EPD AUSTRALASIA LTD

# TECHNICAL GUIDANCE FOR DEVELOPING EPDs ACCORDING TO EN 15804+A2:2019 FOR ASPHALT MIXTURES - AUSTRALIA

FINAL FOR PUBLICATION

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## DOCUMENT CONTROL

The Secretariat is responsible for the review and maintenance of this document with support from the Technical Advisory Group. The Board of Directors is responsible for the approval of this document and its contents.

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# Contents

1. INTRODUCTION .... 3
1.1 Scope .... 3
1.2 Consultation .... 4
1.3 LCA methodology .... 4
1.4 Comparison of EPDs .... 4
2. GOAL AND SCOPE ELEMENTS .... 5
2.1 Reference unit .... 5
2.2 System boundaries .... 6
2.3 System diagrams .... 8
2.4 Life Cycle Inventory data .... 9
2.4.1 Asphalt production .... 10
2.4.2 Raw material production .... 10
2.4.3 Secondary materials .... 13
2.4.4 Energy sources .... 14
2.4.5 Transport processes .... 15
2.4.6 Downstream processes: modules C1-C4 .... 16
2.4.7 Downstream processes: module D .... 17
2.5 Process allocation .... 18
2.6 Impact assessment method .... 19
Glossary .... 20
References .... 22
Appendix A. Stakeholder consultation .... 24
Appendix B. Reference Service Life ($RSL_{asphalt}$) .... 25
Appendix C. Life cycle inventory data .... 26
**Recycled asphalt product** .... 26
**Granulated Blast Furnace Slag (GBFS) sand and aggregates** .... 27
**Calcined bauxite** .... 27
**EAF slag** .... 28
**SBS** .... 29
**Regenerated mineral oil** .... 30
**Crushed glass sand** .... 31
**Ground tyre rubber / Crumb rubber** .... 32
**Recycled plastics** .... 33
**Module C: End-of-life processes** .... 33
Appendix D. Emissions to air .... 34
*United States Environmental Protection Agency tables* .... 36
Appendix E. Reuse, recycling, recovery Allocation .... 41

# 1. INTRODUCTION

This document is developed as an EN 15804:2012+A2:2019 (CEN 2019) aligned Technical Guidance document to support development of Environmental Product Declarations (EPDs) in Australia. It is intended for this document to become a regional appendix to the global Product Category Rules for asphalt mixtures when published by the International EPD System[1].

This document was developed by members of the Australian flexible Pavement Association (AfPA) and start2see. The following organisations were involved through AfPA's National Sustainability Committee:

Reporting by:

## 1.1 SCOPE

The geographical scope of this document is limited to Australia only.

The programme operator is EPD Australasia, www.epd-australasia.com (EPDA). The EPD programme provides an independent framework for businesses in Australia and New Zealand to provide objective, science-based environmental data and other information about their products and services.

[1] The International EPD System has previously published a global PCR for asphalt mixtures based on EN 15804+A1:2014 (PCR 2018:04). The global PCR for asphalt mixtures based on EN 15804+A2:2019 is still to be developed.

The programme operator registers and publishes Environmental Product Declarations (EPDs) and Climate Declarations, which are independently verified and registered documents that communicate transparent and comparable data and other relevant environmental information about the life-cycle environmental impact of products.

The applicable PCR for asphalt mixtures[2], the General Programme Instructions and other relevant programme documents can be accessed on the EPD Australasia website.

The moderator for this Technical Guidance document is Rob Rouwette, start2see.

## 1.2 CONSULTATION

This document has been developed by start2see based on input from the Australian asphalt production industry and stakeholders from the infrastructure sector. A list of stakeholders is included in Appendix A. Stakeholder consultation.

For questions on this Technical Guidance document please contact the moderator (Rob Rouwette); rob.rouwette@start2see.com.au, or Programme Secretariat via info@epd-australasia.com.

## 1.3 LCA METHODOLOGY

This document aligns with the Life Cycle Assessment (LCA) methodology as captured by the following standards:

- ISO 14025:2006 Environmental Labels and Declarations — Type III Environmental Declarations — Principles and Procedures (ISO 2006a)
- ISO 14040:2006 Environmental Management — Life Cycle Assessment — Principles and Framework (ISO 2006b)
- ISO 14044:2006 Environmental Management — Life Cycle Assessment — Requirements and Guidelines (ISO 2006c)
- EN 15804:2012+A2:2019 Sustainability of Construction Works — Environmental Product Declarations — Core Rules for the Product Category of Construction Products. (CEN 2019)

This document will be reviewed periodically to ensure the content is up-to-date and in line with the relevant PCRs and standards.

## 1.4 COMPARISON OF EPDS

Care should be taken when comparing the environmental profile of different asphalt mixtures. Comparisons should take place over a whole-of-life assessment of pavement designs, using identical system boundaries and consistent background data.

This Australian Technical Guidance document provides further guidance to facilitate development of consistent EPDs in Australia.

[2] At the time of publication of this Technical Guidance document, the main PCR for Asphalt mixtures by the International EPD System has not been updated yet to EN 15804:2012+A2:2019.

# 2. GOAL AND SCOPE ELEMENTS

The goal and scope elements of this document align with EN 15804:2012+A2:2019, the core Product Category Rules for Construction Products (PCR 2019:14) and are envisioned to be compatible with the Product Category Rules for asphalt mixtures by the International EPD System[2], complemented with specific rules for Life Cycle Inventory data (section 2.4) and process allocation (section 2.5).

## 2.1 REFERENCE UNIT

The reference unit must be determined in relation to the scope of the EPD (see Table 1):

- Cradle-to-gate with modules C1-C4 and module D (A1-A3, C and D): the declared unit is "*1 metric tonne of asphalt mixture*"
- Cradle-to-gate with options, modules C1-C4 and module D (A1-A3, C and D and additional modules. The additional modules may be A4 and/or A5 and/or B1-B7):
  - the declared unit is *"1 metric tonne of manufactured asphalt mixture",* or
  - if B-modules and use scenarios are not declared, the functional unit is *"A paved surface of 1 m$^2$, which fulfils specified quality criteria during the Reference Service Life (RSL) of the asphalt ($RSL_{asphalt}$)."*
    - If the $RSL_{asphalt}$ value is not available, the values of $RSL_{asphalt}$ from the document *"Long-Life Asphalt Pavements – Technical version. June 2007"* (EAPA 2007) could be taken. See Appendix B. Reference Service Life (RSLasphalt), European average values.
  - if B-modules and use scenarios are declared, the functional unit is *"A paved surface of 1 m$^2$, which fulfils specified quality criteria during the Reference Service Life (RSL) of the construction ($RSL_{construction}$). For $RSL_{construction}$, in the case of roads a default value of 40 years shall be taken and for other construction types a value of 30 years."*
- Cradle-to-grave and module D (A, B, C and D):
  - the declared unit is *"1 metric tonne of manufactured asphalt mixture",* or
  - the functional unit is *"A paved surface of 1 m$^2$, which fulfils specified quality criteria during the Reference Service Life (RSL) of the construction ($RSL_{construction}$). For $RSL_{construction}$, in the case of roads a default value of 40 years shall be taken and for other construction types a value of 30 years."*

EN 15804:2012+A2:2019 allows for cradle-to-gate and cradle-to-gate with options type EPDs (see Table 1) if all of the following conditions for exclusion of modules C1-C4 and module D are met:

1. the product or material is physically integrated with other products during installation so they cannot be physically separated from them at end-of-life, and
2. the product or material is no longer identifiable at end-of-life as a result of a physical or chemical transformation process, and
3. the product or material does not contain biogenic carbon.

Asphalt mixtures do not meet all three conditions for exclusion of modules C1-C4 and module D, and therefore an asphalt EPD shall as a minimum include modules A1-A3, C1-C4 and D. Modules A4 and/or A5 and/or B1-B7 are optional if a cradle-to-gate with options scope is selected, or mandatory if a cradle-to-grave scope is selected.

