pit at end of life: | 1000000 | m2 |
| Volume of overburden moved: | 1000000 | m3 |
| Water infiltration: | 1 | kL per day |
| Puming energy: | 10 | kWh/kL |
| Overburden: | Assume overburden stored and site remediated at end of life.<br>1 km movement to storage by truck<br>Load at both ends with skid steer loader | |
| Blasting & drilling: | Estimate:<br>Drill: 1kWh per m3<br>Blast: Unknown | |

**Figure 23 Fictitious quarry scenario to test potential impacts of excluded activities.**

An inventory of activity was created that included machinery use to remove and store overburden at the start of the quarry’s life and to replace the overburden at the end of its life (Ecoinvent 2.0 model used to assess machinery use). Drilling impacts were estimated, and blasting impacts were assumed to be minimal per tonne of ore extracted. Finally, dewatering was assumed to be provided by electric pumps located in the pit. No capital infrastructure was allowed for in the model.

The result of the study per tonne of ore generated over the quarry life is shown in Figure 24.

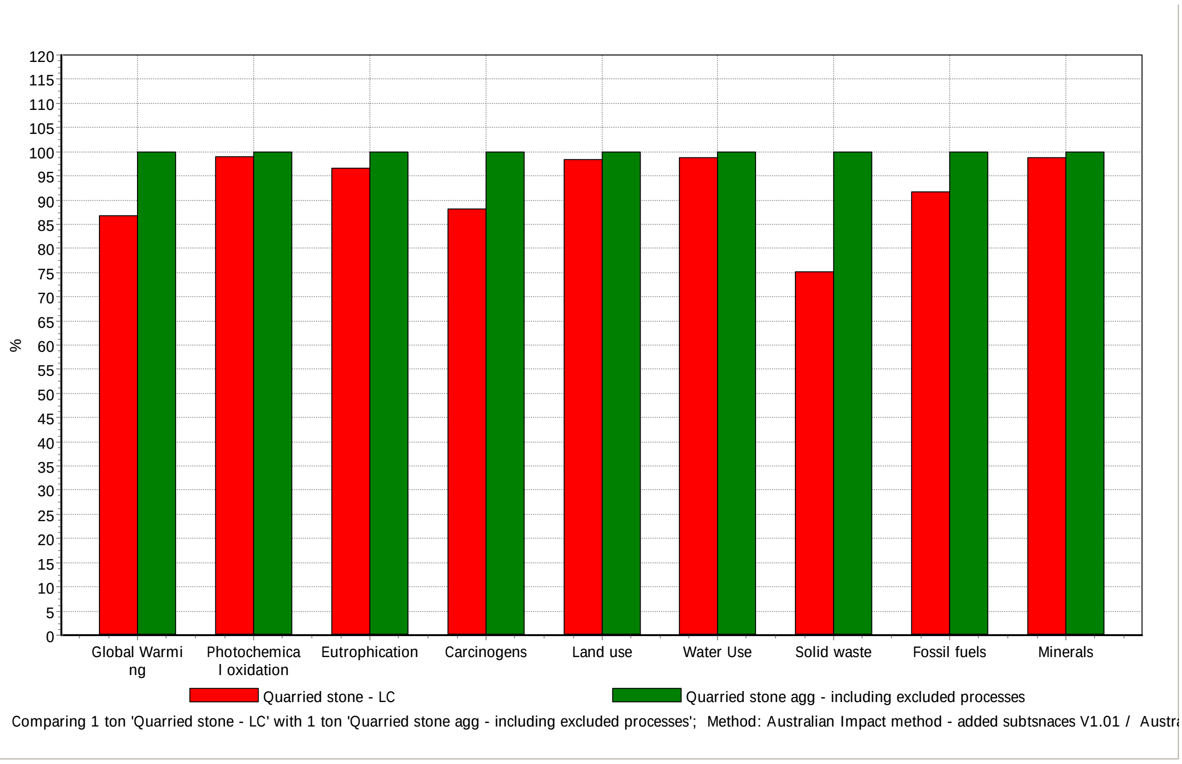


**Figure 24 Inclusion of quarry processes excluded from the system boundary.**

Figure 24 shows that indeed the impacts associated with quarried stone aggregate would be expected to increase if excluded processes were to be included within the system. Excluding the processes has not unfairly biased the study against quarrying.

# 16 Appendix C – Potential impacts of capital goods

A common assumption when assessing ‘long lived’ production processes can be to exclude the impacts of capital equipment manufacture. Exclusion is usually done on the basis that the impacts of manufacturing the capital equipment are minimal when considered over the life of the equipment. In any event, capital equipment requirements between systems considered in this study are likely to be similar, so will not be expected to influence comparison outcomes, however testing the validity of the assumption is still worthwhile.

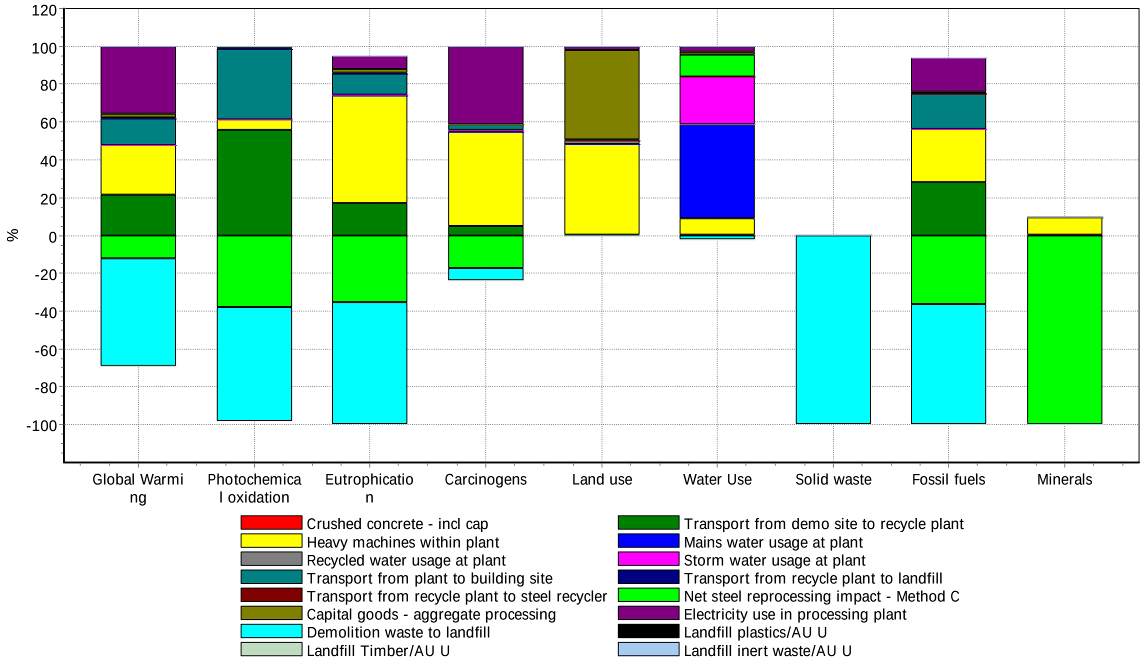
To test the validity of excluding capital equipment from the study, an economic input-output (IO)model for capital goods expenditure in Australia was employed. The model converts raw expenditure on capital equipment to life cycle impacts based on a generic capital good profile, and is based on national account expenditure information in Australia. The IO model was produced by the University of Sydney.

To assess capital impacts over the life of the quarry or recycling facility, the impacts of the capital equipment are first determined, then divided over each tonne of product produced. Key assumptions are described in Table 31 Capital assumptions.

**Table 31 Capital assumptions.**

| | **Value** | |
|---|---|---|
| | A$ millions | |
| Crushing plant and equipment | 3 | |
| Excavators/Loaders | 2 | |
| Maintenance over life (1% of capital p.a.) | 1.5 | |
| Total | 6.5 | |
| | | |
| Assumed plant and equipment life | 30 | years |
| Assumed capacity | 540000 | tonnes pa |
| Lifetime production | 16200000 | tonnes |

The result of the impact assessment per tonne of product produced are shown included as part of the total life cycle assessment for crushed concrete aggregate in Figure 25.



Analyzing 1 ton 'Crushed concrete - incl cap'; Method: Australian Impact method - added subtsnaces V1.01 / Australian annual per capita / characterization

**Figure 25 Impact of capital goods on life cycle impact of recycling process.**

Figure 25 shows that capital equipment is unlikely to contribute more than 5% per tonne produced in most impact categories, so can be excluded without significantly impacting the validity of the study. Land use is the exception, however absolute land use impacts associated with this study are relatively small making the increase appear more significant.

It should also be noted that capital impacts are expected to be similar between the products considered, hence are not expected to impact the comparison in any event.

# 17 Appendix D – Comparison of the quarried stone aggregate inventory to other inventories

Although the development of the inventory for quarried stone aggregate involved industry experts and leveraged knowledge of crushing and processing associated with recycling facilities, it is useful to further compare the outcomes to other studies conducted.

Other inventories compared include:

## 17.1 Ecoinvent 2.0 – Gravel model

A key reference point is the ‘gravel’ inventory developed for the Ecoinvent 2.0 life cycle inventory database. This inventory is based on European practice and incorporates European electricity supply data (reduced global warming impact per unit of energy delivered versus Australia). Strong similarities in process exist between the Ecoinvent model and the inventory developed in this study. Both involve extraction of ore, crushing and movement of ore on-site. Diesel machinery impacts are included in both studies.

## 17.2 Ecoinvent 2.0 – Gravel model – Adjusted for Australian electricity supply.

As mentioned above the Ecoinvent 2.0 model assumes that electricity supply to the quarry is derived from the European electricity grid, which has lower emissions per unit of energy delivered. The transparency of the unit process model makes it possible to change European electricity and replace it with Australian electricity, making the model more representative of the impacts that would be expected of a quarry operated in Australia.

## 17.3 Results of comparison

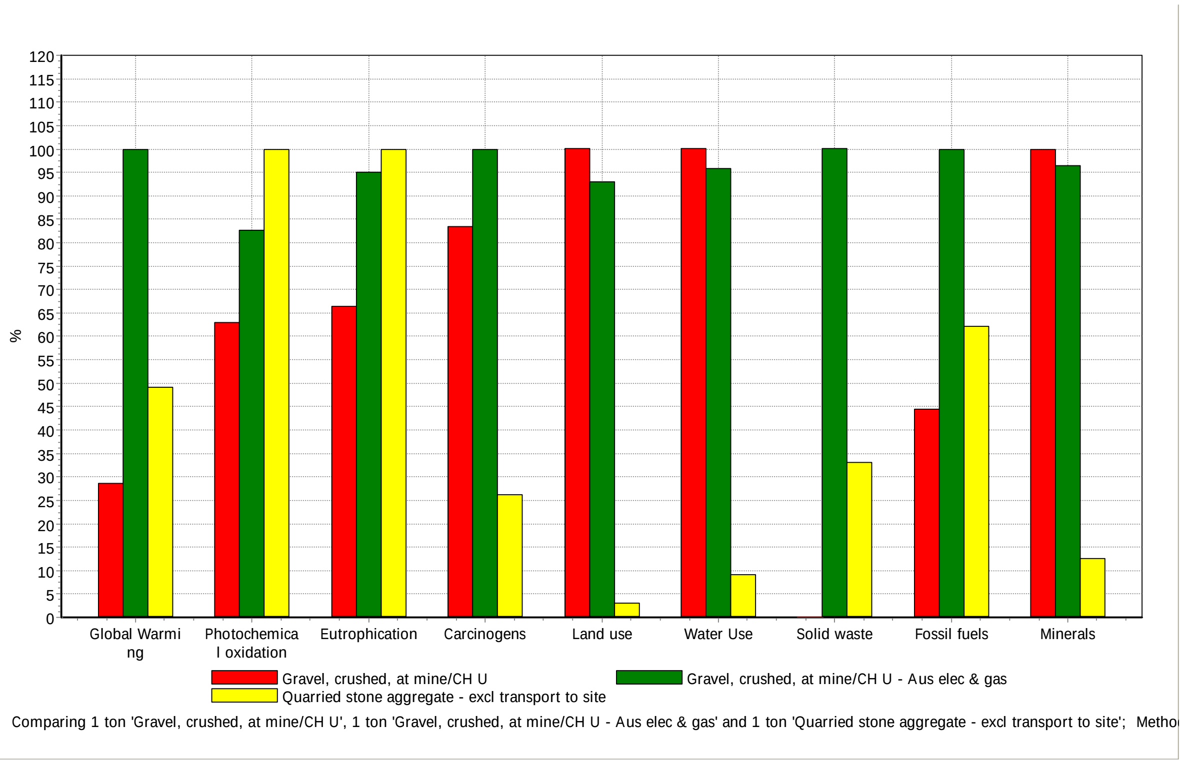


**Figure 26 Comaprison of quarried stone impacts to Ecoindicator 2.0 crushed rock model.**

The comparison shows that the Ecoinvent 2.0 model using European energy profiles has the lowest impact of three considered, however this is due to the lower greenhouse energy profile of electricity generation in Europe. When the Ecoinvent 2.0 model is adjusted to incorporate Australian electricity generation (derived from brown coal predominantly, so greenhouse intensive), the impacts across most indictors increase.

Comparing to the quarried stone aggregate model developed in this study (excluding transport to the building site, which is excluded from the other studies), the Ecoinvent model adjusted for Australian energy profiles tends show increased impacts across most indicators, including global warming. An exception is photochemical oxidation, which could be to do with a different mix of diesel fuel, and stationary energy sources. The difference is not substantial and photochemical oxidation has not been a focus of this study.

**Table 32 Consumption of diesel, electricity and water consumption per tonne of quarried stone aggregate produced.**

| | Unit | Ecoinvent 2.0 | This study |
|---|---|---|---|
| Diesel consumption | litres | 0.33 | 0.94 |
| Electricity consumption | kWh | 9.06 | 2.98 |
| Water consumption | litres | 1362.20 | 153.00 |

A review of the underlying data, suggests that the difference in fuel mix is certainly a key difference between the models. The Ecoinvent data has higher electricity consumption than this study, and reduced diesel fuel consumption. Water consumption is significantly higher under the Ecoinvent model, which is attributed to water extracted directly from the environment (not potable supply), so is likely to be associated with infiltration into the pit.  The high water consumption is likely to be partially a cause of the high electricity consumption which would be required for pumping.

In general the inventory for quarried stone aggregate developed in this study generates similar (in many cases lessor) impacts to those seen in the Ecoinvent 2.0 model, once it is adjusted for Australian energy profiles.  This suggests that the inventory developed in this study probably reflects a ‘best case’ view of quarry impacts.

# 18 Appendix E – Characterisation and Normailisation factors – Australian Impact Assessment method

| Impact category | Sub category | Substance | CAS number | Factor | Unit |
|---|---|---|---|---|---|
| Air | (unspecified) | Carbon dioxide | 000124-38-9 | 1 | kg CO2 / kg |
| Air | (unspecified) | Carbon dioxide, fossil | 000124-38-9 | 1 | kg CO2 / kg |
| Air | (unspecified) | Chlorinated fluorocarbons, hard | | 7100 | kg CO2 / kg |
| Air | (unspecified) | Chlorinated fluorocarbons, soft | | 1600 | kg CO2 / kg |
| Air | (unspecified) | Chloroform | 000067-66-3 | 25 | kg CO2 / kg |
| Air | (unspecified) | Dinitrogen monoxide | 010024-97-2 | 310 | kg CO2 / kg |
| Air | (unspecified) | Ethane, 1-chloro-1,1-difluoro-, HCFC-142 | 000075-68-3 | 1800 | kg CO2 / kg |
| Air | (unspecified) | Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b | 001717-00-6 | 580 | kg CO2 / kg |
| Air | (unspecified) | Ethane, 1,1-difluoro-, HFC-152a | 000075-37-6 | 150 | kg CO2 / kg |
| Air | (unspecified) | Ethane, 1,1,1-trichloro-, HCFC-140 | 000071-55-6 | 100 | kg CO2 / kg |
| Air | (unspecified) | Ethane, 1,1,1-trifluoro-, HCFC-143a | 000420-46-2 | 3800 | kg CO2 / kg |
| Air | (unspecified) | Ethane, 1,1,1,2-tetrafluoro-, HFC-134a | 000811-97-2 | 1200 | kg CO2 / kg |
| Air | (unspecified) | Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113 | 000076-13-1 | 4500 | kg CO2 / kg |
| Air | (unspecified) | Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114 | 000076-14-2 | 7000 | kg CO2 / kg |
| Air | (unspecified) | Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124 | 002837-89-0 | 440 | kg CO2 / kg |
| Air | (unspecified) | Ethane, 2,2-dichloro-1,1,1-trifluoro-, HCFC-123 | 000306-83-2 | 90 | kg CO2 / kg |
| Air | (unspecified) | Ethane, chloropentafluoro-, CFC-115 | 000076-15-3 | 7000 | kg CO2 / kg |
| Air | (unspecified) | Ethane, hexafluoro-, HFC-116 | 000076-16-4 | 9200 | kg CO2 / kg |
| Air | (unspecified) | Ethane, pentafluoro-, HFC-125 | 000354-33-6 | 3400 | kg CO2 / kg |
| Air | (unspecified) | Methane | 000074-82-8 | 21 | kg CO2 / kg |
| Air | (unspecified) | Methane, biogenic | 000074-82-8 | 20 | kg CO2 / kg |
| Air | (unspecified) | Methane, bromochlorodifluoro-, Halon 1211 | 000353-59-3 | 4900 | kg CO2 / kg |
| Air | (unspecified) | Methane, bromotrifluoro-, Halon 1301 | 000075-63-8 | 4900 | kg CO2 / kg |
| Air | (unspecified) | Methane, chlorodifluoro-, HCFC-22 | 000075-45-6 | 1600 | kg CO2 / kg |
| Air | (unspecified) | Methane, chlorotrifluoro-, CFC-13 | 000075-72-9 | 13000 | kg CO2 / kg |
| Air | (unspecified) | Methane, dichloro-, HCC-30 | 000075-09-2 | 15 | kg CO2 / kg |
| Air | (unspecified) | Methane, dichlorodifluoro-, CFC-12 | 000075-71-8 | 7100 | kg CO2 / kg |
| Air | (unspecified) | Methane, tetrachloro-, CFC-10 | 000056-23-5 | 1300 | kg CO2 / kg |
| Air | (unspecified) | Methane, tetrafluoro-, FC-14 | 000075-73-0 | 6500 | kg CO2 / kg |
| Air | (unspecified) | Methane, trichlorofluoro-, CFC-11 | 000075-69-4 | 3400 | kg CO2 / kg |
| Soil | (unspecified) | Carbon dioxide, biogenic | | -1 | kg CO2 / kg |
| | | | | | |
| Impact category | Photochemical oxidation | kg C2H2 | | | |
| Air | (unspecified) | 1-Butanol | 000071-36-3 | 6.20E-01 | kg C2H2 / kg |
| Air | (unspecified) | 1-Butene | 000106-98-9 | 1.08E+00 | kg C2H2 / kg |
| Air | (unspecified) | 1-Butene, 2-methyl- | 000563-46-2 | 7.71E-01 | kg C2H2 / kg |
| Air | (unspecified) | 1-Butene, 3-methyl- | 000563-45-1 | 6.71E-01 | kg C2H2 / kg |
| Air | (unspecified) | 1-Hexene | 000592-41-6 | 8.74E-01 | kg C2H2 / kg |
| Air | (unspecified) | 1-Pentene | 000109-67-1 | 9.77E-01 | kg C2H2 / kg |
| Air | (unspecified) | 1-Propanol | 000071-23-8 | 5.61E-01 | kg C2H2 / kg |
| Air | (unspecified) | 2-Butanol | 000078-92-2 | 4.00E-01 | kg C2H2 / kg |

| | | | | | |
|---|---|---|---|---|---|
| Air | (unspecified) | 2-Butanone, 3-methyl- | 000563-80-4 | 4.90E-01 | kg C2H2 / kg |
| Air | (unspecified) | 2-Butanone, 3,3-dimethyl- | 000075-97-8 | 3.23E-01 | kg C2H2 / kg |
| Air | (unspecified) | 2-Butene (cis) | 000590-18-1 | 1.15E+00 | kg C2H2 / kg |
| Air | (unspecified) | 2-Butene (trans) | 000624-64-6 | 1.13E+00 | kg C2H2 / kg |
| Air | (unspecified) | 2-Butene, 2-methyl- | 000513-35-9 | 8.42E-01 | kg C2H2 / kg |
| Air | (unspecified) | 2-Hexanone | 000591-78-6 | 5.72E-01 | kg C2H2 / kg |
| Air | (unspecified) | 2-Hexene (cis) | 007688-21-3 | 1.07E+00 | kg C2H2 / kg |
| Air | (unspecified) | 2-Hexene (trans) | 004050-45-7 | 1.07E+00 | kg C2H2 / kg |
| Air | (unspecified) | 2-Pentanone | 000107-87-9 | 5.48E-01 | kg C2H2 / kg |
| Air | (unspecified) | 2-Pentene (cis) | 000627-20-3 | 1.12E+00 | kg C2H2 / kg |
| Air | (unspecified) | 2-Pentene (trans) | 000646-04-8 | 1.12E+00 | kg C2H2 / kg |
| Air | (unspecified) | 2-Propanol | 000067-63-0 | 1.88E-01 | kg C2H2 / kg |
| Air | (unspecified) | 3-Hexanone | 000589-38-8 | 5.99E-01 | kg C2H2 / kg |
| Air | (unspecified) | 3-Pentanol | 000584-02-1 | 5.95E-01 | kg C2H2 / kg |
| Air | (unspecified) | Acetaldehyde | 000075-07-0 | 6.41E-01 | kg C2H2 / kg |
| Air | (unspecified) | Acetic acid | 000064-19-7 | 9.70E-02 | kg C2H2 / kg |
| Air | (unspecified) | Acetic acid, butyl ester | 000123-86-4 | 2.69E-01 | kg C2H2 / kg |
| Air | (unspecified) | Acetic acid, ethyl ester | 000141-78-6 | 2.09E-01 | kg C2H2 / kg |
| Air | (unspecified) | Acetic acid, methyl ester | 000079-20-9 | 5.90E-02 | kg C2H2 / kg |
| Air | (unspecified) | Acetic acid, propyl ester | 000109-60-4 | 2.82E-01 | kg C2H2 / kg |
| Air | (unspecified) | Acetone | 000067-64-1 | 9.40E-02 | kg C2H2 / kg |
| Air | (unspecified) | Benzaldehde | | -9.20E-02 | kg C2H2 / kg |
| Air | (unspecified) | Benzene | 000071-43-2 | 2.20E-01 | kg C2H2 / kg |
| Air | (unspecified) | Benzene, 1-propyl- | 000103-65-1 | 6.36E-01 | kg C2H2 / kg |
| Air | (unspecified) | Benzene, 1,2,3-trimethyl- | 000526-73-8 | 1.27E+00 | kg C2H2 / kg |
| Air | (unspecified) | Benzene, 1,2,4-trimethyl- | 000095-63-6 | 1.28E+00 | kg C2H2 / kg |
| Air | (unspecified) | Benzene, 1,3,5-trimethyl- | 000108-67-8 | 1.38E+00 | kg C2H2 / kg |
| Air | (unspecified) | Benzene, 3,5-dimethylethyl- | 000934-74-7 | 1.32E+00 | kg C2H2 / kg |
| Air | (unspecified) | Benzene, ethyl- | 000100-41-4 | 7.30E-01 | kg C2H2 / kg |
| Air | (unspecified) | Butadiene | 000106-99-0 | 8.50E-01 | kg C2H2 / kg |
| Air | (unspecified) | Butanal | 000123-72-8 | 7.95E-01 | kg C2H2 / kg |
| Air | (unspecified) | Butane | 000106-97-8 | 3.52E-01 | kg C2H2 / kg |
| Air | (unspecified) | Butane, 2,2-dimethyl- | 000075-83-2 | 2.41E-01 | kg C2H2 / kg |
| Air | (unspecified) | Butane, 2,3-dimethyl- | 000079-29-8 | 5.41E-01 | kg C2H2 / kg |
| Air | (unspecified) | Butanol, 2-methyl-1- | 000137-32-6 | 4.89E-01 | kg C2H2 / kg |
| Air | (unspecified) | Butanol, 2-methyl-2- | 000075-85-4 | 2.28E-01 | kg C2H2 / kg |
| Air | (unspecified) | Butanol, 3-methyl-1- | 000123-51-3 | 4.33E-01 | kg C2H2 / kg |
| Air | (unspecified) | Butanol, 3-methyl-2- | 000598-75-4 | 4.06E-01 | kg C2H2 / kg |
| Air | (unspecified) | Carbon monoxide | 000630-08-0 | 2.70E-02 | kg C2H2 / kg |
| Air | (unspecified) | Chloroform | 000067-66-3 | 2.30E-02 | kg C2H2 / kg |
| Air | (unspecified) | Cumene | 000098-82-8 | 5.00E-01 | kg C2H2 / kg |
| Air | (unspecified) | Cyclohexane | 000110-82-7 | 2.90E-01 | kg C2H2 / kg |
| Air | (unspecified) | Cyclohexanol | 000108-93-0 | 5.18E-01 | kg C2H2 / kg |
| Air | (unspecified) | Cyclohexanone | 000108-94-1 | 2.99E-01 | kg C2H2 / kg |
| Air | (unspecified) | Decane | 000124-18-5 | 3.84E-01 | kg C2H2 / kg |
| Air | (unspecified) | Diacetone alcohol | 000123-42-2 | 3.07E-01 | kg C2H2 / kg |
| Air | (unspecified) | Diethyl ether | 000060-29-7 | 4.45E-01 | kg C2H2 / kg |
| Air | (unspecified) | Diethyl ketone | 000096-22-0 | 4.14E-01 | kg C2H2 / kg |
| Air | (unspecified) | Diisopropyl ether | 000108-20-3 | 3.98E-01 | kg C2H2 / kg |
| Air | (unspecified) | Dimethyl carbonate | 000616-38-6 | 2.50E-02 | kg C2H2 / kg |
| Air | (unspecified) | Dimethyl ether | 000115-10-6 | 1.89E-01 | kg C2H2 / kg |
| Air | (unspecified) | Dodecane | 000112-40-3 | 3.57E-01 | kg C2H2 / kg |

| | | | | | |
|---|---|---|---|---|---|
| Air | (unspecified) | Ethane | 000074-84-0 | 1.23E-01 | kg C2H2 / kg |
| Air | (unspecified) | Ethane, 1,1,1-trichloro-, HCFC-140 | 000071-55-6 | 9.00E-03 | kg C2H2 / kg |
| Air | (unspecified) | Ethanol | 000064-17-5 | 3.99E-01 | kg C2H2 / kg |
| Air | (unspecified) | Ethanol, 2-butoxy- | 000111-76-2 | 4.83E-01 | kg C2H2 / kg |
| Air | (unspecified) | Ethanol, 2-ethoxy- | 000110-80-5 | 3.86E-01 | kg C2H2 / kg |
| Air | (unspecified) | Ethanol, 2-methoxy- | 000109-86-4 | 3.07E-01 | kg C2H2 / kg |
| Air | (unspecified) | Ethene | 000074-85-1 | 1.00E+00 | kg C2H2 / kg |
| Air | (unspecified) | Ethene, dichloro- (cis) | 000156-59-2 | 4.47E-01 | kg C2H2 / kg |
| Air | (unspecified) | Ethene, dichloro- (trans) | 000156-60-5 | 3.92E-01 | kg C2H2 / kg |
| Air | (unspecified) | Ethene, tetrachloro- | 000127-18-4 | 2.90E-02 | kg C2H2 / kg |
| Air | (unspecified) | Ethene, trichloro- | 000079-01-6 | 3.30E-01 | kg C2H2 / kg |
| Air | (unspecified) | Ethylene glycol | 000107-21-1 | 3.73E-01 | kg C2H2 / kg |
| Air | (unspecified) | Ethyne | 000074-86-2 | 8.50E-02 | kg C2H2 / kg |
| Air | (unspecified) | Formaldehyde | 000050-00-0 | 5.20E-01 | kg C2H2 / kg |
| Air | (unspecified) | Formic acid | 000064-18-6 | 3.20E-02 | kg C2H2 / kg |
| Air | (unspecified) | Heptane | 000142-82-5 | 4.94E-01 | kg C2H2 / kg |
| Air | (unspecified) | Hexane | 000110-54-3 | 4.82E-01 | kg C2H2 / kg |
| Air | (unspecified) | Hexane, 2-methyl- | 000591-76-4 | 4.11E-01 | kg C2H2 / kg |
| Air | (unspecified) | Hexane, 3-methyl- | 000589-34-4 | 3.64E-01 | kg C2H2 / kg |
| Air | (unspecified) | Isobutanol | 000078-83-1 | 3.60E-01 | kg C2H2 / kg |
| Air | (unspecified) | Isobutene | 000115-11-7 | 6.27E-01 | kg C2H2 / kg |
| Air | (unspecified) | Isobutyraldehyde | 000078-84-2 | 5.14E-01 | kg C2H2 / kg |
| Air | (unspecified) | Isopentane | 000078-78-4 | 4.05E-01 | kg C2H2 / kg |
| Air | (unspecified) | Isoprene | 000078-79-5 | 1.09E+00 | kg C2H2 / kg |
| Air | (unspecified) | Isopropyl acetate | 000108-21-4 | 2.11E-01 | kg C2H2 / kg |
| Air | (unspecified) | m-Xylene | 000108-38-3 | 1.10E+00 | kg C2H2 / kg |
| Air | (unspecified) | Methane | 000074-82-8 | 6.00E-03 | kg C2H2 / kg |
| Air | (unspecified) | Methane, dichloro-, HCC-30 | 000075-09-2 | 6.80E-02 | kg C2H2 / kg |
| Air | (unspecified) | Methane, dimethoxy- | 000109-87-5 | 1.60E-01 | kg C2H2 / kg |
| Air | (unspecified) | Methane, monochloro-, R-40 | 000074-87-3 | 5.00E-03 | kg C2H2 / kg |
| Air | (unspecified) | Methanol | 000067-56-1 | 1.40E-01 | kg C2H2 / kg |
| Air | (unspecified) | Methyl ethyl ketone | 000078-93-3 | 3.73E-01 | kg C2H2 / kg |
| Air | (unspecified) | Methyl formate | 000107-31-3 | 2.70E-02 | kg C2H2 / kg |
| Air | (unspecified) | Nitric oxide | 010102-43-9 | -4.27E-01 | kg C2H2 / kg |
| Air | (unspecified) | Nitrogen dioxide | 010102-44-0 | 2.80E-02 | kg C2H2 / kg |
| Air | (unspecified) | Nitrogen oxides | 011104-93-1 | 2.80E-02 | kg C2H2 / kg |
| Air | (unspecified) | NMVOC, non-methane volatile organic compounds, unspecified origin | | 0.398 | kg C2H2 / kg |
| Air | (unspecified) | Nonane | 000111-84-2 | 4.14E-01 | kg C2H2 / kg |
| Air | (unspecified) | o-Xylene | 000095-47-6 | 1.10E+00 | kg C2H2 / kg |
| Air | (unspecified) | Octane | 000111-65-9 | 4.53E-01 | kg C2H2 / kg |
| Air | (unspecified) | p-Xylene | 000106-42-3 | 1.00E+00 | kg C2H2 / kg |
| Air | (unspecified) | Pentanal | 000110-62-3 | 7.65E-01 | kg C2H2 / kg |
| Air | (unspecified) | Pentane | 000109-66-0 | 3.95E-01 | kg C2H2 / kg |
| Air | (unspecified) | Pentane, 2-methyl- | 000107-83-5 | 4.20E-01 | kg C2H2 / kg |
| Air | (unspecified) | Pentane, 3-methyl- | 000096-14-0 | 4.79E-01 | kg C2H2 / kg |
| Air | (unspecified) | Propanal | 000123-38-6 | 7.98E-01 | kg C2H2 / kg |
| Air | (unspecified) | Propane | 000074-98-6 | 1.76E-01 | kg C2H2 / kg |
| Air | (unspecified) | Propane, 2,2-dimethyl- | 000463-82-1 | 1.73E-01 | kg C2H2 / kg |
| Air | (unspecified) | Propene | 000115-07-1 | 1.12E+00 | kg C2H2 / kg |
| Air | (unspecified) | Propionic acid | 000079-09-4 | 1.50E-01 | kg C2H2 / kg |
| Air | (unspecified) | Propylene glycol | 000057-55-6 | 4.57E-01 | kg C2H2 / kg |
| Air | (unspecified) | Propylene glycol methyl ether | 000107-98-2 | 3.55E-01 | kg C2H2 / kg |

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|---|---|---|---|---|---|
| Air | (unspecified) | Propylene glycol t-butyl ether | 057018-52-7 | 4.63E-01 | kg C2H2 / kg |
| Air | (unspecified) | Styrene | 000100-42-5 | 1.40E-01 | kg C2H2 / kg |
| Air | (unspecified) | Sulfur dioxide | 007446-09-5 | 4.80E-02 | kg C2H2 / kg |
| Air | (unspecified) | t-Butyl alcohol | 000075-65-0 | 1.06E-01 | kg C2H2 / kg |
| Air | (unspecified) | t-Butyl ethyl ether | 000637-92-3 | 2.44E-01 | kg C2H2 / kg |
| Air | (unspecified) | t-Butyl methyl ether | 001634-04-4 | 1.75E-01 | kg C2H2 / kg |
| Air | (unspecified) | Toluene | 000108-88-3 | 6.40E-01 | kg C2H2 / kg |
| Air | (unspecified) | Toluene, 2-ethyl- | 000611-14-3 | 8.98E-01 | kg C2H2 / kg |
| Air | (unspecified) | Toluene, 3-ethyl- | 000620-14-4 | 1.02E+00 | kg C2H2 / kg |
| Air | (unspecified) | Toluene, 3,5-diethyl- | 002050-24-0 | 1.30E+00 | kg C2H2 / kg |
| Air | (unspecified) | Toluene, 4-ethyl- | 000622-96-8 | 9.06E-01 | kg C2H2 / kg |
| Air | (unspecified) | Undecane | 001120-21-4 | 3.84E-01 | kg C2H2 / kg |
| Air | (unspecified) | VOC, volatile organic compounds | | 0.398 | kg C2H2 / kg |
| Air | low. pop. | NMVOC, non-methane volatile organic compounds, unspecified origin | | 0 | kg C2H2 / kg |
| | | | | | |
| Impact category | Eutrophication | kg PO4--- eq | | | |
| Air | (unspecified) | Ammonia | 007664-41-7 | 3.50E-01 | kg PO4--- eq / kg |
| Air | (unspecified) | Ammonium, ion | 014798-03-9 | 3.30E-01 | kg PO4--- eq / kg |
| Air | (unspecified) | Nitrate | 014797-55-8 | 1.00E-01 | kg PO4--- eq / kg |
| Air | (unspecified) | Nitric acid | 007697-37-2 | 1.00E-01 | kg PO4--- eq / kg |
| Air | (unspecified) | Nitric oxide | 010102-43-9 | 2.00E-01 | kg PO4--- eq / kg |
| Air | (unspecified) | Nitrogen | 007727-37-9 | 4.20E-01 | kg PO4--- eq / kg |
| Air | (unspecified) | Nitrogen dioxide | 010102-44-0 | 1.30E-01 | kg PO4--- eq / kg |
| Air | (unspecified) | Nitrogen oxides | 011104-93-1 | 1.30E-01 | kg PO4--- eq / kg |
| Air | (unspecified) | Phosphate | 014265-44-2 | 1.00E+00 | kg PO4--- eq / kg |
| Air | (unspecified) | Phosphoric acid | 007664-38-2 | 0.97 | kg PO4--- eq / kg |
| Air | (unspecified) | Phosphorus | 007723-14-0 | 3.06E+00 | kg PO4--- eq / kg |
| Air | (unspecified) | Phosphorus pentoxide | 001314-56-3 | 1.34 | kg PO4--- eq / kg |
| Air | low. pop. | Nitrogen oxides | 011104-93-1 | 1.30E-01 | kg PO4--- eq / kg |
| Soil | agricultural | Ammonia | 007664-41-7 | 3.50E-01 | kg PO4--- eq / kg |
| Soil | agricultural | Ammonium, ion | 014798-03-9 | 3.30E-01 | kg PO4--- eq / kg |
| Soil | agricultural | Nitrate | 014797-55-8 | 1.00E-01 | kg PO4--- eq / kg |
| Soil | agricultural | Nitric acid | 007697-37-2 | 1.00E-01 | kg PO4--- eq / kg |
| Soil | agricultural | Nitrogen | 007727-37-9 | 4.20E-01 | kg PO4--- eq / kg |
| Soil | agricultural | Phosphate | 014265-44-2 | 1.00E+00 | kg PO4--- eq / kg |
| Soil | agricultural | Phosphoric acid | 007664-38-2 | 0.97 | kg PO4--- eq / kg |
| Soil | agricultural | Phosphorus | 007723-14-0 | 3.06E+00 | kg PO4--- eq / kg |
| Soil | agricultural | Phosphorus pentoxide | 001314-56-3 | 1.34 | kg PO4--- eq / kg |
| Soil | industrial | Ammonia | 007664-41-7 | 3.50E-01 | kg PO4--- eq / kg |
| Soil | industrial | Ammonium, ion | 014798-03-9 | 3.30E-01 | kg PO4--- eq / kg |
| Soil | industrial | Nitrate | 014797-55-8 | 1.00E-01 | kg PO4--- eq / kg |
| Soil | industrial | Nitric acid | 007697-37-2 | 1.00E-01 | kg PO4--- eq / kg |
| Soil | industrial | Nitrogen | 007727-37-9 | 4.20E-01 | kg PO4--- eq / kg |
| Soil | industrial | Phosphate | 014265-44-2 | 1.00E+00 | kg PO4--- eq / kg |
| Soil | industrial | Phosphoric acid | 007664-38-2 | 0.97 | kg PO4--- eq / kg |
| Soil | industrial | Phosphorus | 007723-14-0 | 3.06E+00 | kg PO4--- eq / kg |
| Soil | industrial | Phosphorus pentoxide | 001314-56-3 | 1.34 | kg PO4--- eq / kg |
| Water | (unspecified) | Ammonia | 007664-41-7 | 3.50E-01 | kg PO4--- eq / kg |
| Water | (unspecified) | Ammonium, ion | 014798-03-9 | 3.30E-01 | kg PO4--- eq / kg |
| Water | (unspecified) | COD, Chemical Oxygen Demand | | 2.20E-02 | kg PO4--- eq / kg |
| Water | (unspecified) | Nitrate | 014797-55-8 | 1.00E-01 | kg PO4--- eq / kg |
| Water | (unspecified) | Nitric acid | 007697-37-2 | 1.00E-01 | kg PO4--- eq / kg |