**Table 1. Types of EPDs for asphalt mixtures and life cycle stages**

| | Product stage | | | Construction stage | | Use stage | | | | | | | End-of-life stage | | | | Benefits / loads beyond system boundary |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EPD type | **A1** | **A2** | **A3** | **A4** | **A5** | **B1** | **B2** | **B3** | **B4** | **B5** | **B6** | **B7** | **C1** | **C2** | **C3** | **C4** | **D** |
| Cradle-to-gate with modules C1-C4 and module D **Declared unit** | Mandatory | | | | | | | | | | | | Mandatory | | | | Mandatory |
| Cradle-to-gate with options, modules C1-C4 and module D **Functional unit or Declared unit** | Mandatory | | | Optional | | Optional | | | | | | | Mandatory | | | | Mandatory |
| Cradle-to-grave and module D **Functional unit** | Mandatory | | | Mandatory | | Mandatory | | | | | | | Mandatory | | | | Mandatory |
| *Cradle-to-gate** ***Declared unit*** | *Mandatory* | | | | | | | | | | | | | | | | |
| *Cradle-to-gate* with options* ***Functional unit or Declared unit*** | *Mandatory* | | | *Optional* | | | | | | | | | | | | | |

** Only possible if the conditions for exclusion of modules C1-C4 and module D are met.*

## 2.2 SYSTEM BOUNDARIES

The International EPD® System has adopted an LCA calculations procedure, which defines life cycle stages in line with EN 15804 (see stages described in Table 1).

As explained in section 2.1, the scope of the LCA for asphalt mixtures shall be “cradle-to-gate with modules C1-C4 and module D” (A1-A3, C1-C4, D) as a minimum. The scopes of “cradle-to-gate with options” and “cradle-to-grave” (A4 and/or A5 and/or B) are optional:

- A1: Raw Material Supply (mandatory)
- A2: Transport to asphalt plant (mandatory)
- A3: Manufacturing of the asphalt mixture (mandatory)
- A4: Transport to the construction site (optional)
- A5: Asphalt mixture application (optional)
- B1: Use (optional)
- B2: Maintenance of asphalt surface (optional)
- B3: Repair (optional)
- B4: Replacement (optional)

- B5: Refurbishment (optional)
- B6: Operational energy use (information module not considered in this document)
- B7: Operational water use (information module not considered in this document)
- C1: Removal of asphalt (mandatory)
- C2: Transport to waste management plant (mandatory)
- C3: Waste processing (mandatory)
- C4: Disposal (mandatory)
- D: Benefits and loads beyond the system boundary (mandatory)

Modules B6 operational energy use and B7 operational water use are information modules not included in this Technical Guidance document (see Table 2).

The modules B2 Maintenance, B3 Repair, B4 Replacement and B5 Refurbishment completely cover the operations needed for the correct functional performance of the asphalt during its lifetime or the life of the construction. B5 Refurbishment is more focused on other type of infrastructures and constructions (as buildings) but in the case of the asphalt mixtures (not only roads), it does not apply. Definitions of the modules B1 – B5 are provided in the Glossary section of this document.

In the case of B6 and B7 modules, although it is known, for example, that the rugosity of the asphalt (pavement roughness) can significantly affect the energy consumption of vehicles, the science is very imprecise and there are no forms to define this information clearly.

Therefore, module B6 will not be considered within the scope of this Technical Guidance document. In case the owner of the EPD is interested in supplying this information, it shall be reported in the section “Other environmental information” of the EPD.

**Table 2. Life cycle stages potentially included in the system boundaries**

| Product stage | | | Construction stage | | Use stage | | | | | | | End-of-life stage | | | | Benefits beyond system boundary |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw material supply | Transport | Manufacturing | Transport | Construction-installation process | Use | Maintenance | Repair | Replacement | Refurbishment | Operational energy use | Operational water use | De-construction demolition | Transport | Waste processing | Disposal | Reuse, recovery, recycling potential |
| A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | C1 | C2 | C3 | C4 | D |
| | | | Scenario | | Scenario | | | | | | | Scenario | | | | |
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A | ✓ | ✓ | ✓ | ✓ | ✓ |

✓ = life cycle stage is potentially included in an Environmental Product Declaration that follows the Technical Guidance document for asphalt mixtures

## 2.3 SYSTEM DIAGRAMS

A detailed system flow diagram for the cradle-to-gate stages (A1-A3) is depicted in Figure 1. The diagram shows which unit processes are relevant for asphalt producers and their suppliers and can assist with data collection.

An LCA for asphalt mixtures shall include all inputs and outputs to the identified unit processes when relevant:

- Specific (primary) data shall be collected for the asphalt production process
- Specific (primary) data shall be collected for transport of most raw materials to the asphalt manufacturer
- Generic (secondary) data may be used for supply chain processes and emissions from the asphalt plant. To improve consistency of EPDs for asphalt mixtures, prescribed generic life cycle inventory data are included in section 2.4 and "Appendix C. Life cycle inventory data".

See sections 5.1 and 5.2 of IEPDS 2019a for more guidance on data collection.

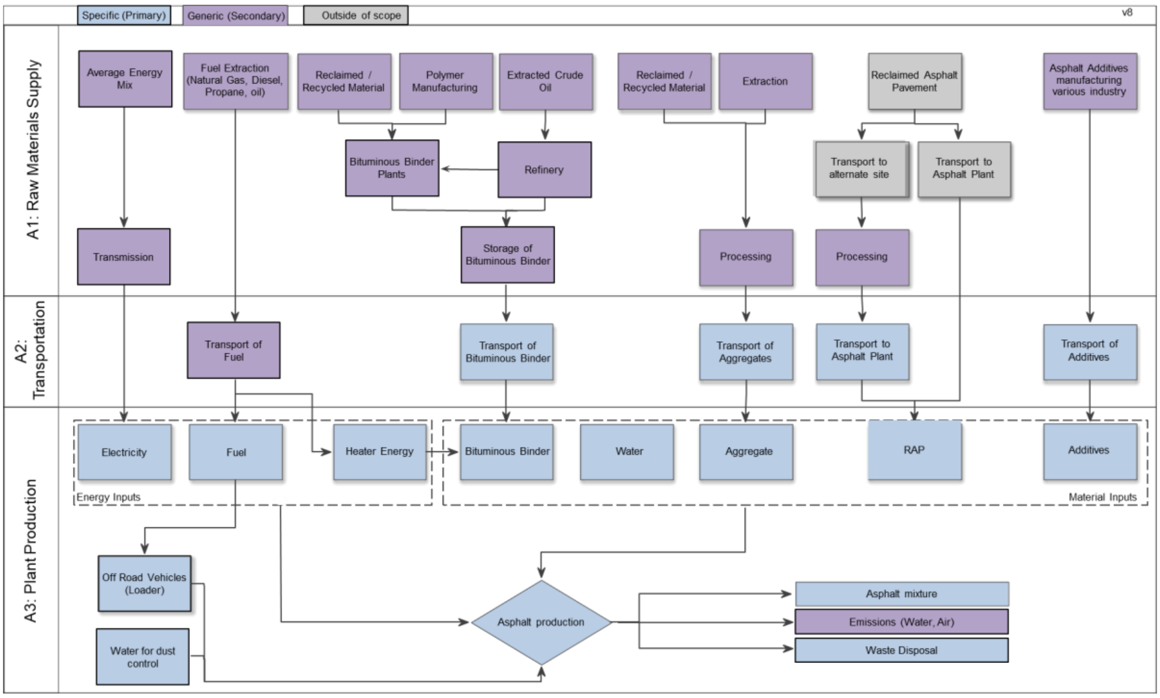


**Figure 1. Diagram of system boundaries (modules A1-A3), processes and data types**

A detailed flow diagram for the end-of-life stages (C1-C4) and module D is depicted in Figure 2. The diagram shows which unit processes are relevant for asphalt LCAs and can assist with data collection and modelling.

An LCA for asphalt mixtures shall include all inputs and outputs to the identified unit processes when relevant:

- Generic (secondary) data may be used for all downstream end-of-life processes. To improve consistency of EPDs for asphalt mixtures, prescribed generic life cycle inventory data are included in section 2.4 and "Appendix C. Life cycle inventory data".