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|---|---|---|---|---|---|
| Water | (unspecified) | Nitrite | 014797-65-0 | 1.00E-01 | kg PO4--- eq / kg |
| Water | (unspecified) | Nitrogen | 007727-37-9 | 4.20E-01 | kg PO4--- eq / kg |
| Water | (unspecified) | Phosphate | 014265-44-2 | 1.00E+00 | kg PO4--- eq / kg |
| Water | (unspecified) | Phosphoric acid | 007664-38-2 | 0.97 | kg PO4--- eq / kg |
| Water | (unspecified) | Phosphorus | 007723-14-0 | 3.06E+00 | kg PO4--- eq / kg |
| Water | (unspecified) | Phosphorus pentoxide | 001314-56-3 | 1.34 | kg PO4--- eq / kg |
| Water | ocean | Ammonia | 007664-41-7 | 3.50E-01 | kg PO4--- eq / kg |
| Water | ocean | Ammonium, ion | 014798-03-9 | 3.30E-01 | kg PO4--- eq / kg |
| Water | ocean | COD, Chemical Oxygen Demand | | 2.20E-02 | kg PO4--- eq / kg |
| Water | ocean | Nitrate | 014797-55-8 | 1.00E-01 | kg PO4--- eq / kg |
| Water | ocean | Nitric acid | 007697-37-2 | 1.00E-01 | kg PO4--- eq / kg |
| Water | ocean | Nitrite | 014797-65-0 | 1.00E-01 | kg PO4--- eq / kg |
| Water | ocean | Nitrogen | 007727-37-9 | 4.20E-01 | kg PO4--- eq / kg |
| Water | ocean | Phosphate | 014265-44-2 | 1.00E+00 | kg PO4--- eq / kg |
| Water | ocean | Phosphoric acid | 007664-38-2 | 0.97 | kg PO4--- eq / kg |
| Water | ocean | Phosphorus | 007723-14-0 | 3.06E+00 | kg PO4--- eq / kg |
| Water | ocean | Phosphorus pentoxide | 001314-56-3 | 1.34 | kg PO4--- eq / kg |
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| Impact category | Carcinogens | DALY | | | |
| Air | (unspecified) | Acetaldehyde | 000075-07-0 | 2.16E-07 | DALY / kg |
| Air | (unspecified) | Acrylonitrile | 000107-13-1 | 1.69E-05 | DALY / kg |
| Air | (unspecified) | Aldrin | 000309-00-2 | 1.93E-01 | DALY / kg |
| Air | (unspecified) | Arsenic | 007440-38-2 | 2.46E-02 | DALY / kg |
| Air | (unspecified) | Benzene | 000071-43-2 | 2.50E-06 | DALY / kg |
| Air | (unspecified) | Benzene, hexachloro- | 000118-74-1 | 8.25E-02 | DALY / kg |
| Air | (unspecified) | Benzo(a)anthracene | 000056-55-3 | 5.86E-02 | DALY / kg |
| Air | (unspecified) | Benzo(a)pyrene | 000050-32-8 | 3.98E-03 | DALY / kg |
| Air | (unspecified) | Benzotrichloride | 000098-07-7 | 6.60E-03 | DALY / kg |
| Air | (unspecified) | Benzyl chloride | 000100-44-7 | 1.04E-05 | DALY / kg |
| Air | (unspecified) | Bis(2-chloroethyl)ether | 000111-44-4 | 4.03E-05 | DALY / kg |
| Air | (unspecified) | Bis(chloromethyl)ether | 000542-88-1 | 7.48E-03 | DALY / kg |
| Air | (unspecified) | Butadiene | 000106-99-0 | 1.58E-05 | DALY / kg |
| Air | (unspecified) | Butadiene, hexachloro- | 000087-68-3 | 4.30E-05 | DALY / kg |
| Air | (unspecified) | Cadmium | 007440-43-9 | 1.35E-01 | DALY / kg |
| Air | (unspecified) | Chloroform | 000067-66-3 | 2.63E-05 | DALY / kg |
| Air | (unspecified) | Cholanthrene, 3-methyl- | 000056-49-5 | 1.67E-01 | DALY / kg |
| Air | (unspecified) | Chromium VI | 018540-29-9 | 0.00584 | DALY / kg |
| Air | (unspecified) | Dibenz(a,h)anthracene | 000053-70-3 | 3.10E+01 | DALY / kg |
| Air | (unspecified) | Dichlorvos | 000062-73-7 | 3.15E-05 | DALY / kg |
| Air | (unspecified) | Dieldrin | 000060-57-1 | 2.70E+01 | DALY / kg |
| Air | (unspecified) | Dioxane, 1,4- | 000123-91-1 | 1.39E-07 | DALY / kg |
| Air | (unspecified) | Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin | | 1.79E+02 | DALY / kg |
| Air | (unspecified) | Epichlorohydrin | 000106-89-8 | 3.02E-07 | DALY / kg |
| Air | (unspecified) | Ethane, 1,1,1,2-tetrachloro- | 000630-20-6 | 3.72E-05 | DALY / kg |
| Air | (unspecified) | Ethane, 1,1,2-trichloro- | 000079-00-5 | 1.10E-05 | DALY / kg |
| Air | (unspecified) | Ethane, 1,1,2,2-tetrachloro- | 000079-34-5 | 2.86E-04 | DALY / kg |
| Air | (unspecified) | Ethane, 1,2-dibromo- | 000106-93-4 | 2.60E-04 | DALY / kg |
| Air | (unspecified) | Ethane, 1,2-dichloro- | 000107-06-2 | 2.98E-05 | DALY / kg |
| Air | (unspecified) | Ethane, hexachloro- | 000067-72-1 | 1.99E-05 | DALY / kg |
| Air | (unspecified) | Ethene, 1,1-dichloro- | 000075-35-4 | 3.43E-06 | DALY / kg |
| Air | (unspecified) | Ethene, chloro- | 000075-01-4 | 2.09E-07 | DALY / kg |
| Air | (unspecified) | Ethene, tetrachloro- | 000127-18-4 | 4.82E-07 | DALY / kg |

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|---|---|---|---|---|---|
| Air | (unspecified) | Ethene, trichloro- | 000079-01-6 | 7.95E-08 | DALY / kg |
| Air | (unspecified) | Ethylene oxide | 000075-21-8 | 1.83E-04 | DALY / kg |
| Air | (unspecified) | Formaldehyde | 000050-00-0 | 9.91E-07 | DALY / kg |
| Air | (unspecified) | Heavy metals, unspecified | | 0.000697 | DALY / kg |
| Air | (unspecified) | Lindane | 000058-89-9 | 3.49E-04 | DALY / kg |
| Air | (unspecified) | Lindane, alpha- | 000319-84-6 | 3.00E-04 | DALY / kg |
| Air | (unspecified) | Lindane, beta- | 000319-85-7 | 9.99E-05 | DALY / kg |
| Air | (unspecified) | Metals, unspecified | | 0.000697 | DALY / kg |
| Air | (unspecified) | Methane, bromodichloro- | 000075-27-4 | 8.76E-06 | DALY / kg |
| Air | (unspecified) | Methane, dichloro-, HCC-30 | 000075-09-2 | 4.36E-07 | DALY / kg |
| Air | (unspecified) | Methane, monochloro-, R-40 | 000074-87-3 | 1.83E-05 | DALY / kg |
| Air | (unspecified) | Methane, tetrachloro-, CFC-10 | 000056-23-5 | 8.38E-04 | DALY / kg |
| Air | (unspecified) | Nickel | 007440-02-0 | 4.29E-05 | DALY / kg |
| Air | (unspecified) | Nickel refinery dust | | 4.74E-02 | DALY / kg |
| Air | (unspecified) | Nickel subsulfide | 012035-72-2 | 9.48E-02 | DALY / kg |
| Air | (unspecified) | PAH, polycyclic aromatic hydrocarbons | 130498-29-2 | 1.70E-04 | DALY / kg |
| Air | (unspecified) | Particulates, diesel soot | | 9.78E-06 | DALY / kg |
| Air | (unspecified) | Phenol, 2,4,6-trichloro- | 000088-06-2 | 2.05E-06 | DALY / kg |
| Air | (unspecified) | Phenol, pentachloro- | 000087-86-5 | 7.21E-03 | DALY / kg |
| Air | (unspecified) | Phthalate, dibutyl- | 000084-74-2 | 3.43E-03 | DALY / kg |
| Air | (unspecified) | Phthalate, dioctyl- | 000117-81-7 | 3.38E-05 | DALY / kg |
| Air | (unspecified) | Polychlorinated biphenyls | 001336-36-3 | 1.97E-03 | DALY / kg |
| Air | (unspecified) | Propylene oxide | 000075-56-9 | 1.17E-05 | DALY / kg |
| Air | (unspecified) | Sodium dichromate | 010588-01-9 | 2.32E-03 | DALY / kg |
| Air | (unspecified) | Styrene | 000100-42-5 | 2.44E-08 | DALY / kg |
| Air | (unspecified) | Trifluralin | 001582-09-8 | 1.10E-07 | DALY / kg |
| Soil | (unspecified) | 1,4-Dioxane | 000123-91-1 | 3.10E-07 | DALY / kg |
| Soil | (unspecified) | 3-Methylcholanthrene | 000056-49-5 | 7.85E-01 | DALY / kg |
| Soil | (unspecified) | Acetaldehyde | 000075-07-0 | 4.77E-07 | DALY / kg |
| Soil | (unspecified) | Acrylonitrile | 000107-13-1 | 7.01E-05 | DALY / kg |
| Soil | (unspecified) | Aldrin | 000309-00-2 | 3.21E+01 | DALY / kg |
| Soil | (unspecified) | Arsenic | 007440-38-2 | 1.32E-02 | DALY / kg |
| Soil | (unspecified) | Benzene | 000071-43-2 | 1.33E-05 | DALY / kg |
| Soil | (unspecified) | Benzene, hexachloro- | 000118-74-1 | 1.47E-01 | DALY / kg |
| Soil | (unspecified) | Benzo(a)anthracene | 000056-55-3 | 1.60E-01 | DALY / kg |
| Soil | (unspecified) | Benzo(a)pyrene | 000050-32-8 | 2.06E-03 | DALY / kg |
| Soil | (unspecified) | Benzotrichloride | 000098-07-7 | 1.32E-01 | DALY / kg |
| Soil | (unspecified) | Benzyl chloride | 000100-44-7 | 4.16E-05 | DALY / kg |
| Soil | (unspecified) | Bis(2-chloroethyl)ether | 000111-44-4 | 8.29E-05 | DALY / kg |
| Soil | (unspecified) | Bis(chloromethyl)ether | 000542-88-1 | 1.68E-02 | DALY / kg |
| Soil | (unspecified) | Butadiene | 000106-99-0 | 1.20E-05 | DALY / kg |
| Soil | (unspecified) | Butadiene, hexachloro- | 000087-68-3 | 8.56E-04 | DALY / kg |
| Soil | (unspecified) | Cadmium | 007440-43-9 | 3.98E-03 | DALY / kg |
| Soil | (unspecified) | Chloroform | 000067-66-3 | 4.12E-06 | DALY / kg |
| Soil | (unspecified) | Chromium VI | 018540-29-9 | 3.68E-07 | DALY / kg |
| Soil | (unspecified) | Dibenz(a,h)anthracene | 000053-70-3 | 2.44E+01 | DALY / kg |
| Soil | (unspecified) | Dichlorvos | 000062-73-7 | 2.25E-05 | DALY / kg |
| Soil | (unspecified) | Dieldrin | 000060-57-1 | 4.17E+02 | DALY / kg |
| Soil | (unspecified) | Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin | | 7.06 | DALY / kg |
| Soil | (unspecified) | Epichlorohydrin | 000106-89-8 | 1.30E-06 | DALY / kg |
| Soil | (unspecified) | Ethane, 1,1,1,2-tetrachloro- | 000630-20-6 | 1.09E-03 | DALY / kg |

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|---|---|---|---|---|---|
| Soil | (unspecified) | Ethane, 1,1,2-trichloro- | 000079-00-5 | 1.24E-04 | DALY / kg |
| Soil | (unspecified) | Ethane, 1,1,2,2-tetrachloro- | 000079-34-5 | 7.54E-03 | DALY / kg |
| Soil | (unspecified) | Ethane, 1,2-dibromo- | 000106-93-4 | 3.81E-03 | DALY / kg |
| Soil | (unspecified) | Ethane, 1,2-dichloro- | 000107-06-2 | 4.58E-04 | DALY / kg |
| Soil | (unspecified) | Ethane, hexachloro- | 000067-72-1 | 5.26E-04 | DALY / kg |
| Soil | (unspecified) | Ethene, 1,1-dichloro- | 000075-35-4 | 5.57E-06 | DALY / kg |
| Soil | (unspecified) | Ethene, chloro- | 000075-01-4 | 7.67E-07 | DALY / kg |
| Soil | (unspecified) | Ethene, tetrachloro- | 000127-18-4 | 6.00E-06 | DALY / kg |
| Soil | (unspecified) | Ethene, trichloro- | 000079-01-6 | 3.22E-07 | DALY / kg |
| Soil | (unspecified) | Ethylene oxide | 000075-21-8 | 2.38E-03 | DALY / kg |
| Soil | (unspecified) | Formaldehyde | 000050-00-0 | 1.83E-06 | DALY / kg |
| Soil | (unspecified) | Lindane | 000058-89-9 | 8.64E-03 | DALY / kg |
| Soil | (unspecified) | Lindane, alpha- | 000319-84-6 | 2.32E-02 | DALY / kg |
| Soil | (unspecified) | Lindane, beta- | 000319-85-7 | 7.36E-03 | DALY / kg |
| Soil | (unspecified) | Methane, bromodichloro- | 000075-27-4 | 7.82E-05 | DALY / kg |
| Soil | (unspecified) | Methane, dichloro-, HCC-30 | 000075-09-2 | 5.99E-06 | DALY / kg |
| Soil | (unspecified) | Methane, monochloro-, R-40 | 000074-87-3 | 5.58E-04 | DALY / kg |
| Soil | (unspecified) | Methane, tetrachloro-, CFC-10 | 000056-23-5 | 3.99E-02 | DALY / kg |
| Soil | (unspecified) | Nickel | 007440-02-0 | 4.21E-09 | DALY / kg |
| Soil | (unspecified) | Nickel refinery dust | | 6.37E-03 | DALY / kg |
| Soil | (unspecified) | Nickel subsulfide | 012035-72-2 | 1.27E-02 | DALY / kg |
| Soil | (unspecified) | Phenol, 2,4,6-trichloro- | 000088-06-2 | 2.76E-06 | DALY / kg |
| Soil | (unspecified) | Phenol, pentachloro- | 000087-86-5 | 1.26E-05 | DALY / kg |
| Soil | (unspecified) | Phthalate, dibutyl- | 000084-74-2 | 6.00E-06 | DALY / kg |
| Soil | (unspecified) | Phthalate, dioctyl- | 000117-81-7 | 3.18E-07 | DALY / kg |
| Soil | (unspecified) | Polychlorinated biphenyls | 001336-36-3 | 2.04E-02 | DALY / kg |
| Soil | (unspecified) | Propylene oxide | 000075-56-9 | 1.40E-04 | DALY / kg |
| Soil | (unspecified) | Styrene | 000100-42-5 | 2.09E-08 | DALY / kg |
| Soil | (unspecified) | Trifluralin | 001582-09-8 | 6.89E-05 | DALY / kg |
| Soil | agricultural | Arsenic | 007440-38-2 | 0.25 | DALY / kg |
| Soil | agricultural | Cadmium | 007440-43-9 | 2.17 | DALY / kg |
| Water | (unspecified) | Acetaldehyde | 000075-07-0 | 9.23E-07 | DALY / kg |
| Water | (unspecified) | Acrylonitrile | 000107-13-1 | 4.16E-05 | DALY / kg |
| Water | (unspecified) | Aldrin | 000309-00-2 | 6.78E+00 | DALY / kg |
| Water | (unspecified) | Arsenic, ion | 017428-41-0 | 6.57E-02 | DALY / kg |
| Water | (unspecified) | Benzene | 000071-43-2 | 4.12E-06 | DALY / kg |
| Water | (unspecified) | Benzene, hexachloro- | 000118-74-1 | 1.25E-01 | DALY / kg |
| Water | (unspecified) | Benzo(a)anthracene | 000056-55-3 | 6.58E-01 | DALY / kg |
| Water | (unspecified) | Benzo(a)pyrene | 000050-32-8 | 2.99 | DALY / kg |
| Water | (unspecified) | Benzotrichloride | 000098-07-7 | 9.46E-03 | DALY / kg |
| Water | (unspecified) | Benzyl chloride | 000100-44-7 | 1.98E-05 | DALY / kg |
| Water | (unspecified) | Bis(2-chloroethyl)ether | 000111-44-4 | 1.61E-04 | DALY / kg |
| Water | (unspecified) | Bis(chloromethyl)ether | 000542-88-1 | 1.54E-02 | DALY / kg |
| Water | (unspecified) | Butadiene | 000106-99-0 | 3.37E-04 | DALY / kg |
| Water | (unspecified) | Butadiene, hexachloro- | 000087-68-3 | 1.08E-04 | DALY / kg |
| Water | (unspecified) | Cadmium, ion | 022537-48-0 | 7.12E-02 | DALY / kg |
| Water | (unspecified) | Chloroform | 000067-66-3 | 2.60E-05 | DALY / kg |
| Water | (unspecified) | Cholanthrene, 3-methyl- | 000056-49-5 | 3.72E+01 | DALY / kg |
| Water | (unspecified) | Chromium VI | 018540-29-9 | 8.26E-10 | DALY / kg |
| Water | (unspecified) | Dibenz(a,h)anthracene | 000053-70-3 | 4.07E+01 | DALY / kg |
| Water | (unspecified) | Dichlorvos | 000062-73-7 | 1.17E-05 | DALY / kg |
| Water | (unspecified) | Dieldrin | 000060-57-1 | 9.75E+01 | DALY / kg |