- The end-of-waste state of asphalt is determined as follows: Reclaimed Asphalt Pavement reaches the end-of-waste state when the reclaimed, milled material has been collected in a truck and transported to a storage pile, ready to be processed for further use. As a result, module C3 is not relevant for asphalt (as the processing is included at the start of life in module A1 or A3).
- Specific data shall be used for module D: the asphalt mixture that is modelled in modules A1-A3 shall also be used to model potential loads and benefits in module D (see section 2.4.7).

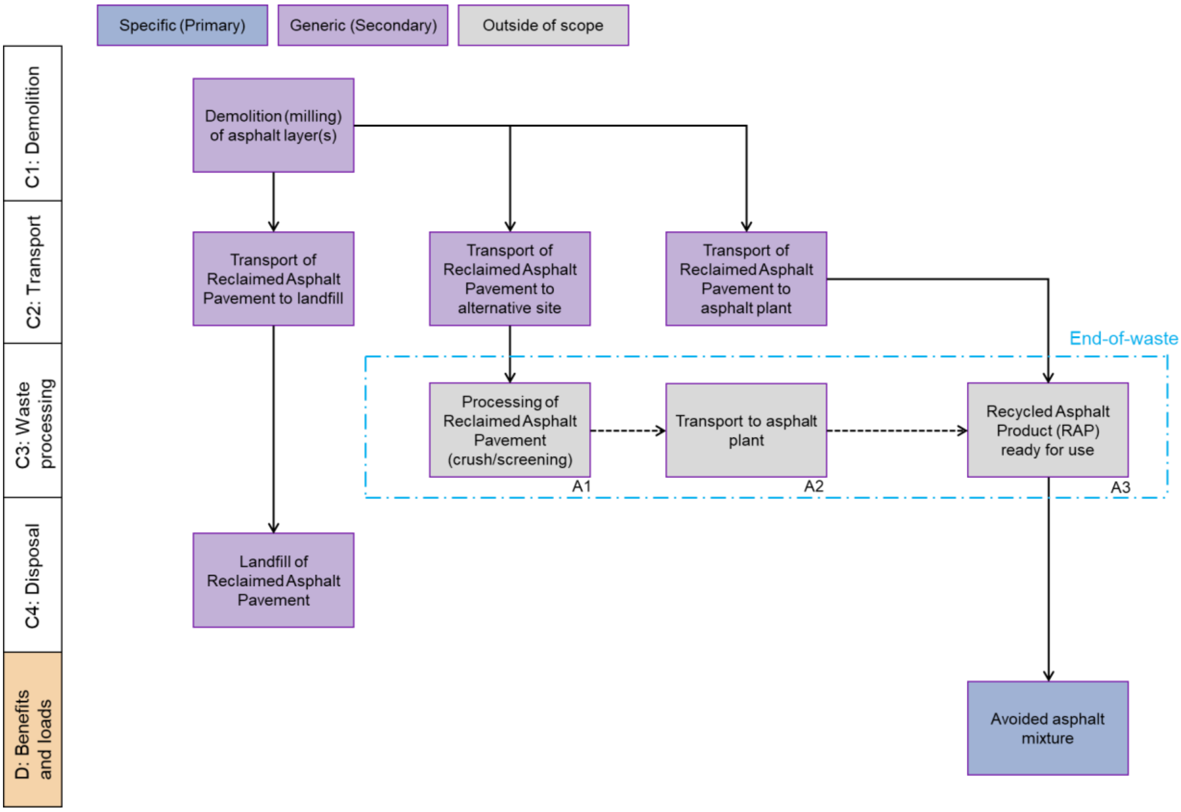


**Figure 2. Diagram of system boundaries (modules C1-C4, D), processes and data types**

## 2.4 LIFE CYCLE INVENTORY DATA

Based on the approach taken by National Asphalt Pavement Association (NAPA 2017), key Australian life cycle inventory data have been prescribed in the Australian Technical Guidance document. An Australian EPD of asphalt mixtures shall use the prescribed life cycle inventory (LCI) data sources for all relevant generic (secondary) data, unless specific (primary) data are available. This approach minimises variances resulting from differences in choice of generic data sources and EPDs in conformance with this Technical Guidance document will reflect only differences in specific data (plant energy use and material use).

Where possible, generic data are to be sourced from the most recent Australian national life cycle inventory database (AusLCI 2021) and the associated AusLCI shadow database developed by the Australian Life Cycle Assessment Society (ALCAS).[3]

[3] For more information on AusLCI, visit: http://www.auslci.com.au/.

Note: the AusLCI shadow database contains proprietary data and is therefore not published. All LCA consultants with an ecoinvent license can access the AusLCI shadow database by contacting ALCAS.

The diagram in Figure 1 indicates for common unit processes whether specific or generic data should be used. All specific data must be reflective of plant production over a period of twelve consecutive months. Annual production data should be as recent as possible and no more than three years old.[4]

### 2.4.1 ASPHALT PRODUCTION

The asphalt production process requires predominantly specific data, such as material and energy input per unit of asphalt produced:

- Material use comprises of all the material inputs into the mixture and water use at the plant (including for dust suppression).
- Energy (fuel and electricity) is mainly used at the asphalt plant for plant (e.g. storage and dosing, drum mixer), burners (e.g. heating of bitumen, drying of aggregates) and internal transport.
    - Energy use for general management (e.g. office, laboratory) is excluded from the system boundaries as per the main PCR. In practice, it may be too difficult to separate energy use for these overhead processes from the main process. If this is the case, the LCA shall justify any deviation from the main PCR (or other relevant standards and guidelines).
- Production waste is typically recycled internally. Any production waste that is not processed internally shall be included in the inventory.

AfPA members have indicated that emissions to air are not measured in a consistent manner across the industry. Relying solely on specific (primary) data is therefore likely to create variations between plants due to differences in emissions measurement creating data gaps. Therefore, generic data shall be used as outlined in Appendix D. Emissions to air, where specific, measured data for a substance are not available.

### 2.4.2 RAW MATERIAL PRODUCTION

In Australia, asphalt typically consists of a bitumen binder, aggregates and fillers. Additives may be added to achieve the desired properties.

In line with section 5 of the main PCR (IEPDS 2018), materials that make up less than 1% of the total mass input - but that are considered environmentally relevant - shall be included when publicly available data exists. Those materials are (not limited to):

- Polymers in binder, broken down into two classes of chemicals: elastomers or rubbers, such as styrene-butadiene-styrene (SBS), and plastomers
- Liquid antistrips, recycling agents and warm-mix chemical additives
- Fibres.

To facilitate data collection and minimise variances the most commonly used raw materials are listed in Table 3, together with the prescribed data sources.

The prescribed data sources shall be used for all relevant raw materials in the LCA of asphalt mixtures. If raw materials (including additives) are used in the production of the asphalt mixture that are not listed in Table 3, then appropriate life cycle inventory data should be used. Data gaps are to be avoided.

[4] E.g. If the EPD is published in September 2021, the specific data should cover the 2018 calendar year or 2019 financial year or a more recent period.

### Table 3. Default data sources for asphalt raw materials and additives

| Type | Generic name | Prescribed data source | Database |
|---|---|---|---|
| **Bitumen** | Bitumen | Bitumen, at refinery/RER U/AusSD U | AusLCI shadow database |
| **Fine aggregates (<5 mm)** | Natural sand | Sand, at mine/CH U/AusSD U | AusLCI shadow database |
| | Manufactured sand | Gravel, crushed, at mine/CH U/AusSD U | AusLCI shadow database |
| | Granulated Blast Furnace Slag (GBFS) sand | #literature data | See appendix C |
| **Coarse aggregates (>5 mm)** | River aggregates | Gravel, round, at mine/CH U/AusSD U | AusLCI shadow database |
| | Crushed rock | Gravel, crushed, at mine/CH U/AusSD U | AusLCI shadow database |
| | Calcined Bauxite | #literature data | See appendix C |
| | Granulated Blast Furnace Slag (GBFS) aggregates | #literature data | See appendix C |
| | EAF slag aggregates | #literature data | See appendix C |
| **Mineral fillers** | Milled limestone | Limestone, milled, loose, at plant/CH U/AusSD U | AusLCI shadow database |
| | Bag house dust | Mostly internally recycled; no impact at point of generation | N/A |
| | Fly ash | Secondary material; no impact at point of generation | N/A |
| **Anti-strip agents** | Hydrated lime | Lime, hydrated, loose, at plant/CH U/AusSD U | AusLCI shadow database |
| | Amines | #Diethanolamine, at plant/RER U/AusSD U | AusLCI shadow database |
| **Cold mix additives** | Diesel | Diesel, at regional storage/RER U/AusSD U | AusLCI shadow database |
| | Vegetable based oil | #Canola oil, at oil mill/AU U | AusLCI |
| **Fibres** | Cellulose | #Cellulose fibre, inclusive blowing in, at plant/CH U/AusSD U[5] (75%) (replacing Borax and Boric acid with Waste paper)<br>Limestone, milled, packed, at plant/CH U/AusSD U (15%)<br>Bitumen, at refinery/RER U/AusSD U (10%)[6] | AusLCI shadow database |

[5] The ecoinvent background report (ecoinvent 2007) shows that the energy used for blowing is negligible. Therefore, this process is considered a reasonable proxy for cellulose fibres, when Borax and Boric acid inputs are excluded.