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|---|---|---|---|---|---|
| Water | (unspecified) | Dioxane, 1,4- | 000123-91-1 | 9.21E-07 | DALY / kg |
| Water | (unspecified) | Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin | | 2.02E+03 | DALY / kg |
| Water | (unspecified) | Epichlorohydrin | 000106-89-8 | 9.90E-07 | DALY / kg |
| Water | (unspecified) | Ethane, 1,1,1,2-tetrachloro- | 000630-20-6 | 3.66E-05 | DALY / kg |
| Water | (unspecified) | Ethane, 1,1,2-trichloro- | 000079-00-5 | 1.23E-05 | DALY / kg |
| Water | (unspecified) | Ethane, 1,1,2,2-tetrachloro- | 000079-34-5 | 2.78E-04 | DALY / kg |
| Water | (unspecified) | Ethane, 1,2-dibromo- | 000106-93-4 | 1.24E-03 | DALY / kg |
| Water | (unspecified) | Ethane, 1,2-dichloro- | 000107-06-2 | 2.98E-05 | DALY / kg |
| Water | (unspecified) | Ethane, hexachloro- | 000067-72-1 | 2.12E-05 | DALY / kg |
| Water | (unspecified) | Ethene, 1,1-dichloro- | 000075-35-4 | 5.88E-05 | DALY / kg |
| Water | (unspecified) | Ethene, chloro- | 000075-01-4 | 2.84E-07 | DALY / kg |
| Water | (unspecified) | Ethene, tetrachloro- | 000127-18-4 | 4.72E-07 | DALY / kg |
| Water | (unspecified) | Ethene, trichloro- | 000079-01-6 | 7.97E-08 | DALY / kg |
| Water | (unspecified) | Ethylene oxide | 000075-21-8 | 1.39E-04 | DALY / kg |
| Water | (unspecified) | Formaldehyde | 000050-00-0 | 4.97E-06 | DALY / kg |
| Water | (unspecified) | Lindane | 000058-89-9 | 4.16E-03 | DALY / kg |
| Water | (unspecified) | Lindane, alpha- | 000319-84-6 | 6.85E-03 | DALY / kg |
| Water | (unspecified) | Lindane, beta- | 000319-85-7 | 5.75E-03 | DALY / kg |
| Water | (unspecified) | Metallic ions, unspecified | | 4.27E-05 | DALY / kg |
| Water | (unspecified) | Methane, bromodichloro- | 000075-27-4 | 9.36E-06 | DALY / kg |
| Water | (unspecified) | Methane, dichloro-, HCC-30 | 000075-09-2 | 4.79E-07 | DALY / kg |
| Water | (unspecified) | Methane, monochloro-, R-40 | 000074-87-3 | 1.78E-05 | DALY / kg |
| Water | (unspecified) | Methane, tetrachloro-, CFC-10 | 000056-23-5 | 8.29E-04 | DALY / kg |
| Water | (unspecified) | Nickel refinery dust | | 5.02E-03 | DALY / kg |
| Water | (unspecified) | Nickel subsulfide | 012035-72-2 | 1.00E-02 | DALY / kg |
| Water | (unspecified) | Nickel, ion | 014701-22-5 | 6.91E-11 | DALY / kg |
| Water | (unspecified) | PAH, polycyclic aromatic hydrocarbons | 130498-29-2 | 2.60E-03 | DALY / kg |
| Water | (unspecified) | Phenol, 2,4,6-trichloro- | 000088-06-2 | 1.05E-05 | DALY / kg |
| Water | (unspecified) | Phenol, pentachloro- | 000087-86-5 | 2.29E-02 | DALY / kg |
| Water | (unspecified) | Phthalate, dibutyl- | 000084-74-2 | 5.34E-02 | DALY / kg |
| Water | (unspecified) | Phthalate, dioctyl- | 000117-81-7 | 6.64E-04 | DALY / kg |
| Water | (unspecified) | Polychlorinated biphenyls | 001336-36-3 | 3.91E-02 | DALY / kg |
| Water | (unspecified) | Propylene oxide | 000075-56-9 | 1.74E-05 | DALY / kg |
| Water | (unspecified) | Sodium dichromate | 010588-01-9 | 3.28E-07 | DALY / kg |
| Water | (unspecified) | Styrene | 000100-42-5 | 1.22E-06 | DALY / kg |
| Water | (unspecified) | Trifluralin | 001582-09-8 | 7.93E-05 | DALY / kg |
| | | | | | |
| Impact category | Land use | Ha a | | | |
| Raw | (unspecified) | Occupation, construction site | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, dump site, benthos | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, dump site, radioactive | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, dump site, radioactive, high | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, dump site, radioactive, low-medium | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, heterogeneous, agricultural | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, industrial area, benthos | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, industrial area, built up | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, industrial area, vegetation | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, oil and gas extraction site | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, pasture and meadow | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, pipelines | | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, traffic area, rail embankment | | 1 | Ha a / Ha_a |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| Raw | (unspecified) | Occupation, traffic area, rail network |  | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, traffic area, road embankment |  | 1 | Ha a / Ha_a |
| Raw | (unspecified) | Occupation, traffic area, road network |  | 1 | Ha a / Ha_a |
| Raw | land | Occupation, arable |  | 1 | Ha a / Ha_a |
| Raw | land | Occupation, arable, intensive |  | 1 | Ha a / Ha_a |
| Raw | land | Occupation, arable, non-irrigated, diverse-intensive |  | 1 | Ha a / Ha_a |
| Raw | land | Occupation, arable, organic |  | 1 | Ha a / Ha_a |
| Raw | land | Occupation, dump site |  | 1 | Ha a / Ha_a |
| Raw | land | Occupation, forest |  | 1 | Ha a / ha a |
| Raw | land | Occupation, forest, extensive |  | 1 | Ha a / ha a |
| Raw | land | Occupation, forest, intensive |  | 1 | Ha a / ha a |
| Raw | land | Occupation, forest, intensive, clear-cutting |  | 1 | Ha a / ha a |
| Raw | land | Occupation, forest, intensive, normal |  | 1 | Ha a / ha a |
| Raw | land | Occupation, forest, intensive, short-cycle |  | 1 | Ha a / ha a |
| Raw | land | Occupation, industrial area |  | 1 | Ha a / ha a |
| Raw | land | Occupation, mineral extraction site |  | 1 | Ha a / ha a |
| Raw | land | Occupation, pasture and meadow, extensive |  | 1 | Ha a / Ha_a |
| Raw | land | Occupation, pasture and meadow, intensive |  | 1 | Ha a / Ha_a |
| Raw | land | Occupation, pasture and meadow, organic |  | 1 | Ha a / Ha_a |
| Raw | land | Occupation, traffic area |  | 1 | Ha a / ha a |
| Raw | land | Occupation, unknown |  | 1 | Ha a / ha a |
| Raw | land | Occupation, urban, continuously built |  | 1 | Ha a / ha a |
| Raw | land | Occupation, urban, discontinuously built |  | 1 | Ha a / ha a |
| Raw | land | Occupation, urban, green areas |  | 1 | Ha a / ha a |
| Raw | land | Occupation, water bodies, artificial |  | 1 | Ha a / ha a |
|  |  |  |  |  |  |
| Impact category | Water Use | KL H2O |  |  |  |
| Raw | (unspecified) | Water, cooling |  | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, cooling, drinking | 007732-18-5 | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, cooling, river |  | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, cooling, salt, ocean | 007732-18-5 | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, cooling, surface | 007732-18-5 | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, cooling, unspecified natural origin/kg | 007732-18-5 | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, cooling, unspecified natural origin/m3 | 007732-18-5 | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, cooling, unspecified/kg |  | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, cooling, well, in ground | 007732-18-5 | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, cooling/kg |  | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, cooling/m3 |  | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, drinking |  | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, fresh | 007732-18-5 | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, from Victorian catchments | 007732-18-5 | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, lake | 007732-18-5 | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, mining, unspecified natural origin/m3 |  | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, process |  | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, process and cooling, unspecified natural origin | 007732-18-5 | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, process, drinking | 007732-18-5 | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, process, river |  | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, process, salt, ocean | 007732-18-5 | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, process, surface | 007732-18-5 | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, process, unspecified natural origin/kg | 007732-18-5 | 1 | KL H2O / ton |

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|---|---|---|---|---|---|
| Raw | (unspecified) | Water, process, unspecified natural origin/m3 | 007732-18-5 | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, process, well, in ground | 007732-18-5 | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, process/kg | | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, process/m3 | | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, reticulated supply | | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, river | 007732-18-5 | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, stormwater | | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, surface | | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, unspecified natural origin /kg | | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, unspecified natural origin/kg | 007732-18-5 | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, unspecified natural origin/m3 | 007732-18-5 | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, well, in ground | 007732-18-5 | 1 | KL H2O / m3 |
| Raw | (unspecified) | Water, well, in ground /kg | | 1 | KL H2O / ton |
| Raw | (unspecified) | Water, well, in ground/m3 | 007732-18-5 | 1 | KL H2O / m3 |
| | | | | | |
| Impact category | Solid waste | kg | | | |
| Waste | (unspecified) | Aluminium waste | | 1 | kg / kg |
| Waste | (unspecified) | Asbestos | | 1 | kg / kg |
| Waste | (unspecified) | ash | | 1 | kg / kg |
| Waste | (unspecified) | Calcium fluoride waste | | 1 | kg / kg |
| Waste | (unspecified) | cardboard | | 1 | kg / kg |
| Waste | (unspecified) | Cathode iron ingots waste | | 1 | kg / kg |
| Waste | (unspecified) | Cathode loss | | 1 | kg / kg |
| Waste | (unspecified) | Chemical waste, inert | | 1 | kg / kg |
| Waste | (unspecified) | Chemical waste, regulated | | 1 | kg / kg |
| Waste | (unspecified) | Chemical waste, unspecified | | 1 | kg / kg |
| Waste | (unspecified) | Chromium waste | | 1 | kg / kg |
| Waste | (unspecified) | Coal tailings | | 1 | kg / kg |
| Waste | (unspecified) | Copper waste | | 1 | kg / kg |
| Waste | (unspecified) | Dross | | 1 | kg / kg |
| Waste | (unspecified) | Dust, unspecified | | 1 | kg / kg |
| Waste | (unspecified) | Glass waste | | 1 | kg / kg |
| Waste | (unspecified) | gypsum | | 1 | kg / kg |
| Waste | (unspecified) | Iron waste | | 1 | kg / kg |
| Waste | (unspecified) | jarosite | | 1 | kg / kg |
| Waste | (unspecified) | limestone | | 1 | kg / kg |
| Waste | (unspecified) | Metal waste | | 1 | kg / kg |
| Waste | (unspecified) | Mineral waste | | 1 | kg / kg |
| Waste | (unspecified) | Mineral waste, from mining | | 1 | kg / kg |
| Waste | (unspecified) | Monasite | | 1 | kg / kg |
| Waste | (unspecified) | Neutralized Acid Effluent | | 1 | kg / kg |
| Waste | (unspecified) | non magenetic fines | | 1 | kg / kg |
| Waste | (unspecified) | Oil waste | | 1 | kg / kg |
| Waste | (unspecified) | Packaging waste, paper and board | | 1 | kg / kg |
| Waste | (unspecified) | Packaging waste, plastic | | 1 | kg / kg |
| Waste | (unspecified) | Packaging waste, steel | | 1 | kg / kg |
| Waste | (unspecified) | Packaging waste, unspecified | | 1 | kg / kg |
| Waste | (unspecified) | Packaging waste, wood | | 1 | kg / kg |
| Waste | (unspecified) | Plastic waste | | 1 | kg / kg |
| Waste | (unspecified) | Polyethylene waste | | 1 | kg / kg |
| Waste | (unspecified) | Polyvinyl chloride waste | | 1 | kg / kg |

| | | | | | |
|---|---|---|---|---|---|
| Waste | (unspecified) | Production waste | | 1 | kg / kg |
| Waste | (unspecified) | Production waste, not inert | | 1 | kg / kg |
| Waste | (unspecified) | Rejects | | 1 | kg / kg |
| Waste | (unspecified) | Rejects, corrugated cardboard | | 1 | kg / kg |
| Waste | (unspecified) | Slags | | 1 | kg / kg |
| Waste | (unspecified) | Slags and ashes | | 1 | kg / kg |
| Waste | (unspecified) | Soot | | 1 | kg / kg |
| Waste | (unspecified) | Steel waste | | 1 | kg / kg |
| Waste | (unspecified) | Stones and rubble | | 1 | kg / kg |
| Waste | (unspecified) | Tails | | 1 | kg / kg |
| Waste | (unspecified) | Tin waste | | 1 | kg / kg |
| Waste | (unspecified) | Tinder from rolling drum | | 1 | kg / kg |
| Waste | (unspecified) | Waste in bioactive landfill | | 1 | kg / kg |
| Waste | (unspecified) | Waste, final, inert | | 1 | kg / kg |
| Waste | (unspecified) | Waste, fly ash | | 1 | kg / kg |
| Waste | (unspecified) | Waste, from construction | | 1 | kg / kg |
| Waste | (unspecified) | Waste, from incinerator | | 1 | kg / kg |
| Waste | (unspecified) | Waste, household | | 1 | kg / kg |
| Waste | (unspecified) | Waste, industrial | | 1 | kg / kg |
| Waste | (unspecified) | Waste, Inert | | 1 | kg / kg |
| Waste | (unspecified) | Waste, inorganic | | 1 | kg / kg |
| Waste | (unspecified) | Waste, limestone | | 1 | kg / kg |
| Waste | (unspecified) | Waste, Shedder dust | | 1 | kg / kg |
| Waste | (unspecified) | Waste, sludge | | 1 | kg / kg |
| Waste | (unspecified) | Waste, solid | | 1 | kg / kg |
| Waste | (unspecified) | Waste, to incineration | | 1 | kg / kg |
| Waste | (unspecified) | Waste, toxic | | 1 | kg / kg |
| Waste | (unspecified) | Waste, unspecified | | 1 | kg / kg |
| Waste | (unspecified) | Wood and wood waste | | 1 | kg / ton |
| Waste | (unspecified) | Wood, sawdust | | 1 | kg / kg |
| Waste | (unspecified) | Zinc waste | | 1 | kg / kg |
| | | | | | |
| Impact category | Fossil fuels | MJ surplus | | | |
| Raw | (unspecified) | Coal, 13.3 MJ per kg, in ground | | 1.1 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 18 MJ per kg, in ground | | 1.25 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 18.0 MJ per kg, in ground | | 1.25 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 18.5 MJ per kg, in ground | | 1.25 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 19.5 MJ per kg, in ground | | 1.355 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 20.0 MJ per kg, in ground | | 1.389 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 20.5 MJ per kg, in ground | | 1.39 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 21.5 MJ per kg, in ground | | 1.4 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 22.1 MJ per kg, in ground | | 1.535 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 22.4 MJ per kg, in ground | | 1.556 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 22.6 MJ per kg, in ground | | 1.57 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 22.8 MJ per kg, in ground | | 1.57 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 23.0 MJ per kg, in ground | | 1.598 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 24.0 MJ per kg, in ground | | 1.67 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 24.1 MJ per kg, in ground | | 1.674 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 26.4 MJ per kg, in ground | | 1.834 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 27.1 MJ per kg, in ground | | 1.882 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 28.0 MJ per kg, in ground | | 1.945 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 28.6 MJ per kg, in ground | | 1.987 | MJ surplus / kg |

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|---|---|---|---|---|---|
| Raw | (unspecified) | Coal, 29.0 MJ per kg, in ground | | 2.014 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 29.3 MJ per kg, in ground | | 2.035 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 30.3 MJ per kg, in ground | | 2.105 | MJ surplus / kg |
| Raw | (unspecified) | Coal, 30.6 MJ per kg, in ground | | 2.126 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 10 MJ per kg, in ground | | 0.61 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 10.0 MJ per kg, in ground | | 0.61 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 14.1 MJ per kg, in ground | | 0.86 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 14.4 MJ per kg, in ground | | 0.9 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 15 MJ per kg, in ground | | 1.2 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 15.0 MJ per kg, in ground | | 0.915 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 7.9 MJ per kg, in ground | | 0.482 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 8 MJ per kg, in ground | | 0.458 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 8.0 MJ per kg, in ground | | 0.488 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 8.1 MJ per kg, in ground | | 0.494 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 8.2 MJ per kg, in ground | | 0.5 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, 9.9 MJ per kg, in ground | | 0.604 | MJ surplus / kg |
| Raw | (unspecified) | Coal, brown, in ground | | 0.6039 | MJ surplus / kg |
| Raw | (unspecified) | Coal, feedstock, 26.4 MJ per kg, in ground | | 1.83 | MJ surplus / kg |
| Raw | (unspecified) | Coal, hard, unspecified, in ground | | 1.32 | MJ surplus / kg |
| Raw | (unspecified) | Energy, from coal | | 6.96E-02 | MJ surplus / MJ |
| Raw | (unspecified) | Energy, from coal, brown | | 6.10E-02 | MJ surplus / MJ |
| Raw | (unspecified) | Energy, from gas, natural | | 8.90E-02 | MJ surplus / MJ |
| Raw | (unspecified) | Energy, from liquified petroleum gas, feedstock | | 8.90E-02 | MJ surplus / MJ |
| Raw | (unspecified) | Energy, from oil | | 8.30E-02 | MJ surplus / MJ |
| Raw | (unspecified) | Gas, mine, off-gas, process, coal mining/kg | 008006-14-2 | 3.9 | MJ surplus / kg |
| Raw | (unspecified) | Gas, mine, off-gas, process, coal mining/m3 | 008006-14-2 | 3.196 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, 30.3 MJ per kg, in ground | 008006-14-2 | 2.69 | MJ surplus / kg |
| Raw | (unspecified) | Gas, natural, 31.65 MJ per m3, in ground | | 2.817 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, 35 MJ per m3, in ground | 008006-14-2 | 3.115 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, 35.0 MJ per m3, in ground | | 3.115 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, 35.2 MJ per m3, in ground | | 3.133 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, 35.9 MJ per m3, in ground | 008006-14-2 | 3.133 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, 36.6 MJ per m3, in ground | 008006-14-2 | 3.26 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, 38.8 MJ per m3, in ground | | 3.453 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, 39.0 MJ per m3, in ground | | 3.471 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, 42.0 MJ per m3, in ground | | 3.7 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, 46.8 MJ per kg, in ground | 008006-14-2 | 4.17 | MJ surplus / kg |
| Raw | (unspecified) | Gas, natural, 50.3 MJ per kg, in ground | | 2.697 | MJ surplus / kg |
| Raw | (unspecified) | Gas, natural, 51.3 MJ per kg, in ground | 008006-14-2 | 2.697 | MJ surplus / kg |
| Raw | (unspecified) | Gas, natural, feedstock, 35 MJ per m3, in ground | 008006-14-2 | 3.12 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, feedstock, 35.0 MJ per m3, in ground | | 3.12 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, natural, feedstock, 46.8 MJ per kg, in ground | 008006-14-2 | 4.17 | MJ surplus / kg |
| Raw | (unspecified) | Gas, natural, in ground | 008006-14-2 | 3.236 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, off-gas, 35.0 MJ per m3, oil production, in ground | | 3.115 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, off-gas, oil production, in ground | 008006-14-2 | 3.115 | MJ surplus / m3 |
| Raw | (unspecified) | Gas, petroleum, 35 MJ per m3, in ground | | 3.115 | MJ surplus / m3 |

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|---|---|---|---|---|---|
| Raw | (unspecified) | Oil, crude, 38400 MJ per m3, in ground | | 3.4 | MJ surplus / l |
| Raw | (unspecified) | Oil, crude, 41 MJ per kg, in ground | | 34 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, 41.0 MJ per kg, in ground | | 3.403 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, 41.9 MJ per kg, in ground | | 3.478 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, 42.0 MJ per kg, in ground | | 3.486 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, 42.6 MJ per kg, in ground | | 3.536 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, 42.7 MJ per kg, in ground | | 3.54 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, 42.8 MJ per kg, in ground | | 3.54 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, 43.4 MJ per kg, in ground | | 3.54 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, 44.0 MJ per kg, in ground | | 3.652 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, 44.6 MJ per kg, in ground | | 3.702 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, 45.0 MJ per kg, in ground | | 3.735 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, feedstock, 41 MJ per kg, in ground | | 3.403 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, feedstock, 42 MJ per kg, in ground | | 3.486 | MJ surplus / kg |
| Raw | (unspecified) | Oil, crude, in ground | | 3.59 | MJ surplus / kg |
| Raw | (unspecified) | Oil, from technosphere | | 3.59 | MJ surplus / kg |
| | | | | | |
| Impact category | Minerals | MJ Surplus | | | |
| Raw | (unspecified) | Aluminium, 24% in bauxite, 11% in crude ore, in ground | 001318-16-7 | 2.38 | MJ Surplus / kg |
| Raw | (unspecified) | Aluminium, in ground | 001318-16-7 | 2.38 | MJ Surplus / kg |
| Raw | (unspecified) | Bauxite, in ground | 001318-16-7 | 0.5 | MJ Surplus / kg |
| Raw | (unspecified) | Chromium ore, in ground | | 0.275 | MJ Surplus / kg |
| Raw | (unspecified) | Chromium, 25.5 in chromite, 11.6% in crude ore, in ground | 007440-47-3 | 0.9165 | MJ Surplus / kg |
| Raw | (unspecified) | Chromium, in ground | 007440-47-3 | 0.9165 | MJ Surplus / kg |
| Raw | (unspecified) | Cinnabar, in ground | | 165.5 | MJ Surplus / kg |
| Raw | (unspecified) | Copper ore, in ground | | 0.415 | MJ Surplus / kg |
| Raw | (unspecified) | Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground | 007440-50-8 | 36.79576 | MJ Surplus / kg |
| Raw | (unspecified) | Copper, in ground | 007440-50-8 | 36.7 | MJ Surplus / kg |
| Raw | (unspecified) | Iron ore, in ground | | 0.029 | MJ Surplus / kg |
| Raw | (unspecified) | Iron, 46% in ore, 25% in crude ore, in ground | 007439-89-6 | 0.051 | MJ Surplus / kg |
| Raw | (unspecified) | Iron, in ground | 007439-89-6 | 0.051 | MJ Surplus / kg |
| Raw | (unspecified) | Lead ore, in ground | | 0.368 | MJ Surplus / kg |
| Raw | (unspecified) | Lead, in ground | 007439-92-1 | 7.35 | MJ Surplus / kg |
| Raw | (unspecified) | Manganese ore, in ground | | 0.141 | MJ Surplus / kg |
| Raw | (unspecified) | Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground | 007439-96-5 | 0.313 | MJ Surplus / kg |
| Raw | (unspecified) | Manganese, in ground | 007439-96-5 | 0.313 | MJ Surplus / kg |
| Raw | (unspecified) | Mercury, in ground | 007439-97-6 | 165.5 | MJ Surplus / kg |
| Raw | (unspecified) | Molybdenum ore, in ground | | 0.041 | MJ Surplus / kg |
| Raw | (unspecified) | Molybdenum, 0.11% in sulfide, Mo 0.41% and Cu 0.36% in crude ore, in ground | 007439-98-7 | 37.14 | MJ Surplus / kg |
| Raw | (unspecified) | Molybdenum, in ground | 007439-98-7 | 41 | MJ Surplus / kg |
| Raw | (unspecified) | Nickel ore, in ground | | 0.356 | MJ Surplus / kg |
| Raw | (unspecified) | Nickel, 1.13% in sulfides, 0.76% in crude ore, in ground | 007440-02-0 | 16.32 | MJ Surplus / kg |
| Raw | (unspecified) | Nickel, 1.98% in silicates, 1.04% in crude ore, in ground | 007440-02-0 | 16.32 | MJ Surplus / kg |

| | | | | | |
|---|---|---|---|---|---|
| Raw | (unspecified) | Nickel, in ground | 007440-02-0 | 23.75 | MJ Surplus / kg |
| Raw | (unspecified) | Pyrolusite, in ground | 014854-26-3 | 0.313 | MJ Surplus / kg |
| Raw | (unspecified) | Tin ore, in ground | | 0.06 | MJ Surplus / kg |
| Raw | (unspecified) | Tin, 79% in cassiterite, 0.1% in crude ore, in ground | 007440-31-5 | 600 | MJ Surplus / kg |
| Raw | (unspecified) | Tin, in ground | 007440-31-5 | 600 | MJ Surplus / kg |
| Raw | (unspecified) | Tungsten ore, in ground | | 0.927 | MJ Surplus / kg |
| Raw | (unspecified) | Zinc 9%, Lead 5%, in sulfide, in ground | | 3.8367 | MJ Surplus / kg |
| Raw | (unspecified) | Zinc ore, in ground | | 0.0164 | MJ Surplus / kg |
| Raw | (unspecified) | Zinc, in ground | 007440-66-6 | 4.09 | MJ Surplus / kg |
| | | | | | |
| Normalization-Weighting set | Australian annual per capita | | | | |
| | | | | | |
| Normalization | | | | | |
| Global Warming | 0.000049702 | | | | |
| Photochemical oxidation | 0.021949442 | | | | |
| Eutrophication | 0.059940018 | | | | |
| Carcinogens | 1597.292728 | | | | |
| Land use | 0.039 | | | | |
| Water Use | 0.001369863 | | | | |
| Solid waste | 0.00072 | | | | |
| Fossil fuels | 4.49E-05 | | | | |
| Minerals | 0.0093 | | | | |
| | | | | | |
| Normalization-Weighting set | Australian annual | | | | |
| | | | | | |
| Normalization | | | | | |
| Global Warming | 1.77E-12 | | | | |
| Photochemical oxidation | 1.10E-09 | | | | |
| Eutrophication | 2.90E-09 | | | | |
| Carcinogens | 3.03E-06 | | | | |
| Land use | 1.98E-09 | | | | |
| Water Use | 1.45E-11 | | | | |
| Solid waste | 3.60E-11 | | | | |
| Fossil fuels | 2.74E-12 | | | | |
| Minerals | 5.17E-10 | | | | |

# 19 Appendix F – Substances excluded from assessment method (Comparing crushed concrete aggregate to quarried stone aggregate)

| **Compartment** | **Substance** | **Unit** | **Crushed concrete** | **Quarried stone - LC** |
|---|---|---|---|---|
| Raw | Additives | µg | 212.35 | 68.60 |
| Raw | Air | ng | 57.80 | 1.79 |
| Raw | Aluminum hydroxide | mg | 66.94 | 66.94 |
| Raw | Anhydrite, in ground | µg | 3.80 | 4.54 |
| Raw | bagasse | g | 28.79 | 0.04 |
| Raw | Barite, 15% in crude ore, in ground | g | 4.12 | 4.97 |
| Raw | Baryte, in ground | pg | 27.28 | 0.85 |
| Raw | Basalt, in ground | mg | 32.08 | 38.57 |
| Raw | Borax, in ground | µg | 1.07 | 1.28 |
| Raw | Cadmium, 0.30% in sulfide, Cd 0.18%, Pb, Zn, Ag, In, in ground | µg | 23.01 | 27.62 |
| Raw | Calcite, in ground | g | 30.06 | 36.10 |
| Raw | Calcium sulfate, in ground | pg | 0.78 | 0.02 |
| Raw | Carbon | µg | 287.29 | 59.66 |
| Raw | Carbon dioxide, in air | g | 4.91 | 5.92 |
| Raw | Carbon, in organic matter, in soil | µg | 786.17 | 947.39 |
| Raw | Cerium, 24% in bastnasite, 2.4% in crude ore, in ground | pg | 0.00 | 0.00 |
| Raw | Chromium, 25.5% in chromite, 11.6% in crude ore, in ground | mg | 257.22 | 309.12 |
| Raw | Chrysotile, in ground | µg | 11.65 | 14.00 |
| Raw | Clay, bentonite, in ground | g | -301.87 | 1.40 |
| Raw | Clay, unspecified, in ground | g | 3.63 | 4.33 |
| Raw | Coal washery waste | g | -44.67 | x |
| Raw | Cobalt, in ground | µg | 21.38 | 25.77 |
| Raw | Colemanite, in ground | µg | 917.31 | 957.24 |
| Raw | Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground | mg | 17.93 | 21.52 |
| Raw | Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground | mg | 4.76 | 5.71 |
| Raw | Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground | mg | 23.64 | 28.38 |
| Raw | Diatomite, in ground | ng | 8.80 | 10.58 |
| Raw | Dolomite, in ground | g | -858.56 | 0.36 |
| Raw | Energy, from biomass | Wh | 322.12 | 151.35 |
| Raw | Energy, from hydro power | Wh | 760.54 | 145.08 |
| Raw | Energy, from hydrogen | J | 0.00 | 0.00 |
| Raw | Energy, from peat | J | 0.00 | 0.00 |
| Raw | Energy, from solar | J | 819.07 | 25.37 |
| Raw | Energy, from sulfur | J | 0.00 | 0.00 |
| Raw | Energy, from uranium | J | 0.00 | 0.00 |
| Raw | Energy, from wood | J | 0.00 | 0.00 |
| Raw | Energy, gross calorific value, in biomass | kJ | 47.76 | 57.52 |
| Raw | Energy, gross calorific value, in biomass, primary forest | J | 54.50 | 65.68 |
| Raw | Energy, kinetic (in wind), converted | kJ | 20.01 | 24.10 |
| Raw | Energy, kinetic, flow, in wind | kJ | 48.70 | 18.29 |
| Raw | Energy, potential (in hydropower reservoir), converted | kJ | 141.60 | 170.33 |
| Raw | Energy, potential, stock, in barrage water | kJ | -214.36 | x |

| | | | | |
|---|---|---|---|---|
| Raw | Energy, recovered | J | 0.00 | 0.00 |
| Raw | Energy, solar, converted | J | 287.39 | 346.14 |
| Raw | Energy, unspecified | J | 0.00 | 0.00 |
| Raw | Feldspar, in ground | µg | 26.28 | 8.52 |
| Raw | Ferromanganese | g | -62.53 | 0.01 |
| Raw | Fluorine, 4.5% in apatite, 1% in crude ore, in ground | mg | 2.62 | 3.16 |
| Raw | Fluorine, 4.5% in apatite, 3% in crude ore, in ground | mg | 1.16 | 1.39 |
| Raw | Fluorine, in ground | mg | 7.70 | 7.70 |
| Raw | Fluorspar, 92%, in ground | mg | 71.02 | 85.58 |
| Raw | Fluorspar, in ground | pg | 0.54 | 0.02 |
| Raw | Gadolinium, 0.15% in bastnasite, 0.015% in crude ore, in ground | pg | 0.00 | 0.00 |
| Raw | Gallium, 0.014% in bauxite, in ground | pg | 815.21 | 981.86 |
| Raw | Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore, in ground | ng | 47.74 | 57.40 |
| Raw | Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore, in ground | ng | 87.54 | 105.25 |
| Raw | Gold, Au 1.4E-4%, in ore, in ground | ng | 104.81 | 126.02 |
| Raw | Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore, in ground | ng | 160.09 | 192.48 |
| Raw | Gold, Au 4.3E-4%, in ore, in ground | ng | 39.68 | 47.71 |
| Raw | Gold, Au 4.9E-5%, in ore, in ground | ng | 95.03 | 114.26 |
| Raw | Gold, Au 6.7E-4%, in ore, in ground | ng | 147.13 | 176.90 |
| Raw | Gold, Au 7.1E-4%, in ore, in ground | ng | 165.90 | 199.47 |
| Raw | Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground | ng | 9.94 | 11.95 |
| Raw | Granite, in ground | pg | 239.12 | 287.85 |
| Raw | Graphite, from technosphere | µg | 119.74 | 108.82 |
| Raw | Gravel, in ground | g | 72.76 | 69.45 |
| Raw | Gypsum, in ground | g | 78.87 | 0.07 |
| Raw | Helium, 0.08% in natural gas, in ground | ng | 4.12 | 4.96 |
| Raw | Indium, 0.005% in sulfide, In 0.003%, Pb, Zn, Ag, Cd, in ground | ng | 422.44 | 507.16 |
| Raw | Kaolinite, 24% in crude ore, in ground | mg | 1.43 | 1.72 |
| Raw | Kieserite, 25% in crude ore, in ground | µg | 5.39 | 6.49 |
| Raw | Landfill cover, m3 | mm3 | 167.08 | x |
| Raw | Lanthanum, 7.2% in bastnasite, 0.72% in crude ore, in ground | pg | 0.00 | 0.00 |
| Raw | Lead, 5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In, in ground | mg | 3.43 | 4.13 |
| Raw | Limestone, in ground | g | -703.14 | 3.92 |
| Raw | Magnesite, 60% in crude ore, in ground | g | 0.97 | 1.17 |
| Raw | Magnesium, 0.13% in water | µg | 1.93 | 2.32 |
| Raw | Metamorphous rock, graphite containing, in ground | µg | 106.04 | 127.50 |
| Raw | Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground | µg | 439.38 | 527.47 |
| Raw | Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground | µg | 62.47 | 74.99 |
| Raw | Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground | mg | 109.43 | 131.88 |
| Raw | Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground | µg | 228.90 | 274.79 |
| Raw | Molybdenum, 0.11% in sulfide, Mo 4.1E-2% and Cu 0.36% in crude ore, in ground | mg | 220.86 | 266.16 |
| Raw | Neodymium, 4% in bastnasite, 0.4% in crude ore, in ground | pg | 0.00 | 0.00 |
| Raw | Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground | µg | 112.18 | 135.02 |
| Raw | Nitrogen, in air | ng | 5.76 | 0.18 |
| Raw | Occupation, permanent crop, fruit, intensive | m2s | 618.55 | 745.40 |
| Raw | Occupation, water bodies, artificial | mm2a | 420.34 | 505.76 |
| Raw | Occupation, water courses, artificial | m2a | 0.22 | 0.04 |
| Raw | Olivine, in ground | µg | 1.37 | 1.63 |

| | | | | |
|---|---|---|---|---|
| Raw | Oxygen, in air | g | 5.60 | 0.07 |
| Raw | Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground | µg | 1.01 | 1.22 |
| Raw | Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground | µg | 2.43 | 2.92 |
| Raw | Peat, in ground | µg | 558.16 | 652.07 |
| Raw | Phosphorus pentoxide | mg | 30.78 | 30.78 |
| Raw | Phosphorus, 18% in apatite, 12% in crude ore, in ground | mg | 4.62 | 5.57 |
| Raw | Phosphorus, 18% in apatite, 4% in crude ore, in ground | mg | 10.49 | 12.64 |
| Raw | Potassium chloride | ng | 1.74 | 0.05 |
| Raw | Praseodymium, 0.42% in bastnasite, 0.042% in crude ore, in ground | pg | 0.00 | 0.00 |
| Raw | Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground | ng | 25.08 | 30.22 |
| Raw | Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground | ng | 89.91 | 108.35 |
| Raw | Refractories, from technosphere | g | -33.34 | 0.01 |
| Raw | Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground | ng | 23.17 | 27.92 |
| Raw | Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground | ng | 72.56 | 87.44 |
| Raw | Rhenium, in crude ore, in ground | ng | 32.42 | 39.07 |
| Raw | Rutile, in ground | pg | 0.00 | 0.00 |
| Raw | Samarium, 0.3% in bastnasite, 0.03% in crude ore, in ground | pg | 0.00 | 0.00 |
| Raw | Sand, river, in ground | g | 577.81 | 4.52 |
| Raw | Sand, unspecified, in ground | mg | 13.50 | 4.91 |
| Raw | Secondary glass | mg | 7.73 | 2.50 |
| Raw | Shale, in ground | µg | 10.76 | 12.86 |
| Raw | Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In, in ground | µg | 1.14 | 1.37 |
| Raw | Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore, in ground | ng | 815.77 | 980.98 |
| Raw | Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore, in ground | ng | 75.24 | 90.48 |
| Raw | Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore, in ground | ng | 171.84 | 206.64 |
| Raw | Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore, in ground | ng | 168.44 | 202.56 |
| Raw | Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground | ng | 111.14 | 133.65 |
| Raw | Sodium chloride, in ground | g | 0.91 | 1.06 |
| Raw | Sodium nitrate, in ground | pg | 170.15 | 200.04 |
| Raw | Sodium sulphate, various forms, in ground | mg | 20.02 | 24.12 |
| Raw | Stibnite, in ground | ng | 0.91 | 1.10 |
| Raw | Sulfur dioxide, secondary | mg | 91.26 | 91.23 |
| Raw | Sulfur, bonded | ng | 1.37 | 0.04 |
| Raw | Sulfur, in ground | µg | 203.40 | 241.00 |
| Raw | Sylvite, 25 % in sylvinite, in ground | µg | 681.91 | 821.42 |
| Raw | Talc, in ground | µg | 153.43 | 184.78 |
| Raw | Tantalum, 81.9% in tantalite, 1.6E-4% in crude ore, in ground | µg | 0.89 | 1.07 |
| Raw | Tellurium, 0.5ppm in sulfide, Te 0.2ppm, Cu and Ag, in crude ore, in ground | ng | 122.37 | 147.15 |
| Raw | TiO2, 54% in ilmenite, 2.6% in crude ore, in ground | mg | 42.18 | 50.82 |
| Raw | TiO2, 95% in rutile, 0.40% in crude ore, in ground | ng | 20.86 | 24.27 |
| Raw | Transformation, from arable | mm2 | 0.13 | 0.16 |
| Raw | Transformation, from arable, non-irrigated | mm2 | 16.38 | 19.72 |
| Raw | Transformation, from arable, non-irrigated, fallow | mm2 | 0.01 | 0.01 |
| Raw | Transformation, from dump site, inert material landfill | mm2 | 0.60 | 0.70 |
| Raw | Transformation, from dump site, residual material landfill | mm2 | 1.69 | 2.04 |
| Raw | Transformation, from dump site, sanitary landfill | mm2 | 0.06 | 0.07 |
| Raw | Transformation, from dump site, slag compartment | mm2 | 0.01 | 0.01 |
| Raw | Transformation, from forest | cm2 | 10.42 | 12.56 |

|  |  |  |  |  |
|---|---|---|---|---|
| Raw | Transformation, from forest, extensive | mm2 | 39.24 | 47.27 |
| Raw | Transformation, from forest, intensive, clear-cutting | mm2 | 0.49 | 0.59 |
| Raw | Transformation, from industrial area | mm2 | 0.72 | 0.87 |
| Raw | Transformation, from industrial area, benthos | mm2 | 0.00 | 0.00 |
| Raw | Transformation, from industrial area, built up | mm2 | 0.00 | 0.00 |
| Raw | Transformation, from industrial area, vegetation | mm2 | 0.01 | 0.01 |
| Raw | Transformation, from mineral extraction site | mm2 | 8.75 | 8.98 |
| Raw | Transformation, from pasture and meadow | mm2 | 5.63 | 6.65 |
| Raw | Transformation, from pasture and meadow, intensive | mm2 | 0.01 | 0.02 |
| Raw | Transformation, from sea and ocean | mm2 | 307.44 | 370.50 |
| Raw | Transformation, from shrub land, sclerophyllous | mm2 | 3.06 | 3.66 |
| Raw | Transformation, from tropical rain forest | mm2 | 0.49 | 0.59 |
| Raw | Transformation, from unknown | cm2 | 46.53 | 9.85 |
| Raw | Transformation, to arable | mm2 | 4.77 | 5.74 |
| Raw | Transformation, to arable, non-irrigated | mm2 | 16.39 | 19.74 |
| Raw | Transformation, to arable, non-irrigated, fallow | mm2 | 0.03 | 0.03 |
| Raw | Transformation, to dump site | mm2 | 11.87 | 14.30 |
| Raw | Transformation, to dump site, benthos | mm2 | 307.33 | 370.37 |
| Raw | Transformation, to dump site, inert material landfill | mm2 | 0.60 | 0.70 |
| Raw | Transformation, to dump site, residual material landfill | mm2 | 1.69 | 2.04 |
| Raw | Transformation, to dump site, sanitary landfill | mm2 | 0.06 | 0.07 |
| Raw | Transformation, to dump site, slag compartment | mm2 | 0.01 | 0.01 |
| Raw | Transformation, to forest | mm2 | 5.87 | 6.97 |
| Raw | Transformation, to forest, intensive | mm2 | 0.45 | 0.54 |
| Raw | Transformation, to forest, intensive, clear-cutting | mm2 | 0.49 | 0.59 |
| Raw | Transformation, to forest, intensive, normal | mm2 | 38.13 | 45.92 |
| Raw | Transformation, to forest, intensive, short-cycle | mm2 | 0.49 | 0.59 |
| Raw | Transformation, to heterogeneous, agricultural | mm2 | 48.44 | 58.37 |
| Raw | Transformation, to industrial area | mm2 | 43.03 | 19.48 |
| Raw | Transformation, to industrial area, benthos | mm2 | 0.11 | 0.13 |
| Raw | Transformation, to industrial area, built up | mm2 | 6.98 | 8.36 |
| Raw | Transformation, to industrial area, vegetation | mm2 | 125.02 | 43.11 |
| Raw | Transformation, to mineral extraction site | cm2 | 10.17 | 12.27 |
| Raw | Transformation, to pasture and meadow | mm2 | 0.25 | 0.31 |
| Raw | Transformation, to permanent crop, fruit, intensive | mm2 | 0.28 | 0.33 |
| Raw | Transformation, to sea and ocean | mm2 | 0.00 | 0.00 |
| Raw | Transformation, to shrub land, sclerophyllous | mm2 | 4.83 | 4.30 |
| Raw | Transformation, to traffic area, rail embankment | mm2 | 0.17 | 0.20 |
| Raw | Transformation, to traffic area, rail network | mm2 | 0.18 | 0.22 |
| Raw | Transformation, to traffic area, road embankment | mm2 | 0.41 | 0.49 |
| Raw | Transformation, to traffic area, road network | mm2 | 13.72 | 16.52 |
| Raw | Transformation, to unknown | mm2 | 0.92 | 1.11 |
| Raw | Transformation, to urban, discontinuously built | mm2 | 0.00 | 0.00 |
| Raw | Transformation, to water bodies, artificial | cm2 | 44.27 | 8.51 |
| Raw | Transformation, to water courses, artificial | mm2 | 3.15 | 3.79 |
| Raw | Ulexite, in ground | µg | 36.87 | 44.41 |
| Raw | Uranium, in ground | mg | 1.96 | 2.36 |
| Raw | Vermiculite, in ground | µg | 11.53 | 13.25 |
| Raw | Volume occupied, final repository for low-active radioactive waste | mm3 | 4.04 | 4.87 |
| Raw | Volume occupied, final repository for radioactive waste | mm3 | 1.02 | 1.23 |
| Raw | Volume occupied, reservoir | m3day | 0.88 | 1.05 |
| Raw | Volume occupied, underground deposit | mm3 | 29.02 | 34.86 |