[6] Proxy chosen based on the MSDS for JRS VIATOP premium

| Type | Generic name | Prescribed data source | Database |
|---|---|---|---|
| **Polymers** | SBS (Styrene-Butadiene-Styrene) | #literature data | See appendix C |
| | EVA (Ethylene-Vinyl Acetate) | Ethylene vinyl acetate copolymer, at plant/RER U/AusSD U | AusLCI shadow database |
| | Fisher-Tropsch wax | #Paraffin, at plant/RER U/AusSD U | AusLCI shadow database |
| **Recycling agents** | Re-generated mineral oil | #literature data | See appendix C |
| **Secondary materials** | Recycled Asphalt Product (RAP) | Secondary material; processing after end-of-waste to be included | See appendix C |
| | Crushed glass sand | Adapted from ecoinvent v3 | See appendix C |
| | Foundry sand | Secondary material; no impact at point of generation | N/A |
| | Ground tyre rubber / rubber crumb[7] | #literature data | See appendix C |
| | Recycled plastics | Secondary material; processing after end-of-waste to be included | See appendix C |
| | Fly ash | Secondary material; no impact at point of generation | N/A |
| **Warm mix additives** | liquid surfactant, e.g. Cecabase® | #Ethoxylated alcohols, unspecified, at plant/RER U/AusSD U (95%)<br>Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U/AusSD U (5%)[8] | AusLCI shadow database |
| | Evotherm | #Diethanolamine, at plant/RER U/AusSD U[9] | AusLCI shadow database |
| | liquid surfactant, e.g. CWM® | #Trimethylamine, at plant/RER U/AusSD U[10] | AusLCI shadow database |
| | Narrow cut kerosene | #Kerosene, at regional storage/RER U/AusSD U | AusLCI shadow database |

*# indicates proxy data have been selected for these additives. The use of proxy data is preferred over leaving data gaps in the LCI.*

The list of materials has been reviewed in 2021 for alignment with the Sustainability Assessment Tool for Innovative Pavements (SAT), which is being developed by the Australian Road Research Board (ARRB) through a joint initiative by the West Australian Road Research and Innovation Program (WARRIP) and the National Asset Centre of Excellence (NACOE), with funding by Main Roads Western Australia (Main Roads) and the Queensland Department of Transport and Main Roads (TMR).

[7] Ground tyre rubber can function as a polymer, a binder extender or a filler

[8] Proxy chosen based on the MSDS for Cecabase RT Bio10 issued by Fulton Hogan

[9] Proxy chosen based on the MSDS for Evotherm PC-1770

[10] Proxy chosen based on the MSDS for Chemoran CWM

### 2.4.3 SECONDARY MATERIALS

Asphalt pavements have been recognised for their ability to incorporate various secondary materials. The use of secondary materials requires specific attention when developing an EPD, as secondary materials cross the system boundaries between multiple product systems and thus necessitate allocation. In line with EN 15804:2012+A2:2019, the following allocation rules apply:

- The sum of the allocated inputs and outputs of a unit process shall be equal to the inputs and outputs of the unit process before allocation. This means no double counting or omission of inputs or outputs through allocation is permitted.
    - Note: For secondary materials this means that the definition of the end-of-waste state is important to ensure no double counting or omission of material recycling processes occurs.
    - For example, reclaimed asphalt pavement at the end-of-life of a pavement is placed in a truck and transported to a processing site or directly to an asphalt plant (module C2). The processing (crushing, screening) at a processing site should be included in stage A1. Transport of RAP from an external processing site to the asphalt plant should be included in module A2. This delineation is depicted in Figure 1 and Figure 2.
- Irrespective of the allocation approach chosen (for a co-production process or) for secondary flows crossing the system boundary between product systems, specific inherent properties of such co-products or flows, for example calorific content, composition (biogenic carbon content, bitumen content, etc.), shall not be allocated but always reflect the physical flows.
    - Note: When the end-of-life of an asphalt mixture (in a pavement) is modelled, the product composition of the original asphalt mixture should be reflected in the material that is collected for recycling and hence the impacts and benefits modelled in Module D should reflect the original product composition. This avoids a situation where the benefits in Module D are disconnected from the material supplied.

Guidance to modelling of Reclaimed Asphalt Pavement / Recycled Asphalt Product (RAP):

- When RAP is sourced from a stockpile or road pavement, the exact composition of the product may be unknown. In these cases, a default effective bitumen content of 4.4% may be assumed for asphalt sourced from stockpiles and pavement.
- RAP used in asphalt typically consists of end-of-life pavement material and plant returns. “Plant returns” is the binder coated aggregate from the start up and end of production runs that is re-directed to waste, as well as asphalt returned to the plant due to overordering. In line with ISO 14021, only post-industrial and post-consumer recycled materials count towards recycled content, which means plant returns shall not be reported in the Resource Use parameter “Secondary Materials”. If the share of plant returns in the total RAP use of a plant is unknown, a default of 10% should be applied for metro plants and 30% for regional plants. Plant returns do not have to be determined at product (asphalt mix) level, as this would be nonsensical due to homogenisation of RAP stockpiles.

**How to deal with Reclaimed Asphalt Pavement / Recycled Asphalt Product (RAP)?**

*Definitions of RAP:*

- *Reclaimed Asphalt Pavement, when the material comes out of the road*
- *Recycled Asphalt Product, when the material is used in new asphalt.*

Transport of Reclaimed Asphalt Pavement from road end-of-life site to a processing site needs to be included at the end-of-life. Reclaimed Asphalt Pavement reaches the end-of-waste state when the reclaimed, milled material has been collected in a truck and transported to a storage pile, ready to be processed for further use.

Processing (i.e. crushing, screening) and (if processing is conducted at an alternative site) transport of the material to the asphalt plant is part of the life cycle of the secondary material and needs to be accounted for as part of the Recycled Asphalt Product that is incorporated into new asphalt products.

Further guidance to allocation procedures for “waste” reuse, recycling and recovery is provided in the General Programme Instructions of the International EPD System and Appendix E. Reuse, recycling, recovery Allocation.

### 2.4.4 ENERGY SOURCES

Energy used in asphalt production typically consists of electricity, natural gas, diesel and/or fuel oil. For production and transport of fuels, as well as generation, transmission and distribution of electricity, generic data can be used. The prescribed data sources for energy inputs are listed in Table 4.