| | | | | |
|---|---|---|---|---|
| Raw | Water, turbine use, unspecified natural origin | m3 | 1.18 | 1.41 |
| Raw | Wood, hard, standing | cm3 | 1.55 | 1.87 |
| Raw | Wood, primary forest, standing | mm3 | 5.06 | 6.09 |
| Raw | Wood, soft, standing | cm3 | 2.97 | 3.57 |
| Raw | Wood, unspecified, standing/m3 | mm3 | 0.03 | 0.04 |
| Raw | Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground | mg | 23.16 | 27.88 |
| Raw | Zirconium, 50% in zircon, 0.39% in crude ore, in ground | µg | 1.15 | 1.38 |
| Air | 1,4-Butanediol | pg | 285.60 | 343.41 |
| Air | Acenaphthene | pg | 339.28 | 408.75 |
| Air | Acetonitrile | ng | 530.88 | 639.74 |
| Air | Acrolein | ng | 116.35 | 140.15 |
| Air | Acrylic acid | ng | 13.42 | 16.14 |
| Air | Actinides, radioactive, unspecified | µBq | 33.75 | 40.62 |
| Air | Aerosols, radioactive, unspecified | mBq | 0.86 | 1.03 |
| Air | Aldehydes, unspecified | µg | 4.72 | 5.67 |
| Air | Aluminum | mg | 25.15 | 30.30 |
| Air | Ammonium carbonate | ng | 93.46 | 112.33 |
| Air | Antimony | µg | 2.98 | 3.31 |
| Air | Antimony-124 | nBq | 4.46 | 5.31 |
| Air | Antimony-125 | nBq | 46.56 | 55.44 |
| Air | Argon-41 | mBq | 452.93 | 545.57 |
| Air | Arsine | pg | 0.16 | 0.19 |
| Air | Barium | µg | -61.51 | 34.64 |
| Air | Barium-140 | µBq | 3.03 | 3.61 |
| Air | Benzal chloride | pg | 0.00 | 0.01 |
| Air | Benzaldehyde | ng | 50.57 | 60.91 |
| Air | Benzene, pentachloro- | ng | 2.99 | 3.27 |
| Air | Beryllium | µg | 146.98 | 13.48 |
| Air | Biphenyl | µg | -1.18 | 7.91 |
| Air | Bismuth | µg | -1.16 | x |
| Air | Boron | mg | 41.35 | 14.22 |
| Air | Boron trifluoride | pg | 0.00 | 0.00 |
| Air | Bromine | µg | 138.81 | 167.24 |
| Air | Butanol | pg | 0.89 | 1.06 |
| Air | Butene | mg | 1.07 | 1.29 |
| Air | Butyrolactone | pg | 82.65 | 99.38 |
| Air | Calcium | µg | 430.36 | 514.34 |
| Air | Caprolactam | ng | 95.07 | 35.71 |
| Air | Carbon-14 | Bq | 3.51 | 4.22 |
| Air | Carbon dioxide, biogenic | g | 89.55 | 33.71 |
| Air | Carbon dioxide, land transformation | mg | 17.16 | 20.68 |
| Air | Carbon disulfide | mg | 5.82 | 7.04 |
| Air | Carbon monoxide, biogenic | mg | 6.64 | 7.85 |
| Air | Carbon monoxide, fossil | g | 10.39 | 12.57 |
| Air | Cerium-141 | nBq | 734.23 | 874.22 |
| Air | Cesium-134 | nBq | 35.16 | 41.87 |
| Air | Cesium-137 | nBq | 623.36 | 742.21 |
| Air | Chlorine | µg | -12.93 | 648.09 |
| Air | Chlorosilane, trimethyl- | pg | 241.17 | 289.98 |
| Air | Chromium | mg | 1.67 | 1.26 |
| Air | Chromium-51 | nBq | 47.05 | 56.02 |
| Air | Cobalt | µg | 56.34 | 81.07 |

|  |  |  |  |  |
|---|---|---|---|---|
| Air | Cobalt-58 | nBq | 65.52 | 78.01 |
| Air | Cobalt-60 | nBq | 578.79 | 689.14 |
| Air | Copper | mg | 2.60 | 2.25 |
| Air | Cyanide | mg | -102.66 | 0.05 |
| Air | Ethyl acetate | µg | 24.39 | 29.32 |
| Air | Ethyl cellulose | ng | 48.73 | 58.59 |
| Air | Ethylene diamine | pg | 150.29 | 180.98 |
| Air | Fluoride | mg | 121.28 | 4.22 |
| Air | Fluorine | mg | -3.33 | 0.04 |
| Air | Fluosilicic acid | µg | 1.86 | 2.23 |
| Air | Furan | µg | 1.01 | 1.21 |
| Air | Heat, waste | MJ | 61.68 | 49.67 |
| Air | Helium | mg | 1.94 | 2.34 |
| Air | Hydrocarbons, aliphatic, alkanes, cyclic | µg | 1.53 | 1.84 |
| Air | Hydrocarbons, aliphatic, alkanes, unspecified | mg | 10.66 | 12.85 |
| Air | Hydrocarbons, aliphatic, unsaturated | µg | 352.72 | 424.91 |
| Air | Hydrocarbons, aromatic | mg | 2.91 | 3.51 |
| Air | Hydrocarbons, chlorinated | µg | 3.28 | 3.95 |
| Air | Hydrocarbons, sulfur | ng | -14.18 | x |
| Air | Hydrocarbons, unspecified | mg | -105.60 | 179.36 |
| Air | Hydrogen | mg | 2.04 | 2.45 |
| Air | Hydrogen-3, Tritium | Bq | 20.27 | 24.41 |
| Air | Hydrogen chloride | g | 2.51 | 1.44 |
| Air | Hydrogen cyanide | pg | 0.00 | 0.00 |
| Air | Hydrogen fluoride | mg | 9.82 | 3.85 |
| Air | Hydrogen peroxide | ng | 36.30 | 43.65 |
| Air | Hydrogen sulfide | mg | -55.42 | 3.50 |
| Air | Iodine | µg | 73.74 | 88.84 |
| Air | Iodine-129 | mBq | 3.55 | 4.27 |
| Air | Iodine-131 | mBq | 179.23 | 215.90 |
| Air | Iodine-133 | µBq | 7.71 | 9.23 |
| Air | Iodine-135 | µBq | 8.87 | 10.67 |
| Air | Iron | mg | 1.11 | 1.34 |
| Air | Isocyanic acid | µg | 1.98 | 2.39 |
| Air | Krypton-85 | Bq | 1.42 | 1.71 |
| Air | Krypton-85m | mBq | 66.33 | 79.30 |
| Air | Krypton-87 | mBq | 26.94 | 32.32 |
| Air | Krypton-88 | mBq | 26.31 | 31.51 |
| Air | Krypton-89 | mBq | 6.58 | 7.85 |
| Air | Lanthanum-140 | nBq | 258.85 | 308.20 |
| Air | Lead | mg | -12.32 | 0.63 |
| Air | Lead-210 | mBq | 21.00 | 25.29 |
| Air | Lithium | ng | -77.24 | x |
| Air | Magnesium | mg | 7.04 | 0.46 |
| Air | Magnesium oxide | mg | 4.46 | 0.00 |
| Air | Manganese | mg | -4.90 | 1.02 |
| Air | Manganese-54 | nBq | 24.09 | 28.69 |
| Air | Mercaptans, unspecified | pg | 0.01 | 0.00 |
| Air | Mercury | µg | -20.86 | 123.73 |
| Air | Methacrylic acid, methyl ester | ng | 503.33 | 71.14 |
| Air | Methyl acrylate | ng | 15.23 | 18.31 |
| Air | Methyl amine | pg | 29.79 | 35.82 |

| | | | | |
|---|---|---|---|---|
| Air | Methyl borate | pg | 0.01 | 0.01 |
| Air | Methyl mercaptan | ng | -7.10 | x |
| Air | Molybdenum | µg | -87.48 | 21.68 |
| Air | Monoethanolamine | µg | 1.52 | 1.83 |
| Air | Naphthalene | ng | -286.02 | x |
| Air | Niobium-95 | nBq | 2.86 | 3.41 |
| Air | Noble gases, radioactive, unspecified | kBq | 34.08 | 41.04 |
| Air | Organic substances, unspecified | pg | 3.31 | 0.10 |
| Air | Ozone | mg | 1.21 | 1.46 |
| Air | Paraffins | pg | 128.67 | 154.66 |
| Air | Particulates | mg | -233.35 | x |
| Air | Particulates, < 10 um | mg | -242.62 | 729.81 |
| Air | Particulates, < 2.5 um | g | 3.37 | 4.01 |
| Air | Particulates, > 10 um | g | 1.06 | 1.24 |
| Air | Particulates, > 10 um (process) | g | 1.40 | x |
| Air | Particulates, > 2.5 um, and < 10um | mg | 467.33 | 579.02 |
| Air | Particulates, unspecified | g | -114.66 | 0.06 |
| Air | Phenol | µg | 7.57 | 12.31 |
| Air | Phosphine | pg | 11.60 | 13.95 |
| Air | Platinum | pg | 48.73 | 58.68 |
| Air | Plutonium-238 | nBq | 0.48 | 0.58 |
| Air | Plutonium-alpha | nBq | 1.11 | 1.34 |
| Air | Polonium-210 | mBq | 37.13 | 44.73 |
| Air | Polychlorinated dioxins and furans | ng | -13.26 | 1.13 |
| Air | Potassium | mg | 0.84 | 1.01 |
| Air | Potassium-40 | mBq | 4.83 | 5.82 |
| Air | Protactinium-234 | µBq | 481.65 | 579.78 |
| Air | Radioactive species, other beta emitters | mBq | 14.13 | 17.00 |
| Air | Radium-226 | mBq | 20.97 | 25.24 |
| Air | Radium-228 | mBq | 4.70 | 5.66 |
| Air | Radon-220 | mBq | 191.71 | 230.96 |
| Air | Radon-222 | kBq | 63.68 | 76.65 |
| Air | Ruthenium-103 | nBq | 0.63 | 0.75 |
| Air | Scandium | ng | 162.71 | 195.97 |
| Air | Selenium | µg | 996.26 | 66.77 |
| Air | Silicon | mg | 1.45 | 1.74 |
| Air | Silicon tetrafluoride | ng | 79.31 | 95.57 |
| Air | Silver | ng | 17.09 | 20.59 |
| Air | Silver-110 | nBq | 6.23 | 7.42 |
| Air | Sodium | mg | 0.85 | 1.02 |
| Air | Sodium carbonate | ng | 45.20 | 45.20 |
| Air | Sodium chlorate | µg | 0.83 | 1.00 |
| Air | Sodium formate | ng | 11.48 | 13.82 |
| Air | Sodium hydroxide | ng | 134.95 | 162.26 |
| Air | Soot | µg | -61.42 | x |
| Air | Strontium | µg | 31.50 | 37.95 |
| Air | Sulfate | mg | 2.99 | 3.60 |
| Air | Sulfur hexafluoride | µg | 17.07 | 21.27 |
| Air | Sulfur oxides | g | 42.65 | 19.06 |
| Air | Sulfur trioxide | mg | -36.50 | x |
| Air | Sulfuric acid | mg | 78.09 | 7.09 |
| Air | Terpenes | ng | 442.40 | 533.12 |

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|---|---|---|---|---|
| Air | Thallium | ng | 175.92 | 210.60 |
| Air | Thorium | ng | 193.37 | 232.88 |
| Air | Thorium-228 | mBq | 1.12 | 1.35 |
| Air | Thorium-230 | mBq | 1.92 | 2.32 |
| Air | Thorium-232 | mBq | 1.51 | 1.82 |
| Air | Thorium-234 | µBq | 481.74 | 579.89 |
| Air | Tin | µg | 17.27 | 20.78 |
| Air | Titanium | µg | 35.23 | 42.40 |
| Air | Uranium | ng | 173.23 | 208.59 |
| Air | Uranium-234 | mBq | 5.74 | 6.92 |
| Air | Uranium-235 | µBq | 271.78 | 327.15 |
| Air | Uranium-238 | mBq | 9.52 | 11.46 |
| Air | Uranium alpha | mBq | 26.18 | 31.52 |
| Air | Vanadium | mg | 0.33 | 1.14 |
| Air | water | mg | 37.19 | 44.80 |
| Air | Xenon-131m | mBq | 123.50 | 148.06 |
| Air | Xenon-133 | Bq | 3.92 | 4.69 |
| Air | Xenon-133m | mBq | 17.06 | 20.53 |
| Air | Xenon-135 | Bq | 1.61 | 1.93 |
| Air | Xenon-135m | Bq | 0.95 | 1.13 |
| Air | Xenon-137 | mBq | 18.04 | 21.52 |
| Air | Xenon-138 | mBq | 160.08 | 191.28 |
| Air | Xylene | mg | 6.92 | 16.56 |
| Air | Zinc | mg | -1.23 | 3.35 |
| Air | Zinc-65 | nBq | 120.31 | 143.25 |
| Air | Zirconium | µg | 1.26 | 1.52 |
| Air | Zirconium-95 | nBq | 117.60 | 140.02 |
| Water | 1-Methylfluorene | ng | -54.06 | 0.01 |
| Water | 1,4-Butanediol | pg | 114.24 | 137.36 |
| Water | 2-Hexanone | µg | -3.10 | 0.00 |
| Water | 2-Methylnaphthalene | µg | -7.51 | 0.00 |
| Water | 4-Methyl-2-pentanone | pg | 25.41 | 30.60 |
| Water | Acenaphthene | ng | 318.89 | 384.30 |
| Water | Acenaphthylene | ng | 19.94 | 24.03 |
| Water | Acetic acid | µg | 19.97 | 24.04 |
| Water | Acetone | µg | -4.74 | 0.00 |
| Water | Acidity, unspecified | mg | -1.04 | 0.01 |
| Water | Acrylate, ion | ng | 31.77 | 38.20 |
| Water | Actinides, radioactive, unspecified | mBq | 5.76 | 6.94 |
| Water | Alkylated benzenes | µg | -23.36 | 0.00 |
| Water | Alkylated fluorenes | µg | -1.35 | 0.00 |
| Water | Alkylated naphthalenes | ng | -381.73 | 0.08 |
| Water | Alkylated phenanthrenes | ng | -158.83 | 0.03 |
| Water | Aluminum | mg | 198.84 | 288.20 |
| Water | Antimony | µg | 59.08 | 102.36 |
| Water | Antimony-122 | µBq | 1.80 | 2.14 |
| Water | Antimony-124 | mBq | 0.94 | 1.13 |
| Water | Antimony-125 | mBq | 0.85 | 1.03 |
| Water | AOX, Adsorbable Organic Halogen as Cl | µg | 43.35 | 52.22 |
| Water | Arsenic | µg | -104.59 | 2.67 |
| Water | Barite | mg | 191.49 | 230.77 |
| Water | Barium | mg | -534.70 | 57.04 |

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|---|---|---|---|---|
| Water | Barium-140 | µBq | 7.88 | 9.38 |
| Water | Benzene, 1,2-dichloro- | ng | 38.41 | 46.18 |
| Water | Benzene, chloro- | ng | 793.08 | 953.61 |
| Water | Benzene, ethyl- | mg | 1.19 | 1.48 |
| Water | Benzoic acid | µg | -481.84 | 0.10 |
| Water | Beryllium | µg | 15.88 | 26.25 |
| Water | Bis(2-ehtylhexyl)phthalate | pg | 0.03 | x |
| Water | BOD5, Biological Oxygen Demand | g | 11.99 | 13.74 |
| Water | Boron | mg | 2.31 | 3.92 |
| Water | Bromate | µg | 66.61 | 79.09 |
| Water | Bromide | mg | -101.71 | 0.02 |
| Water | Bromine | mg | 36.15 | 43.56 |
| Water | Butanol | ng | 88.50 | 106.41 |
| Water | Butene | ng | 43.31 | 52.13 |
| Water | Butyl acetate | ng | 115.05 | 138.33 |
| Water | Butyrolactone | pg | 198.36 | 238.51 |
| Water | Cadmium | µg | -15.48 | 1.32 |
| Water | Calcium | g | -1.52 | 0.00 |
| Water | Calcium, ion | g | 2.65 | 3.13 |
| Water | Carbonate | µg | 123.75 | 148.10 |
| Water | Carboxylic acids, unspecified | mg | 222.32 | 267.92 |
| Water | Cerium-141 | µBq | 3.15 | 3.75 |
| Water | Cerium-144 | µBq | 0.96 | 1.14 |
| Water | Cesium | µg | 51.27 | 61.78 |
| Water | Cesium-134 | µBq | 786.29 | 946.78 |
| Water | Cesium-136 | nBq | 559.13 | 665.73 |
| Water | Cesium-137 | mBq | 662.73 | 797.91 |
| Water | Chlorate | µg | 554.84 | 659.20 |
| Water | Chloride | g | 31.47 | 38.06 |
| Water | Chlorides | g | -17.08 | 0.00 |
| Water | Chlorinated solvents, unspecified | ng | 358.90 | 425.19 |
| Water | Chlorine | µg | 10.41 | 89.72 |
| Water | Chromate | pg | 0.00 | 0.00 |
| Water | Chromium | mg | -1.46 | 0.01 |
| Water | Chromium-51 | mBq | 1.00 | 1.19 |
| Water | Chromium, ion | µg | 298.33 | 337.80 |
| Water | Cobalt | mg | 2.47 | 2.99 |
| Water | Cobalt-57 | µBq | 17.75 | 21.13 |
| Water | Cobalt-58 | mBq | 7.45 | 8.94 |
| Water | Cobalt-60 | mBq | 5.83 | 6.99 |
| Water | Copper | µg | -714.75 | 40.76 |
| Water | Copper, ion | mg | 1.54 | 1.79 |
| Water | Crude oil | µg | -886.18 | 3.01 |
| Water | Cumene | µg | 216.45 | 260.56 |
| Water | Cyanide | µg | 464.42 | 559.43 |
| Water | Cyanide (inorganic) compounds | µg | -285.04 | 1.44 |
| Water | Detergent, anionic | pg | 9.82 | 0.30 |
| Water | Dibenzofuran | ng | -90.23 | 0.02 |
| Water | Dibenzothiophene | ng | -73.14 | 0.01 |
| Water | Dichromate | µg | 1.71 | 2.06 |
| Water | DOC, Dissolved Organic Carbon | g | 3.60 | 4.34 |
| Water | Ethanol | ng | 203.63 | 244.84 |

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|---|---|---|---|---|
| Water | Ethene | µg | 90.25 | 108.65 |
| Water | Ethene, dichloro- (trans) | pg | 0.03 | x |
| Water | Ethyl acetate | pg | 13.81 | 16.61 |
| Water | Ethylene diamine | pg | 364.34 | 438.75 |
| Water | Fluoride | mg | -0.75 | 12.90 |
| Water | Fluorine | ng | -664.69 | 0.13 |
| Water | Fluosilicic acid | µg | 3.34 | 4.02 |
| Water | Glutaraldehyde | µg | 23.64 | 28.49 |
| Water | Hardness | g | -4.70 | 0.00 |
| Water | Heat, waste | Btu | 787.90 | 948.49 |
| Water | Hexanoic acid | µg | -99.70 | 0.02 |
| Water | Hydrocarbons, aliphatic, alkanes, unspecified | mg | 6.66 | 8.03 |
| Water | Hydrocarbons, aliphatic, unsaturated | µg | 615.22 | 741.41 |
| Water | Hydrocarbons, aromatic | mg | 27.36 | 32.97 |
| Water | Hydrocarbons, chlorinated | pg | 0.08 | 0.00 |
| Water | Hydrocarbons, unspecified | mg | 3.46 | 6.21 |
| Water | Hydrogen-3, Tritium | kBq | 1.52 | 1.83 |
| Water | Hydrogen peroxide | ng | 413.87 | 496.14 |
| Water | Hydrogen sulfide | µg | 602.57 | 673.92 |
| Water | Hydroxide | µg | 1.10 | 1.32 |
| Water | Hypochlorite | µg | 81.33 | 97.99 |
| Water | Iodide | mg | 5.14 | 6.19 |
| Water | Iodine-131 | µBq | 169.93 | 204.34 |
| Water | Iodine-133 | µBq | 4.95 | 5.89 |
| Water | Iron | mg | -84.22 | 0.02 |
| Water | Iron-59 | µBq | 1.36 | 1.62 |
| Water | Iron, ion | mg | 230.25 | 271.42 |
| Water | Lanthanum-140 | µBq | 8.39 | 9.99 |
| Water | Lead | µg | -316.24 | 826.76 |
| Water | Lead-210 | mBq | 38.18 | 46.01 |
| Water | Lead 210 | pg | -0.05 | 0.00 |
| Water | Lithium | µg | -509.87 | 0.10 |
| Water | Lithium, ion | µg | 6.52 | 7.84 |
| Water | m-Xylene | µg | -14.41 | 0.00 |
| Water | Magnesium | mg | 91.43 | 464.56 |
| Water | Manganese | mg | 6.17 | 7.66 |
| Water | Manganese-54 | µBq | 458.16 | 549.83 |
| Water | Mercury | µg | 21.02 | 24.67 |
| Water | Methanol | µg | 34.80 | 41.92 |
| Water | Methychloride | ng | -19.09 | 0.00 |
| Water | Methyl acrylate | ng | 297.55 | 357.77 |
| Water | Methyl amine | pg | 71.50 | 85.97 |
| Water | Methyl ethyl ketone | ng | -86.52 | 321.52 |
| Water | Methyl formate | pg | 23.56 | 28.33 |
| Water | Molybdenum | µg | 141.47 | 182.90 |
| Water | Molybdenum-99 | µBq | 2.89 | 3.45 |
| Water | n-Decane | µg | -13.88 | 0.00 |
| Water | n-Docosane | ng | -507.20 | 0.10 |
| Water | n-Dodecane | µg | -26.29 | 0.01 |
| Water | n-Eicosane | µg | -7.22 | 0.00 |
| Water | n-Hexacosane | ng | -316.33 | 0.06 |
| Water | n-Hexadecane | µg | -28.70 | 0.01 |