**Table 4. Default data sources for energy inputs**

| Energy type | Prescribed data source | Database |
|---|---|---|
| **Electricity, Australian** | Electricity, low voltage, Australian/AU U | AusLCI |
| **Electricity, NSW/ACT** | Electricity, low voltage, New South Wales/AU U | AusLCI |
| **Electricity, Northern Territory** | Electricity, low voltage, Northern Territory/AU U | AusLCI |
| **Electricity, Queensland** | Electricity, low voltage, Queensland/AU U | AusLCI |
| **Electricity, South Australia** | Electricity, low voltage, South Australia/AU U | AusLCI |
| **Electricity, Tasmania** | Electricity, low voltage, Tasmania/AU U | AusLCI |
| **Electricity, Victoria** | Electricity, low voltage, Victoria/AU U | AusLCI |
| **Electricity, Western Australia** | Electricity, low voltage, Western Australia/AU U | AusLCI |
| **Natural gas, Australian, combusted*** | Natural gas, burned in industrial furnace >100kW/RER U* | AusLCI shadow database |
| **Natural gas, Australian, fuel** | Natural gas, high pressure, Australia/AU U | AusLCI |

| Energy type | Prescribed data source | Database |
|---|---|---|
| **Diesel, combusted*** | Diesel, burned in building machine/GLO U/AusSD U | AusLCI shadow database |
| **Diesel, fuel** | Diesel, at regional storage/RER U/AusSD U | AusLCI shadow database |
| **Heavy Fuel Oil, combusted*** | Heavy fuel oil, burned in industrial furnace 1MW, non-modulating/RER U/AusSD U | AusLCI shadow database |
| **Heavy Fuel Oil, fuel** | Heavy fuel oil, at regional storage/RER U/AusSD U | AusLCI shadow database |
| **LPG, combusted*** | liquefied petroleum gas, burned in industrial furnace >100kW/RER U/adapted/AU U | AusLCI |
| **LPG, fuel** | Liquefied petroleum gas, at service station/CH U/AusSD U | AusLCI shadow database |

** Fuels that are combusted in the manufacturing process to dry and heat raw materials contribute to the plant's process emissions to air. As indicated in section 2.4.1, process emissions to air are to be based on default values, to avoid variations between plants on the basis of measurement accuracy or completeness. See "Appendix D. Emissions to air" for details on how to calculate emissions to air.*

### 2.4.5 TRANSPORT PROCESSES

Transport is relevant throughout the life cycle of asphalt mixtures, from transport of raw materials and fuels to the asphalt plant to transport of asphalt products to the construction site. For all transport processes, a combination of specific and generic data can be used:

- Specific data relate to the transport mode (e.g. 20 t truck) and transport distance (km) from supplier to asphalt plant.
- Generic data relate to the impacts associated with the transport process. The prescribed data sources for transport processes are listed in Table 5.

**Table 5. Default data sources for transport**

| Type | Prescribed data source | Database |
|---|---|---|
| **Road transport, truck, 3.5-16t load** | Transport, truck, 3,5 to 16t, fleet average/AU U | AusLCI |
| **Road transport, truck 16-28t load** | Transport, truck, 16 to 28t, fleet average/AU U | AusLCI |
| **Road transport, truck 40t load** | Transport, truck, 40t load/AU U | AusLCI |
| **Rail transport** | Transport, freight, rail/AU U | AusLCI |
| **Water transport, barge** | Transport, barge/RER U/AusSD U | AusLCI shadow database |
| **Water transport, container ship** | Transport, transoceanic freight ship/OCE U/AusSD U | AusLCI shadow database |
| **Water transport, bulk tanker** | Transport, transoceanic tanker/OCE U/AusSD U | AusLCI shadow database |

As a rule, raw materials should be traced back to their production location. As this is not always possible, due to the complex nature of supply logistics it might not always be clear which transport processes are to be included in the LCA, supply transport legs that should be included in the LCA are explained in the following table.

**Table 6. Default supply transport legs to be included in the LCA**

| Raw material input | From | To |
|---|---|---|
| **Bitumen** | Production location.<br><br>To account for import of bitumen, transport from production location to Australia should be included as 8,890tkm of "Transport, transoceanic tanker/OCE U/AusSD U" or by using specific distance data if the production location and transport distance is known, plus transport from port terminal to asphalt plant using specific data. | Asphalt plant |
| **Aggregates** | Quarry | Asphalt plant |
| **Additives** | Manufacturing location | Asphalt plant |
| **Other secondary materials** | (end-of-waste) Processing plant | Asphalt plant |
| **Liquid fuels** | Immediate supplier of liquid fuel | Asphalt plant |
| **RAP (from processing plant)** | Average/typical distance from the end-of waste state (if external to asphalt plant) | Asphalt plant |
| **RAP (from road construction project)** | Transport should be included in module C2 (see Figure 1 and Figure 2) | |

### 2.4.6 DOWNSTREAM PROCESSES: MODULES C1-C4

With the introduction of EN 15804:2012+A2:2019, end-of-life (modules C1-C4) and potential loads and benefits beyond the system boundaries (module D) shall be included in the LCA and EPD.

For end-of-life stages, generic scenarios and data may be used (see Figure 2). The default scenarios and data sources for end-of-life processes are shown in Table 7, Table 8 and Table 9. The life cycle inventory data are included in Appendix C. Life cycle inventory data.

**Table 7. Default end-of-life scenarios**

| End-of-life disposal option | Pavement in metro areas | Pavement in regional areas | Pavement millings containing coal tar |
|---|---|---|---|
| **Recycling into asphalt** | 90% | 75% | 0% |
| **Downcycling as granular subbase or back fill** | 10% | 25% | 0% |
| **Landfill** | 0% | 0% | 100% |
| **Incineration** | 0% | 0% | 0% |

The end-of-life scenarios in the previous table are based on estimates, as industry statistics are not available.

**Table 8. Default data sources for end-of-life processes**

| Module | Process | Prescribed data source | Database |
|---|---|---|---|
| **C1** | Milling of asphalt | Diesel, burned in building machine/GLO U/AusSD U | AusLCI shadow database |
| **C2** | Transport | Transport, truck, 16 to 28t, fleet average/AU U | AusLCI |
| **C3** | Not relevant | | |
| **C4** | Disposal in landfill | Disposal, asphalt, 0.1% water, to sanitary landfill/CH U/AusSD U | AusLCI shadow database |

**Table 9. Default scenarios for transport of asphalt to an asphalt plant, processing plant or landfill site (Module C2)**

| Flow | Process | Distance | Comment |
|---|---|---|---|
| Transport of Reclaimed Asphalt Pavement to asphalt plant /processing plant | transport, truck, 16 to 28t, fleet average/AU U | 30 km | Estimated distance |
| Transport of Reclaimed Asphalt Pavement to landfill site | transport, truck, 16 to 28t, fleet average/AU U | 60 km | Estimated distance |

In principle, waste processing is part of the product system under study. In the case of materials leaving the system as secondary materials or fuels, such processes as collection and transport before the end-of-waste state are, as a rule, part of the waste processing of the system under study. However, after having reached the “end-of-waste” state further processing may also be necessary in order to replace primary material or fuel input in another product system. Such processes are considered to be beyond the system boundary and are assigned to module D. Secondary material having left the system can be declared as substituting primary production in module D, when it has reached functional equivalence of the substituted primary material.

### 2.4.7 DOWNSTREAM PROCESSES: MODULE D

The loads and benefits beyond the system boundary in module D quantify the value the material has when it is recycled (or reused). As outlined in Table 7, most asphalt is recycled into new asphalt or downcycled into roadbase material.

The loads associated with processing reclaimed asphalt in module D are captured in Table 14.

The benefits associated with the recovered materials need to take into account the fact that bitumen loses some of its effective binder capacity over time due to oxidation, as well as the fact that during the milling process some coarse aggregates are chipped and in effect become fine aggregates. Table 10 provides default module D recovery factors for the materials in the asphalt mix that are recycled into new asphalt. Table 11 outlines which primary materials are being replaced by each of the components in an asphalt mixture.