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|---|---|---|---|---|
| Water | n-Octadecane | µg | -7.07 | 0.00 |
| Water | n-Tetradecane | µg | -11.51 | 0.00 |
| Water | Naphthalene | µg | -8.65 | 0.00 |
| Water | Nickel | µg | -102.94 | 13.72 |
| Water | Niobium-95 | µBq | 70.91 | 85.30 |
| Water | Nitrogen, organic bound | mg | 5.10 | 6.15 |
| Water | Nitrogen, total | mg | -195.09 | 9.89 |
| Water | non-filtrable residue | µg | 7.31 | 1.52 |
| Water | Non-prescribed liquids | pg | 0.10 | 0.00 |
| Water | o-Cresol | µg | -13.61 | 0.00 |
| Water | o-Xylene | pg | 133.76 | 161.04 |
| Water | o + p-Xyxlene | µg | -10.46 | 0.00 |
| Water | Oil and grease | mg | -9.61 | 0.00 |
| Water | Oils, unspecified | g | -11.84 | 4.21 |
| Water | Organic substances, unspecified | pg | 0.60 | 0.02 |
| Water | p-Cresol | µg | -14.68 | 0.00 |
| Water | p-Cymene | ng | -47.38 | 0.01 |
| Water | Paraffins | pg | 373.41 | 448.84 |
| Water | Pentamethylbenzene | ng | -35.50 | 0.01 |
| Water | Pentanone, methyl- | µg | -1.99 | 0.00 |
| Water | Phenanthrene | ng | -134.81 | 0.03 |
| Water | Phenol | mg | 4.53 | 5.93 |
| Water | Phenol, 2,4-dimethyl- | µg | -13.29 | 0.00 |
| Water | Phosphorus, total | mg | -102.92 | 0.95 |
| Water | Phthalate, diethyl- | pg | 0.02 | x |
| Water | Polonium-210 | mBq | 53.93 | 64.98 |
| Water | Potassium | pg | 52.43 | 1.62 |
| Water | Potassium-40 | mBq | 13.98 | 16.84 |
| Water | Potassium, ion | mg | 261.31 | 314.56 |
| Water | Propane, 1,2,3-trichloro- | pg | 0.18 | x |
| Water | Propene | µg | 85.83 | 103.33 |
| Water | Protactinium-234 | mBq | 8.88 | 10.69 |
| Water | Radioactive species, alpha emitters | µBq | 89.65 | 108.02 |
| Water | Radioactive species, Nuclides, unspecified | Bq | 3.45 | 4.16 |
| Water | Radium-224 | Bq | 2.56 | 3.09 |
| Water | Radium-226 | Bq | 9.66 | 11.64 |
| Water | Radium-228 | Bq | 5.13 | 6.18 |
| Water | Radium 226 | pg | -17.08 | 0.00 |
| Water | Radium 228 | pg | -0.09 | 0.00 |
| Water | Rubidium | µg | 513.03 | 618.26 |
| Water | Ruthenium-103 | nBq | 610.56 | 726.96 |
| Water | Scandium | µg | 45.81 | 55.19 |
| Water | Selenium | µg | 43.83 | 58.41 |
| Water | Silicon | g | 3.48 | 4.19 |
| Water | Silver | µg | -997.04 | 0.20 |
| Water | Silver-110 | mBq | 5.44 | 6.52 |
| Water | Silver, ion | µg | 41.06 | 49.49 |
| Water | Sodium | g | -4.83 | 0.00 |
| Water | Sodium-24 | µBq | 21.89 | 26.07 |
| Water | Sodium formate | ng | 27.58 | 33.21 |
| Water | Sodium, ion | g | 15.78 | 19.01 |
| Water | Solids, inorganic | mg | 199.61 | 240.48 |

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|---|---|---|---|---|
| Water | Solved organics | µg | -527.37 | 0.00 |
| Water | Solved solids | mg | -604.70 | 116.09 |
| Water | Strontium | mg | 69.61 | 115.10 |
| Water | Strontium-89 | µBq | 96.93 | 116.09 |
| Water | Strontium-90 | Bq | 4.95 | 5.97 |
| Water | Styrene (ethenylbenzene) | ng | -7.74 | 51.44 |
| Water | Sulfate | g | 1.29 | 2.07 |
| Water | Sulfate and sulfides | ng | 27.18 | 9.29 |
| Water | Sulfates | mg | -34.44 | 0.01 |
| Water | Sulfide | µg | 62.93 | 75.84 |
| Water | Sulfite | µg | 220.88 | 266.12 |
| Water | Sulfur | mg | 8.13 | 11.31 |
| Water | Sulfur dioxide | µg | -0.24 | 1.56 |
| Water | Surfactants | µg | -395.08 | 0.08 |
| Water | Suspended solids, unspecified | g | 2.07 | 0.92 |
| Water | t-Butyl methyl ether | µg | 111.54 | 134.41 |
| Water | Technetium-99m | µBq | 67.04 | 79.83 |
| Water | Tellurium-123m | µBq | 101.72 | 122.47 |
| Water | Tellurium-132 | nBq | 167.54 | 199.48 |
| Water | Thallium | µg | 0.76 | 7.63 |
| Water | Thorium-228 | Bq | 10.25 | 12.36 |
| Water | Thorium-230 | Bq | 1.21 | 1.46 |
| Water | Thorium-232 | mBq | 1.93 | 2.33 |
| Water | Thorium-234 | mBq | 8.88 | 10.69 |
| Water | Tin | µg | -106.64 | 0.02 |
| Water | Tin, ion | µg | 67.81 | 79.19 |
| Water | Titanium | µg | -408.43 | 0.08 |
| Water | Titanium, ion | mg | 8.60 | 10.35 |
| Water | TOC, Total Organic Carbon | g | 3.61 | 4.34 |
| Water | Toluene | mg | 5.75 | 7.84 |
| Water | Total Alkalinity | mg | -37.37 | 0.01 |
| Water | Total biphenyls | µg | -1.51 | 0.00 |
| Water | Total dibenzothiophenes | ng | -4.66 | 0.00 |
| Water | Total dissolved solids | g | -21.09 | 0.00 |
| Water | Total suspended solids | g | -1.30 | 0.00 |
| Water | Tributyltin compounds | µg | 29.80 | 118.37 |
| Water | Triethylene glycol | µg | 25.55 | 30.78 |
| Water | Tungsten | µg | 32.43 | 39.07 |
| Water | Uranium-234 | mBq | 10.66 | 12.83 |
| Water | Uranium-235 | mBq | 17.59 | 21.17 |
| Water | Uranium-238 | mBq | 46.22 | 55.65 |
| Water | Uranium alpha | mBq | 511.69 | 615.95 |
| Water | Vanadium | µg | -12.88 | 0.00 |
| Water | Vanadium, ion | mg | 3.19 | 3.83 |
| Water | VOC, volatile organic compounds, unspecified origin | mg | 17.97 | 21.65 |
| Water | waste water | g | -1.08 | 0.08 |
| Water | Waste water/m3 | mm3 | 134.44 | 134.40 |
| Water | Water | mg | 42.68 | 8.86 |
| Water | Water, discharge from stormwater | dm3 | 153.10 | x |
| Water | Water, discharged stormwater | kg | x | 153.10 |
| Water | Xylene | mg | 4.88 | 6.33 |
| Water | Yttrium | µg | -3.20 | 0.00 |

| | | | | |
|---|---|---|---|---|
| Water | Zinc | mg | -24.90 | 0.07 |
| Water | Zinc-65 | µBq | 296.82 | 353.41 |
| Water | Zinc, ion | mg | 25.98 | 29.35 |
| Water | Zirconium-95 | µBq | 3.44 | 4.09 |
| Waste | Waste to recycling | pg | 3.46 | 0.11 |
| Soil | 2,4-D | ng | 178.10 | 214.63 |
| Soil | Aclonifen | ng | 27.37 | 32.97 |
| Soil | Aluminum | mg | 26.27 | 31.21 |
| Soil | Ammonia | µg | -0.19 | 1.24 |
| Soil | Antimony | ng | -8.49 | 59.12 |
| Soil | Atrazine | pg | 90.77 | 109.14 |
| Soil | Barium | mg | 11.99 | 14.46 |
| Soil | Benomyl | ng | 1.14 | 1.37 |
| Soil | Bentazone | ng | 13.97 | 16.83 |
| Soil | Benzene, ethyl- | ng | -135.16 | 898.19 |
| Soil | Beryllium | mg | 3.59 | 2.23 |
| Soil | Boron | µg | 251.69 | 303.27 |
| Soil | Calcium | mg | 104.60 | 124.54 |
| Soil | Carbetamide | ng | 5.55 | 6.69 |
| Soil | Carbofuran | ng | 622.40 | 750.04 |
| Soil | Carbon | mg | 97.87 | 112.69 |
| Soil | Chloride | mg | 95.88 | 115.52 |
| Soil | Chlorothalonil | ng | 597.57 | 719.74 |
| Soil | Chromium | µg | 239.99 | 265.69 |
| Soil | Chromium (III) compounds | ng | 3.23 | 11.07 |
| Soil | Cobalt | µg | 3.97 | 1.40 |
| Soil | Copper | mg | 7.53 | 4.78 |
| Soil | Cumene (1-methylethylbenzene) | ng | -51.22 | 340.36 |
| Soil | Cyanide (inorganic) compounds | ng | -0.33 | 2.19 |
| Soil | Cyclohexane | µg | -0.46 | 3.05 |
| Soil | Cypermethrin | ng | 88.02 | 106.07 |
| Soil | Fenpiclonil | ng | 24.46 | 29.47 |
| Soil | Fluoride | mg | 1.43 | 1.65 |
| Soil | Glyphosate | µg | 6.30 | 7.58 |
| Soil | Heat, waste | kJ | 10.02 | 12.02 |
| Soil | Hexane | µg | -1.21 | 8.07 |
| Soil | Iron | mg | 56.68 | 88.82 |
| Soil | Lead | mg | 9.48 | 5.92 |
| Soil | Linuron | ng | 210.96 | 254.09 |
| Soil | Magnesium | mg | 20.16 | 24.12 |
| Soil | Mancozeb | ng | 776.12 | 934.80 |
| Soil | Manganese | mg | 1.09 | 1.30 |
| Soil | Mercury | µg | 141.67 | 88.22 |
| Soil | Metaldehyde | ng | 1.20 | 1.44 |
| Soil | Metolachlor | µg | 1.53 | 1.84 |
| Soil | Metribuzin | ng | 27.33 | 32.91 |
| Soil | Molybdenum | ng | 713.59 | 716.96 |
| Soil | Napropamide | ng | 2.12 | 2.55 |
| Soil | Oils, biogenic | µg | 93.43 | 112.54 |
| Soil | Oils, unspecified | g | 3.69 | 4.45 |
| Soil | Orbencarb | ng | 147.57 | 177.74 |
| Soil | Phosphorus | mg | 1.24 | 1.49 |

| | | | | |
|---|---|---|---|---|
| Soil | Pirimicarb | ng | 1.32 | 1.59 |
| Soil | Polycyclic aromatic hydrocarbons | µg | -0.28 | 1.86 |
| Soil | Potassium | mg | 8.62 | 10.39 |
| Soil | Selenium | ng | 74.54 | 20.97 |
| Soil | Silicon | mg | 7.11 | 7.68 |
| Soil | Sodium | mg | 48.00 | 57.85 |
| Soil | Strontium | µg | 242.17 | 291.85 |
| Soil | Sulfur | mg | 16.71 | 19.67 |
| Soil | Sulfuric acid | pg | 17.41 | 20.93 |
| Soil | Tebutam | ng | 5.02 | 6.05 |
| Soil | Teflubenzuron | ng | 1.82 | 2.19 |
| Soil | Thiram | ng | 2.01 | 2.43 |
| Soil | Tin | µg | 2.94 | 2.94 |
| Soil | Titanium | µg | 5.65 | 6.81 |
| Soil | Toluene (methylbenzene) | µg | -0.32 | 2.15 |
| Soil | Total Volatile Organic Compounds | µg | -0.97 | 6.45 |
| Soil | Vanadium | ng | 161.79 | 194.91 |
| Soil | Xylene | µg | -0.75 | 4.98 |
| Soil | Zinc | mg | 10.42 | 10.55 |
| Non mat. | Aluminium mass input | mg | 41.04 | 8.52 |
| Non mat. | Copper mass input | mg | 47.84 | 15.12 |
| Non mat. | show on tree | µg | 199.90 | 181.66 |
| Non mat. | Steel mass flow | oz | 284.79 | 0.04 |
| Non mat. | Truck travel distance, urban | m | 785.42 | 791.81 |
| Non mat. | waste to landfill | kg | -1011.31 | 0.00 |
| Non mat. | Wastewater reuse | dm3 | 38.30 | 38.30 |
| Economic | AU database, energy end use indicator, electricity delivered | MJ | 34.74 | 11.45 |
| Economic | AU database, energy end use indicator, energy in capital equipment | Wh | 100.09 | 954.73 |
| Economic | AU database, energy end use indicator, energy losses in electricty distribution | kJ | -190.47 | x |
| Economic | AU database, energy end use indicator, energy losses in electricty transmission | kJ | 939.14 | 299.66 |
| Economic | AU database, energy end use indicator, feedstock energy | MJ | -5.69 | 0.00 |
| Economic | AU database, energy end use indicator, fuel extraction and delivery | MJ | -4.73 | 1.70 |
| Economic | AU database, energy end use indicator, powerplant conversion losses | MJ | 81.61 | 32.67 |
| Economic | AU database, energy end use indicator, process heat | MJ | -80.75 | 0.69 |
| Economic | AU database, energy end use indicator, transport energy | MJ | 6.42 | 14.63 |

## 19.1 Impact assessment alteration undertaken as part of this study

As part of this study a number of changes to the Australian impact assessment were undertaken associated with ‘excluded substances’ checks. Actions taken are summarised in the table below.

| Compartment | Substance Investigated | Include in assessment method recalculation | Reason |
|---|---|---|---|
| Raw | Occupation, arable, non-irrigated | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, dump site | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, forest, intensive | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, forest, intensive, normal | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, forest, intensive, short-cycle | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, industrial area | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, mineral extraction site | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, permanent crop, fruit, intensive | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, shrub land, sclerophyllous | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, traffic area | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, urban, discontinuously built | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, urban, green areas | Yes | Substance impacts Land Use indicator |
| Raw | Occupation, water bodies, artificial | No | Water bodies used in Hydro power excluded from assessment. |
| Raw | Occupation, water courses, artificial | No | Water bodies used in Hydro power excluded from assessment. |
| Raw | Oil, crude, 42 MJ per kg, in ground | Yes | Substance impacts Fossil Fuels indicator |
| Raw | Transformation, from arable | No | Transformation not assessed |
| Raw | Transformation, from arable, non-irrigated | No | Transformation not assessed |
| Raw | Transformation, from arable, non-irrigated, fallow | No | Transformation not assessed |
| Raw | Transformation, from dump site, inert material landfill | No | Transformation not assessed |
| Raw | Transformation, from dump site, residual material landfill | No | Transformation not assessed |
| Raw | Transformation, from dump site, sanitary landfill | No | Transformation not assessed |
| Raw | Transformation, from dump site, slag compartment | No | Transformation not assessed |
| Raw | Transformation, from forest | No | Transformation not assessed |
| Raw | Transformation, from forest, extensive | No | Transformation not assessed |
| Raw | Transformation, from forest, intensive, clear-cutting | No | Transformation not assessed |
| Raw | Transformation, from industrial area | No | Transformation not assessed |
| Raw | Transformation, from industrial area, benthos | No | Transformation not assessed |
| Raw | Transformation, from industrial area, built up | No | Transformation not assessed |
| Raw | Transformation, from industrial area, vegetation | No | Transformation not assessed |
| Raw | Transformation, from mineral extraction site | No | Transformation not assessed |
| Raw | Transformation, from pasture and meadow | No | Transformation not assessed |
| Raw | Transformation, from pasture and meadow, intensive | No | Transformation not assessed |
| Raw | Transformation, from sea and ocean | No | Transformation not assessed |
| Raw | Transformation, from shrub land, sclerophyllous | No | Transformation not assessed |
| Raw | Transformation, from tropical rain forest | No | Transformation not assessed |

| | | | |
|---|---|---|---|
| Raw | Transformation, from unknown | No | Transformation not assessed |
| Raw | Transformation, to arable | No | Transformation not assessed |
| Raw | Transformation, to arable, non-irrigated | No | Transformation not assessed |
| Raw | Transformation, to arable, non-irrigated, fallow | No | Transformation not assessed |
| Raw | Transformation, to dump site | No | Transformation not assessed |
| Raw | Transformation, to dump site, benthos | No | Transformation not assessed |
| Raw | Transformation, to dump site, inert material landfill | No | Transformation not assessed |
| Raw | Transformation, to dump site, residual material landfill | No | Transformation not assessed |
| Raw | Transformation, to dump site, sanitary landfill | No | Transformation not assessed |
| Raw | Transformation, to dump site, slag compartment | No | Transformation not assessed |
| Raw | Transformation, to forest | No | Transformation not assessed |
| Raw | Transformation, to forest, intensive | No | Transformation not assessed |
| Raw | Transformation, to forest, intensive, clear-cutting | No | Transformation not assessed |
| Raw | Transformation, to forest, intensive, normal | No | Transformation not assessed |
| Raw | Transformation, to forest, intensive, short-cycle | No | Transformation not assessed |
| Raw | Transformation, to heterogeneous, agricultural | No | Transformation not assessed |
| Raw | Transformation, to industrial area | No | Transformation not assessed |
| Raw | Transformation, to industrial area, benthos | No | Transformation not assessed |
| Raw | Transformation, to industrial area, built up | No | Transformation not assessed |
| Raw | Transformation, to industrial area, vegetation | No | Transformation not assessed |
| Raw | Transformation, to mineral extraction site | No | Transformation not assessed |
| Raw | Transformation, to pasture and meadow | No | Transformation not assessed |
| Raw | Transformation, to permanent crop, fruit, intensive | No | Transformation not assessed |
| Raw | Transformation, to sea and ocean | No | Transformation not assessed |
| Raw | Transformation, to shrub land, sclerophyllous | No | Transformation not assessed |
| Raw | Transformation, to traffic area, rail embankment | No | Transformation not assessed |
| Raw | Transformation, to traffic area, rail network | No | Transformation not assessed |
| Raw | Transformation, to traffic area, road embankment | No | Transformation not assessed |
| Raw | Transformation, to traffic area, road network | No | Transformation not assessed |
| Raw | Transformation, to unknown | No | Transformation not assessed |
| Raw | Transformation, to urban, discontinuously built | No | Transformation not assessed |
| Raw | Transformation, to water bodies, artificial | No | Transformation not assessed |
| Raw | Transformation, to water courses, artificial | No | Transformation not assessed |
| Raw | Water, salt, ocean | Yes | Substance impacts Water indicator |
| Raw | Water, salt, sole | Yes | Substance impacts Water indicator |
| Raw | Water, turbine use, unspecified natural origin | No | Water used in Hydro power excluded in water use assessment. |
| Air | Carbon dioxide, land transformation | No | Transformation not assessed |
| Air | Carbon monoxide, fossil | Yes | Substance impacts Global Warming indicator |
| Air | Hydrocarbons, aliphatic, alkanes, cyclic | No | Substance does not impact Global Warming, nor Carcinogens indicator |
| Air | Hydrocarbons, aliphatic, alkanes, unspecified | No | Substance does not impact Global Warming |
| Air | Hydrocarbons, aliphatic, unsaturated | No | Substance does not impact Global Warming |
| Air | Hydrocarbons, aromatic | No | Substance does not impact Global Warming |
| Air | Hydrocarbons, chlorinated | No | Substance does not impact Global Warming |
| Air | Hydrocarbons, sulfur | No | Substance does not impact Global Warming |
| Air | Hydrocarbons, unspecified | No | Substance does not impact Global Warming |
| Air | Methane, bromo-, Halon 1001 | Yes | Substance impacts Global Warming indicator |
| Air | Methane, dichlorofluoro-, HCFC-21 | Yes | Substance impacts Global |

| | | | |
|---|---|---|---|
| | | | Warming indicator |
| Air | Methane, fossil | Yes | Substance impacts Global Warming indicator |
| Air | Methane, tetrafluoro-, CFC-14 | Yes | Substance impacts Global Warming indicator |
| Air | Methane, trifluoro-, HFC-23 | Yes | Substance impacts Global Warming indicator |
| Waste | bauxite residue | Yes | Substance impacts Solid Waste indicator |
| Waste | Prescribed liquid waste | Yes | Substance impacts Solid Waste indicator |
| Waste | Sodium hydroxide | Yes | Substance impacts Solid Waste indicator |
| Waste | spent potliner | Yes | Substance impacts Solid Waste indicator |
| Waste | Waste to recycling | No | Substance impacts are unclear |
| Waste | Waste, chemicals, inert | Yes | Substance impacts Solid Waste indicator |
| Waste | Waste, mining | Yes | Substance impacts Solid Waste indicator |
| Waste | waste, non-prescribed/m3 | Yes | Substance impacts Solid Waste indicator |
| Waste | Waste, nuclear, medium active | Yes | Substance impacts Solid Waste indicator |

# 20 Appendix G – Peer review comments and actions taken.

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Centre for Design
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info@therightenvironment.net
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Date
May 30, 2008

Your reference
-

Our reference
08.0020-L08.0039

Concerning
Peer review LCA of recycled concrete versus traditional aggregate

Dear Andrew Carre,

RMIT has asked theRightenvironment to conduct a peer review according to the ISO guidelines laid down in the ISO standard 14044:2006, "Environmental management – Life cycle assessment – Requirements and guidelines" on a LCA study comparing crushed concrete aggregate with traditionally quarried stone aggregate, prepared Andrew Carre and Rob Rouwette, dated 30 May 2008.

After receiving the draft report, RMIT and theRightenvironment shared three rounds of feedback before the final review took place. The topics discussed are included in appendix G of the final report.

TheRightenvironment concludes that:
- the methods used to carry out the LCA are consistent with the ISO 14044:2006,
- 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.

We would like to thank RMIT for the open discussions we shared and hope our review has contributed to the overall quality of the study.

Yours sincerely,

J. Meijer
*President*

| Section | Comment | Action | Status |
|---|---|---|---|
| 1 | It is good practice to exclude parts of the life cycle, but whenever this is done, and there is a different exclusion for products compared, as is the case for quarried aggregate, it is good practice to make a qualitative assessment of the processes that where excluded, for example, in terms of land transformation. Has this been done? | Added: Where processes associated with quarried stone aggregate were excluded, potential impacts were assessed to ensure that beneficial processes were not being excluded that might disadvantage the quarried product in the comparison (refer Appendix B). | Satisfactory |
| 1 | Are they expected to be equal for both products? If so that would provide a good reason not to include infrastructure impacts. | Added: Capital infrastructure (crushers, machinery etc) was considered to be similar between systems, however transport infrastructure could have been potentially different between systems hence was included. Appendix C describes how capital impacts were tested. | Satisfactory |
| 1 | What would be a current scenario for treatment of concrete rubble for Australia, or even Melbourne, in percentages over different waste treatment possibilities? This is important to know, since the study includes avoided processes. The best way to model these avoided products would be the current mix of treatment for the main assessment, and since the avoidance is probably time related (more and more rubble will get recycled in the future, at least that is to be expected), it would be only fair to include a sensitivity analysis to show the result of scenario's where recycling is more common.<br>A sensitivity scenario with 51% recycling and 49% landfill as a case for avoided landfill would be beneficial to show the impact on the current economy as a whole. This would complement the product to product comparison. | Added sensitivity to explore benefits as recycling becomes more prevalent. | The role of the sensitivity analysis is not of comparing quarrying to recycling, it is to show the relative improvement that Australia can still make in increasing recycling as compared to landfill. The potential for improvement is 49% since already 51% is being recycled. That can be of interest for parties that want to promote the extend of recycling of rubble. |
| 1 | This touched upon allocation, it seems that 100% allocation of the processes within the dotted line is used and 0% of the processes outside of it. More and more common approaches there are based on economical value of the output of the process outside of the boundaries and the value of the inputs going into the system, usually with a waste product, it changes from a negative (you pay to have it treated) to a positive value (you pay to acquire it and use it). Has that been considered and part of a sensitivity analysis | Added: Avoided impacts were considered in detail in Appendix A.<br>Detailed exploration of alternatives incorporated into Appendix A. Ultimately use VCS for determining avoided steel production impacts. | Satisfactory, Three methods have been applied, to the reviewers opinion the most balanced one has been chosen for the study.<br>The reviewer regards 'method B' as unrealistic; method A is based on the same principles but is more balanced. |

| Section | Comment | Action | Status |
|---|---|---|---|
| 1 | Does this mean no primary data from a quarry was used? This results in use of the results for internal purposes, but not for external communications. The client is perfectly allowed to publish information on the recycling, but stakeholder involvement from a representation of the quarrying industry is required by ISO to be able to communicate externally about the comparison | Added: Inventory data generated for the quarried stone aggregate processes were reviewed by a panel of experts at Alex Fraser, with a combined experience of over 50 years in quarrying and concrete recycling. Estimates were also compared to existing quarry data inventories, and 'best case' data used wherever contradictions arose. The inventory data comparisons are shown in Appendix D. | Satisfactory |
| 1 | How is concrete rubble being produced? Isn't there a demolition site where trucks are loaded? If dump trucks are included for the quarry, why not the equipment for the concrete at the demolition site? This is a difference between both systems that should not be there. | Added:<br>i) sensitivity analysis at various fuel consumption points<br>ii) Concrete collection transport is included. | Satisfactory |
| 1 | How would you describe the estimate for the diesel consumption of the dump truck of 0.16 l/t? It is good practice to use best-case scenario's for the product that is being compared to worst-case scenarios for the product of the commissioning party. This is considered fair.<br>Usually a sensitivity analysis can show robustness to variations where both best-average-and- worst cases as scenarios are being compared. Has this been considered | Added sensitivity for fuel consumption, and found minimal overall impact on result.<br>Fuel consumption used reflects 'medium' duty level and assumes 50 t cartage on 60t capacity truck. Arguably consistent 50 t load would not be a 'low' duty cycle. Refer sensitivity study added. | Satisfactory |
| 1 | Usually a sensitivity analysis can show robustness to variations where both best-average-and- worst cases as scenarios are being compared. Has this been considered? | Added sensitivity for fuel consumption, and found minimal overall impact on result. | Satisfactory |
| 1.1 | How do you define large? What tends to be good practice is to include a definition for significant difference in terms of a difference of 10%. Looking at the table | Deleted subjective comment. | Resolved |
| 1.1 | The relation between photochemical oxidation and c2h2 might not be clear to all readers, please include the impact categories as a first column in table 2 | Impact categories included | Resolved |
| 1.1 | Please include the results from normalization step to indicate key impact categories, emphasising key environmental impacts that matter the most | Normalisation included in body of report. | Resolved |
| 1.1 | Please use the same precision for all numbers, for example 2 or 3 digits. Using different numbers of digits tends to express different precision, that is probably not the case. | Precision altered to 2 significant figures. | Resolved |
| 1.1 | The total waste for crushing does not add up to 1012, is there an explanation | Table error. Corrected. | Resolved |
| 1.1 | why where these impact categories selected | Categories are those specified by impact assessment method. | Satisfactory |
| 1.1 | please use a consistent unit for global warming, in table 2 it is stated differently | Modified units to show kg CO2. | Resolved |
| 1.1 | The goal emphasises $CO_2$, water and solid waste, this is not reflected in the wording here, could you make this more consistent | Added wording to emphasise that chart reflects global warming results only. | Satisfactory |

| Section | Comment | Action | Status |
|---|---|---|---|
| 1.1 | Please relate to the goal and scope, that locations different from Melbourne are likely to result in different relative impacts | Added: The goal of the study was to study Alex Fraser recycling operations in Melbourne, so distance variation applies mainly to various delivery locations within the city. The sensitivity study result suggested that the benefits of recycled concrete were substantial enough that even when quarry sites were closer to the building site, crushed concrete aggregate could still have a lower environmental impact. To maintain an even handed approach delivery distances were assumed to be identical between crushed concrete aggregate and quarried stone aggregate. | Satisfactory |
| 5 | Did you include a sensitivity analysis on transportation distance later on? How does this relate to the average or aggregated situation | Added: A difference that may exist between Alex Fraser sites would be transport distance (both inbound and outbound), however because sites are located at roughly equivalent distances from the centre of Melbourne (20km approximately), within the city boundaries, it was felt that transport distances at each site could be considered to be equivalent. Nevertheless, differences in transport distances were considered in a sensitivity analysis undertaken in Section | Satisfactory |
| 5.1 | Please remove the information between brackets, material specifications are not part of a reference unit, different material options can be used to meet the requirements of the unit. The two products are examples of how to meet the requirements. It is better to use a separate sentence. | Bracketed information deleted. | Resolved |
| 5.1 | I can understand the road base use, the wet-mix application is more complicated though, based on pore size, water absorption and with the use of cement and possible additives. If it does not serve a specific purpose I recommend to exclude this, if it does, a remark has to be made referring to what I just described with a statement which materials is to be expected to be more prone to this effect. That product is bound to have an environmental performance that is higher in terms of impact. I would delete it, since all other information in this report is based on base material | Wet mix application comment deleted. Study reflects road base products only. | Resolved |
| 5.1 | Interesting thought, my experience is that mass counts, that would result in opposite conclusions. Can you check whether volume or mass is the key for a functional performance of a sub-base | Comments regarding density differences deleted. | Resolved |
| 5.2 | As stated before, when including biodiversity metrics such as land occupation and transformation, the scores for transformation will be positive (environmental benefit) for a quarry. Please adjust the sentence as to where both negative and positive effects are to be expected. One question there, would the cleared soil and biomass not be sold, and therefore generate an additional product, or would this be small enough to be considered capital goods? This could very well be the case, but it is another example of a positive effect. | Added: Potential impacts were explored in more detail in Appendix B. It is unlikely that inclusion of the excluded processes would reduce the environmental impacts of the quarried stone aggregate system | Satisfactory |
| 5.2 | If transportation is an important factor, as stated before, than road infrastructure will vary along the same lines, this can not be discriminating enough to influence the results, but the difference is there. This could be enhanced if a more regional approach is applied. | Added: For these reasons, infrastructure impacts have been excluded from the study, with the exception of road infrastructure, which has been included due to the significance of transportation in the systems compared.<br>[Road infrastructure is included in transport modelling.] | Satisfactory |

| Section | Comment | Action | Status |
|---|---|---|---|
| 5.3.1 | Can you give me an example? | Added: As the plant produces multiple products, unrelated to the crushed concrete aggregate product, it is not possible to allocate its total impact to a single product. Instead the plant impacts are allocated to crushed concrete aggregate on a production tonnage basis. The production tonnage allocation method is described in Section<br>The plant manufactures products from asphalt, bricks, rock and concrete. The main share of production is between concrete and rock (approx 80%). The rock crushed is a harder material than the concrete, so is assumed to require greater energy (slightly) to process. Other than that, we believe that mass as an allocation key is conservative for crushed concrete product. | Satisfactory |
| 5.3.2 | Steel in concrete rubble is predominantly rebar, and not structural steel, that has a higher market value and will be sold separately. Rebar steel is usually produced by re-melting of recycled steel, and to a much lesser extend using primary steel. The mix of primary and secondary steel in rebar and in structural grade steel is different all over Europe and America, and I expect it to be different in Australia as well. The way of modelling right now is a best case for crushed concrete and does not comply with ISO standards and current practive. I expect changes here. If you have production data on rebar, use them, if you don't have them, try to use economical allocation on the ratio of value per ton of rebar and structural steel, or contact IISI, they have the information | Added: A number of methods were considered regarding the avoided impacts associated with recycled steel. Of these methods a method the most accurately and conservatively reflected the benefits was chosen (refer Appendix A) | Satisfactory |
| 5.4 | Are there literature references available for the method? | A listing of the factors used in the assessment method is attached in Appendix E. | Satisfactory |
| 5.4 | Can I receive a csv-file or spreadsheet with the methodology to be able to review the factors being used | Attached in appendix | Resolved |
| 5.4 | Also, a list of classified impacts for the functional units and non-classified impacts is useful to understand the extend of completeness | Attached in appendix | Resolved |
| 5.4 | Please check the list of non-classified impacts where I have marked them yellow and resolve any issues regarding wording as the reason for not classifying the impacts where it should be classified | Impact assessment method updated to include substances where relevant. Refer appendix G. | Resolved |
| 7 | Did you consider using the EcoInvent 2.0 data, they became available two months ago | Re-ran study using Ecoindicator 2.0 data. | Satisfactory |
| 7 | What impacts have been considered, for example emissions | Added: Refer diagram for global warming breakdown of electricity supply. | Satisfactory |
| 7.1 | This would assume the same number and scale of operations of both recycling plants and landfills, that can be true, but is hard to believe. Is there more that can be said about this? The same applies for quarries versus recycling plants. Since we are dealing with a specific case I could be off, because my remarks usually deal with average situations | Added: More generally, the three recycling plants associated with Alex Fraser's operations are all located approximately 20km from the Melbourne Central Business District (CBD). This location means that they are likely to be convenient to demolition activities in many cases, but not necessarily all. Landfills in Melbourne tend to be located at greater distances from the CBD, potentially making distances to demolition sites greater, however this will not be true in all cases. For the purposes of this study it was felt that no distance advantage should be allocated to the recycling process, as it could not be proven in all cases without undertaking a detailed transport study. | Satisfactory |
| 7.1 | Did you try using the EcoInvent 2.0 data for landfill of inert materials in general and concrete in particular? They are your best proxy, and can be included. This would solve questions like: what it is the assumption for leaching, what is the assumption for landfill gas mining, has the performance of the landfill been allocated towards the composition of concrete rubble (multi-input allocation). | Added: Demolition waste degradation in landfill was modelled using existing data from Ecoinvent 2.0 and processing operations were based on Australian industry datasets | Satisfactory |

| Section | Comment | Action | Status |
|---|---|---|---|
| 7.1 | How does this relate to the same energy use for similar processes at the quarry? Wouldn't they be higher too? You can express this as a best-case to clarify it to the reader | Given that the predominant co-product of the plant is crushed stone which is harder than concrete and therefore requires more energy to produce, this would represent a worst case assumption for crushed concrete aggregate (hardness of crushed concrete aggregate typically 80 megapascals, hardness of crushed stone typically 100 megapascals) | Satisfactory |
| 7.1 | Does this mean they are not included | Added that dust is excluded from study. | Satisfactory |
| 7.1 | Please check EcoInvent or other sources for material specific landfill processes. They are all available and can be included. | Added reference in table that refers to Ecoinvent 2.0. All waste models leverage Ecoinvent 2.0 data adjusted for Australian landfill processing practices. | Satisfactory |
| 7.1 | As expressed before, rebar is produced using EAF techniques; using 65% of BOF is an overstatement of the positive feedback from avoiding production of primary steel. Doing so would extend you time horizon to multiple life cycles which is a disputed technique. The most clear cut approach is to use EAF as the proxy, resulting in a closed-loop where processing is the only impact, corrected for the losses during the life cycle (which are expected to be very small for this case). I need more evidence to be able to accept the applied reasoning. | Added: Once reprocessing impacts have been assessed, a unit of structural steel generated is assumed to avoid a proportion of a unit of structural steel produced in Australia in accordance with the Method C described in Appendix A | Satisfactory |
| 7.2 | Was this part of sensitivity analysis? | Added: Ultimately, this assumption makes it difficult to conclude a difference between crushed concrete aggregate and quarried stone aggregate when it comes to water use. The measure in retained in the study to give the reader a sense of water use to be expected through both processes, and cannot be used to differentiate the processes.<br>[No sensitivity analysis was undertaken] | Satisfactory |
| 17 | What are the drivers for the differences in figure 24, between the green and yellow columns? Are they real impacts, or differences in completeness of the databases, for example, have a look at land use and carcinogens? An analysis of driving factors can reveal real differences or modelling differences. | Drivers explained. Underlying data reviewed. | Satisfactory |
| 7.2 | Please adjust the wording for many, earlier on you used other arguments not to adjust the water consumption because some where more dry and other more wet, please be consistent | Added: This assumption is considered to be a 'best case' assumption as stone is typically harder than concrete so requires more energy to crush (crushed concrete aggregate typically has a hardness of 80 megapascals whereas crushed stone typically has a hardness of 100 megapascals). | Satisfactory |
| 7.2 | Please include my earlier comments on transformation to make this statement more balanced. | Comment deleted because subjective. | Resolved |
| 8.2 | Can I receive a csv or spreadsheet file with the factors? It would be a good idea to include both the classification and normalisation factors in an appendix. This will enhance reproducibility. | Appendices added. | Resolved |
| 9.3 | What about water and waste? They are presented to be of special interest, why not include them here too? | Chart was created due to client request. Water and waste not included, as not requested. | Satisfactory |
| 10.1.1 | how do 15 km and 10 in the equation relate to each other | Error in calculation example. Error corrected. | Resolved |
| 10.2 | My earlier suggestions on the best case included now remain, suggesting a more moderate avoidance that structural steel for the study baseline | Appendix A added using VCS and an extremely conservative view of avoided impacts from steel manufacture. | Satisfactory |
| 10.2 | Why did you only include CO2 here and not all impacts? I would like to see the total comparison here too | Have only added CO2 in sensitive studies to simplify reporting. | The reader should be aware that not all environmental impacts are included in the sensitivity analysis |

| Section | Comment | Action | Status |
|---|---|---|---|
| 11 | If I read the table correctly; should there not be a minus symbol for the 4.9 value?<br>The conclusion that this study is more conservative is not substantiated by the examples; the differences are true difference, the biggest one in background data. The 4.9 is even higher, and seems to be a good adjustment. Please rephrase here and in the summary | Poorly drafted comparison table. New table drafted along with more thorough explanation of findings. | Resolved |
| 13.1 | Can you specify which processes you have used? This is not clear | Reference table modified to show only those databases used in study. | Satisfactory |
| 13.1 | Also, if you used European data, did you regionalise for Australia by using Australian grid and transportation data? If so, please specify, if not, please adjust | Except where explicitly stated, European models have been modified to use Australian energy profiles and transport data. | Satisfactory |
| 13.1 | Did you use EcoInvent 1.0 or 2.0, please specify, this seems to be an old reference | Used Ecoinvent 2.0 for final report. | Resolved |