**Table 10. Default recovery factors for asphalt collected for recycling into new asphalt at end of life**

| Component | Recovery rates |
|---|---|
| **Bitumen / PMB** | 100% |
| **Coarse aggregates** | 100% |
| **Fine aggregates** | 100% |
| **Filler** | 100% |
| **Other** | 100% |

**Table 11. Default virgin materials that are being replaced for asphalt collected for recycling at end of life**

<table>
<tr><th>Component</th><th>Replaced primary material if recycled into asphalt</th><th>Replaced primary material if downcycled as roadbase</th></tr>
<tr><td>Bitumen / PMB</td><td>Bitumen, at refinery/RER U/AusSD U</td><td rowspan="4">Stabilised roadbase material:<br>99% Gravel, crushed, at mine/CH U/AusSD U<br>1% Bitumen, at refinery/RER U/AusSD U</td></tr>
<tr><td>Coarse aggregates</td><td>95% replaces coarse aggregates: Gravel, crushed, at mine/CH U/AusSD U<br>5% replaces fine aggregates: Sand, at mine/CH U/AusSD U</td></tr>
<tr><td>Fine aggregates</td><td>Sand, at mine/CH U/AusSD U</td></tr>
<tr><td>Other*</td><td>Sand, at mine/CH U/AusSD U</td></tr>
</table>

** All other materials, including filler, in the RAP are assumed to replace virgin sand in the asphalt mix design of the next life cycle.*

## 2.5 PROCESS ALLOCATION

An asphalt plant typically produces a range of asphalt mixtures, depending on customer demand. It is not practical to measure energy consumption for a particular batch and to assign this to a mix design, because the energy consumption can have been influenced by the previous batch. Therefore, it is recommended to use either:

- Method A: Determine the energy use for each mix design based on the composition, specific heat capacity of components, moisture content of raw materials and the plant's overall efficiency.
- Method B: assign the annual energy consumption of the plant equally across all products (by mass).

The method used shall be stated in the EPD.

## 2.6 IMPACT ASSESSMENT METHOD

The impact assessment method shall follow EN 15804:2012+A2:2019.[11]

The requirements from EN 15804 need to be considered when reporting environmental indicators, for example:

- Information modules that generate any input or output flows considered in the declaration of module D shall also be declared. For example, the declaration of benefits of material and energy recovery in module D from packaging recovery in module A5 is only possible if optional module A5 has been declared, including all related processes.
- A manufacturer may choose to declare additional technical information without calculating the optional life cycle stages (A4 and/or A5 and/or B1-B7) to ensure proper understanding of the asphalt's function in a construction works and thus support proper scenario development at the construction works level.
- Bitumen is a feedstock energy source and therefore contributes to the parameter: "Use of non-renewable primary energy resources used as raw materials".
- The parameter "Secondary Material" shall only include post-industrial and post-consumer recycled materials, in line with ISO 14021. For asphalt products, common secondary materials include RAP recovered from roads, rubber crumb, fly ash, crushed glass and waste plastics. previous use or from waste which substitutes primary materials.
    - RAP from plant returns should not be counted towards secondary materials, and neither should bag house filter dust (internal recycling) and slag aggregates (valuable by-product).
- The biogenic carbon content of the asphalt mixture shall de declared in the EPD, unless the mass of biogenic carbon containing materials in the product is less than 5% of the mass of the product.
- For packaged products (e.g. bagged cold mix used for minor repairs):
    - The mass of the packaging shall be stated on the EPD
    - The biogenic carbon content of the packaging shall de declared in the EPD, unless the mass of biogenic carbon containing materials in the packaging is less than 5% of the total mass of the packaging.

[11] Note that Table 3 (core environmental impact indicators) of EN 15804:2012+A2:2019 contains an error regarding the unit to be used for Eutrophication aquatic freshwater. The correct unit is *kg P-equivalents*. A corrigendum was published in August 2021 (EN 15804:2012+A2:2019/AC:2021).

# GLOSSARY

## Acronyms:

| | |
|---|---|
| AfPA | Australian flexible Pavement Association |
| ALCAS | Australian Life Cycle Assessment Society |
| CPC | Central Product Classification |
| EAPA | European Asphalt Pavement Association |
| EPA | Environmental Protection Agency |
| EPD | Environmental Product Declaration |
| EPDA | EPD Australasia |
| IEPDS | International EPD System |
| ISO | International Organization for Standardization |
| LCA | Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| NAPA | National Asphalt Pavement Association |
| PCR | Product Category Rules |
| RAP | Reclaimed Asphalt Pavement / Recycled Asphalt Product |
| RSL | Reference Service Life |

## Units:

| | |
|---|---|
| kg | kilogram |
| kWh | kiloWatthour |
| $m^2$ | square metre |
| $m^3$ | cubic metre |
| MJ | MegaJoule |
| tkm | tonne-kilometre |

**Use stage definitions for asphalt mixtures:**

Module B1 Use of the installed product: This module covers environmental aspects and impacts arising from components of the construction works during their normal (i.e. anticipated) use, such as release of substances from the asphalt mixture to indoor air, soil or water.

Module B2 Maintenance: This module covers the combination of all planned technical and associated administrative actions during the service life to maintain the asphalt product installed in a construction works in a state in which it can perform its required functional and technical performance. This includes preventative and regular maintenance activity such as cleaning, and the planned servicing, replacement or mending of worn, damaged or degraded parts. Water and energy usage required for cleaning, as part of maintenance shall be included in this module, and not in modules B6 and B7.

The regular inspection of a road surface would be considered as maintenance.

Maintenance, repair and replacement of a whole section of the building as part of a concerted programme for the building would be considered as refurbishment.

Module B3 Repair: The module "repair" covers a combination of all technical and associated administrative actions during the service life associated with corrective, responsive or reactive treatment of an asphalt product installed in construction works to return it to an acceptable condition in which it can perform its required functional and technical performance. It also covers the preservation of the aesthetic qualities of the product. Replacement of a broken component or part due to damage should be assigned to "repair", whereas replacement of a whole element due to damage should be assigned to the module "replacement".

Module B4 Replacement: The module "replacement" covers the combination of all technical and associated administrative actions during the service life associated with the return of a construction product to a condition in which it can perform its required functional or technical performance, by replacement of a whole construction element.

Replacement of a broken component or part due to damage should be included as "repair", but replacement of a whole construction element due to damage should be considered as "replacement". Replacement of a whole construction element as part of a concerted replacement programme for the construction works should be considered as "refurbishment".

Module B5 Refurbishment: The module "refurbishment" covers the combination of all technical and associated administrative actions during the service life of a product associated with the return of the construction works or their parts to a condition in which it can perform its required functions. These activities cover a concerted programme of maintenance, repair and/or replacement activity, across a significant part or whole section of the construction works.

Restoration activities should be included within refurbishment.

# REFERENCES


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| AusLCI 2021 | The Australian National Life Cycle Inventory Database (AusLCI) is an ongoing initiative delivered by the Australian Life Cycle Assessment Society (ALCAS)<br>Retrieved from http://alcas.asn.au/AusLCI/ |
| CEN 2019 | EN 15804:2012+A2:2019, Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products. Brussels, Belgium: European Committee for Standardization, 2019 |
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| EPDA | EPD Australasia<br>http://www.epd-australasia.com/<br>Instructions of the Australasian EPD Programme – a Regional Annex to the General Programme Instructions (2018) Version 3.0 Published 18.09.2018. |
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| IEPDS 2019a | International EPD System (IEPDS), Product Category Rules (PCR) 2018:04, Asphalt mixtures, Product category classification: UN CPC 1533 & 3794, version 1.03, 6 September 2019 |

| | |
|---|---|
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| IEPDS 2021 | International EPD System (IEPDS), General Programme Instructions for the International EPD® System, GPI version 4.0, 29 March 2021 |
| ISO 2006a | ISO 14025:2006 Environmental labels and declarations – Type III environmental declarations - Principles and procedures. Geneva, Switzerland: International Organization for Standardization, 2006 |
| ISO 2006b | ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework. Geneva, Switzerland: International Organization for Standardization, 2006 |
| ISO 2006c | ISO 14044:2006, Environmental management - Life cycle assessment - Requirements and guidelines. Geneva, Switzerland: International Organization for Standardization, 2006 |
| NAPA 2017 | National Asphalt Pavement Association (NAPA), Product Category Rules (PCR) for Asphalt Mixtures, Version 1.0, 31 January 2017<br>http://www.asphaltpavement.org/PDFs/EPD_Program/NAPA_Product_Category_Rules_%20final.pdf |
| US EPA 2004 | AP 42, Fifth Edition, Volume I, Chapter 11: Mineral Products Industry, United States Environmental Protection Agency, 2004<br>https://www3.epa.gov/ttn/chief/ap42/ch11/index.html |
| Versalis | Eni-Versalis, SBS, Styrene-Butadiene-Styrene block copolymers, Proprietary process technology, San Donato Milanese<br>https://www.versalis.eni.com/irj/go/km/docs/versalis/Contenuti%20Versalis/IT/Documenti/La%20nostra%20offerta/Licensing/Elastomeri/SBS.pdf |

# APPENDIX A. STAKEHOLDER CONSULTATION

Stakeholders that have been explicitly invited to provide comments on the Technical Guidance document:

- EPD Australasia
  - Technical Advisory Group
- The International EPD Programme
  - PCR moderator for Asphalt Mixtures (IEPDS 2019a)
- Australian Flexible Pavement Association (AfPA) members, including:
  - Alex Fraser
  - Boral
  - Colas
  - Downer
  - Fulton Hogan
  - Kypreos Group
  - SAMI Bitumen Technologies
- Infrastructure Sustainability Council of Australia (ISCA)
- Road Authorities:
  - NSW: Transport for NSW
  - South Australia: Department for Infrastructure and Transport (DIT)
  - Queensland: Transport and Main Roads (TMR)
  - Tasmania: Department of State Growth, Transport Services
  - Victoria: VicRoads
  - Western Australia: Main Roads WA
- Australian Road Research Board (ARRB)
- Austroads
- Australian Life Cycle Assessment Society (ALCAS)
- Life Cycle Association of New Zealand (LCANZ)
- National Asphalt Pavement Association (NAPA - US)
- European Asphalt Pavement Association (EAPA)

A range of other stakeholders have been informed of the publication of the draft document for public consultation.

# APPENDIX B. REFERENCE SERVICE LIFE ($RSL_{ASPHALT}$)

Table 12 shows the Durability of Surface Layers expressed in years of service life for major roads / motorways / heavily trafficked roads.

Table 13 shows the Durability of Surface Layers expressed in years of service life for secondary roads.

### Table 12. Durability of surface layers on major roads

| Major roads / motorways / heavily trafficked | | | |
|---|---|---|---|
| Type | 15% Lowel level | European average | 85% Higher level |
| AC | 8 | 14 | 18 |
| AC-TL 30-40 mm | 8 | 12 | 18 |
| AC-VTL 25-30 mm | 8 | 10 | 12 |
| UTLAC | 8 | 10 | 12 |
| PA | 8 | 10 | 14 |
| 2L-PA [1]) | 9 | 11 | 12 |
| SMA | 14 | 20 | 25 |
| HRA | 17 | 21 | 25 |
| Mastic-A | 18 | 21 | 24 |

Soft-A is not used here
[1]) Only based on Dutch results

### Table 13. Durability of surface layers on secondary roads

| Secondary roads | | | |
|---|---|---|---|
| Type | 15% Lowel level | European average | 85% Higher level |
| AC | 10 | 15 | 20 |
| AC-TL | 10 | 15 | 20 |
| AC-VTL | 10 | 12 | 14 |
| 2L-PA [1]) | 10 | 11 | 12 |
| SMA | 16 | 20 | 25 |
| HRA | 20 | 25 | 30 |
| Mastic-A | 18 | 24 | 30 |
| Soft-A | 8 | 12 | 25 |

PA and UTLAC are not used here
[1]) Only based on Dutch results

# APPENDIX C. LIFE CYCLE INVENTORY DATA

This appendix contains life cycle inventory data for any relevant unit process not included in AusLCI or the AusLCI shadow database, or which has been adjusted. This allows LCA practitioners to duplicate LCI data and minimise variances resulting from differences in choice of generic data sources.

LCI data are provided for the following unit processes:

- Recycled Asphalt Product
- Granulated Blast Furnace Slag (GBFS) sand and aggregates
- Calcined bauxite
- EAF slag
- Styrene-Butadiene-Styrene copolymer (SBS)
- Recycled mineral oil
- Crushed glass sand
- Ground tyre rubber
- Recycled plastics
- End-of-life processes (Module C)

## RECYCLED ASPHALT PRODUCT

Reclaimed Asphalt Pavement is often transported directly from the road end-of-life site to an asphalt plant. Energy use for processing Reclaimed Asphalt Pavement into Recycled Asphalt Product that is used in the production of new asphalt is therefore typically included in the asphalt plant's energy use. However, some manufacturers use RAP that is processed by contractors off-site. One AfPA member has provided the following data obtained from two RAP processing facilities. The facilities use a power screen with a front-end loader to feed material and then move processed material to a nearby stockpile. No electricity or water is being used for the RAP reprocessing at these two locations.

**Table 14. LCI data for Recycled Asphalt Product**

| Category | Flow | Unit | Amount | Comment |
|---|---|---|---|---|
| **Output: Product** | Recycled Asphalt Product (RAP), at processing plant/AU U | kg | 1,000 | |
| | **Inputs** | | | |
| **Input: Materials /Energy** | Diesel, burned in building machine/GLO U/AusSD U | L | 0.267 | Crushing, screening and front-end loader |

## GRANULATED BLAST FURNACE SLAG (GBFS) SAND AND AGGREGATES

Granulated Blast Furnace Slag (GBFS) sand and aggregates are produced from blast furnace slag (BFS) by crushing, screening and processing to remove all single size aggregates and metals[12]. The graded material is sold as a sand or aggregate, depending on the particle size. As LCI data for GBFS sand and aggregates are not readily available in AusLCI or the AusLCI shadow database, start2see has developed a proxy Australian LCI for GBFS sand and aggregates based on AusLCI data for BFS and electricity for processing, see Table 15.

**Table 15. LCI data for Granulated Blast Furnace Slag sand and aggregates**

| Category | Flow | Unit | Amount | Comments |
|---|---|---|---|---|
| **Output: Product** | Granulated Blast Furnace Slag (GBFS) sand and aggregates/AU U | kg | 1 | |
| | | **Inputs** | | |
| **Input: Materials /Fuels** | blast furnace slag allocation, at steel plant/AU U | kg | 1 | |
| **Input: Materials /Fuels** | electricity, low voltage, Australian/AU U | kWh | 0.030 | Energy for crushing and screening. Based on slag mill manufacturer data[13] |

## CALCINED BAUXITE

Calcined Bauxite is produced by sintering high-alumina bauxite in rotary, round or shaft kilns at high temperatures[14]. As LCI data for calcined bauxite are not readily available in AusLCI or the AusLCI shadow database, start2see has developed a proxy Australian LCI for calcined bauxite based on ecoinvent data for calcined clay, see Table 16.

[12] http://www.asms.com.au/steel-slag-asphalt-sand

[13] https://www.alibaba.com/product-detail/Ground-granulated-blast-furnace-slag-vertical_60778813844.html

[14] https://alchemymineral.com/calcined-bauxite

### Table 16. LCI data for calcined bauxite

| Category | Flow | Unit | Amount | Comments |
|---|---|---|---|---|
| **Output: Product** | Calcined bauxite, at plant/AU U | kg | 1 | |
| | | **Inputs** | | |
| **Input: Materials /Fuels** | Bauxite, at mine/GLO U/AusSD U | kg | 1 | Quantity refers to dry bauxite mass (11% moisture) |
| **Input: Materials /Fuels** | Petroleum coke, at refinery/RER U/AusSD U | kg | 0.063 | |
| **Input: Materials /Fuels** | electricity, low voltage, Australian/AU U | kWh | 0.025 | |
| | | **Outputs** | | |
| **Output: Emissions to air** | Carbon dioxide, fossil | kg | 0.20 | |
| **Output: Emissions to air** | Dinitrogen monoxide | kg | 1.23E-6 | |
| **Output: Emissions to air** | Methane, fossil | kg | 6.15E-6 | |
| **Output: Emissions to air** | Water | kg | 0.11 | Evaporated water content in bauxite |

## EAF SLAG

EAF slag is a by-product from electric arc furnace (EAF) steelmaking processes. As LCI data for EAF slag are not readily available in AusLCI or the AusLCI shadow database, start2see has developed a proxy Australian LCI for EAF slag based on AusLCI data for blast furnace slag, see Table 17.

### Table 17. LCI data for EAF slag

| Category | Flow | Unit | Amount | Comments |
|---|---|---|---|---|
| **Output: Product** | electric arc furnace slag allocation, at steel plant/AU U | kg | 1 | |
| | | **Inputs** | | |
| **Input: Materials /Fuels** | Steel, electric, un- and low-alloyed, at plant/RER U/AusSD U | kg | 0.01272 | Mass balance is incorrect as this represents the share of EAF steel production allocated to the slag. |

## SBS

Polymer modified bitumen is widely used for both road and industrial applications. The range of polymer types and the range of polymer contents used in the bitumen vary depending on the technical requirements of the application. One of the most common polymer types used is styrene butadiene styrene (SBS) in its granular form.

An internal industry review of polymer modified products within Europe determined that a typical SBS polymer content is around 3.5% m/m in the final product (Eurobitume 2012).

As LCI data for SBS production are not readily available in AusLCI or the AusLCI shadow database, start2see has developed a proxy LCI for SBS based on proprietary process technology from Eni-Versalis for production of Styrene-Butadiene-Styrene block copolymers (Versalis). Care should be taken when using the proxy LCI, as only high-level data are described in the source document. Furthermore, the amount of butadiene and styrene copolymers can vary from SBS product to SBS product.

### Table 18. LCI data for SBS

| Category | Flow | Unit | Amount | Comment |
|---|---|---|---|---|
| **Output: Product** | Styrene-Butadiene-Styrene copolymer, SBS, at plant/AU U | kg | 1 | |
| | | **Inputs** | | |
| **Input: Materials /Energy** | Polybutadiene, at plant/RER U/AusSD U | kg | 0.7 | Estimate for butadiene content[15] |
| **Input: Materials /Energy** | Polystyrene, general purpose, GPPS, at plant/RER U/AusSD U | kg | 0.3 | Estimate for styrene content[15] |
| **Input: Materials /Energy** | Paraffin, at plant/RER U/AusSD U | kg | 0.01 | Estimate for paraffinic oil extensor |
| **Input: Materials /Energy** | Electricity, high voltage, at grid/US U/AusSD U | kWh | 0.5 | No production of SBS in Australia. Production assumed to be located in the USA. |
| **Input: Materials /Energy** | Steam, for chemical processes, at plant/RER U/AusSD U | kg | 5.5 | |
| **Input: Materials /Energy** | Water, cooling | $m^3$ | 0.2 | |
| | | **Outputs** | | |
| **Output: Emissions to air** | Cyclopentane | kg | 0.012 | Worst case: assumes solvents are emitted to air |

[15] Proxy composition based on Sigma-Aldrich product 182877 (CAS Number 9003-55-8)

## REGENERATED MINERAL OIL

As LCI data for regenerated waste oil are not readily available in AusLCI or the AusLCI shadow database, start2see has developed an Australian LCI for re-generated waste oil based on a study by Abdalla & Fehrenbach (Abdalla 2017).

According to (Abdalla 2017), included processes cover:

- all processes on the refinery site
- transport from the waste producer to the regeneration plant
- all external processes due to regeneration (e.g. fuel production or electrical power supply, crude oil drilling and production, digging and mining).
- downstream processes like waste disposal
- by-products of the regeneration process, e.g. surplus of process energy.

The report covers four different waste oil refining technologies. The LCI below represents an unweighted average across these four technologies. It should be noted that the data in Abdalla & Fehrenbach require an unusual level of interpretation, and the LCI should be considered a proxy for re-refined waste oil.

Table 19 contains the description of flows of materials and energy (life cycle inventory) associated with the throughput of 1 tonne of waste oil in a refinery (generating nearly 850 kg fuel oil).

### Table 19. LCI data for re-generated waste oil

| Category | Flow | Unit | Amount | Comments |
|---|---|---|---|---|
| **Output: Product** | Re-refined waste oil, fuel oil (light fuel oil quality), at refinery/RER U/AusSD U | kg | 849.1 | Co-product allocation unknown. Presume 100% |
| **Output: Product** | Re-refined waste oil, gas oil, at refinery/RER U/AusSD U | kg | 20 | Co-product allocation unknown. Presume 0% |
| **Output: Product** | Re-refined waste oil, gases, at refinery/RER U/AusSD U | kg | 4.3 | Co-product allocation unknown. Presume 0% |
| **Output: Product** | Re-refined waste oil, light ends, at refinery/RER U/AusSD U | kg | 18.3 | Co-product allocation unknown. Presume 0% |
| | | **Inputs** | | |
| **Input: From technosphere** | Oil, from technosphere | kg | 1000 | Waste oil |
| **Input: Materials /Energy** | Bentonite, at mine/DE U/AusSD U | kg | 18 | |
| **Input: Materials /Energy** | Electricity, medium voltage, production UCTE, at grid/UCTE U/AusSD/Link U | MJ | 54.05 | |

| Category | Flow | Unit | Amount | Comments |
|---|---|---|---|---|
| **Input: Materials /Energy** | Refinery gas, burned in furnace/MJ/RER U/AusSD U | MJ | 838.35 | |
| **Input: Transport** | Transport, lorry >16t, fleet average/RER U/AusSD/Link U | tkm | 100 | Transport of waste oil to refinery |
| **Input: Transport** | Transport, freight, rail/RER U/AusSD/Link U | tkm | 600 | Transport of waste oil to refinery |

## CRUSHED GLASS SAND

The LCI data for Australian "crushed glass sand" are based on a glass cullet process in the ecoinvent v3.4 database: "Glass cullet, sorted {RoW}| treatment of waste glass from unsorted public collection, sorting | Cut-off, U". Key inputs to the process need to be changed (as per Table 20) in order to make the process more representative for Australia.

**Important note:** Other inputs and outputs (not mentioned in the table hereafter) remain unchanged from the ecoinvent v3.4 process and have to be included in the LCI.[16]

**Table 20. Partial LCI data for crushed glass sand**

| Category | Updated flow | Unit | Amount | Original name |
|---|---|---|---|---|
| **Output: Product** | Glass cullet, sorted {AU}\| treatment of waste glass from unsorted public collection, sorting \| Cut-off, U | kg | 1 | Glass cullet, sorted {RoW}\| treatment of waste glass from unsorted public collection, sorting \| Cut-off, U |
| | | **Inputs** | | |
| **Input: Materials /Fuels** | electricity, low voltage, Australian/AU U | kWh | 0.00375 | Electricity, medium voltage {AU}\| market for \| Cut-off, U<br>Electricity, medium voltage {NZ}\| market for electricity, medium voltage \| Cut-off, U<br>Electricity, medium voltage {RAF}\| market group for \| Cut-off, U<br>Electricity, medium voltage {RAS}\| market group for \| Cut-off, U<br>Electricity, medium voltage {RLA}\| market group for \| Cut-off, U |

[16] To protect ecoinvent's intellectual property, only the changes to the process are listed in this document.

| Category | Updated flow | Unit | Amount | Original name |
|---|---|---|---|---|
| | | | | Electricity, medium voltage {RNA}\| market group for \| Cut-off, U<br>Electricity, medium voltage {RoW}\| market for \| Cut-off, U<br>Electricity, medium voltage {RU}\| market for \| Cut-off, U |

## GROUND TYRE RUBBER / CRUMB RUBBER

Finely ground tyre rubber (crumb rubber) can be used as a polymer addition to bitumen. As LCI data for ground tyre rubber are not readily available in AusLCI or the AusLCI shadow database, start2see has developed an Australian LCI for ground tyre rubber based on a study by Corti & Lombardi (Corti 2004). The process described in Table 21 includes grinding, crushing and mechanical pulverization of waste tyres.

The co-product allocation can have a significant effect on the impacts for the two types of crumb rubber that are produced. Finer crumb rubber has a higher value than coarser material. This is reflected in the presumed economic allocation factors.

### Table 21. LCI data for rubber crumb

| Category | Flow | Unit | Amount | Comments |
|---|---|---|---|---|
| **Output: Product** | Rubber from waste tyres, fine pulverised (<0.7 mm)/AU U | kg | 630 | Crumb rubber<br>Co-product allocation estimated at 66% (~$650/t)* |
| **Output: Product** | Rubber from waste tyres, pulverised (<2 mm)/AU U | kg | 310 | Ground tyre rubber<br>Co-product allocation estimated at 28% (~$550/t)* |
| **Output: Product** | Textile fibres from waste tyres/AU U | kg | 60.0 | Co-product allocation estimated at 0% (~$0/t)* |
| **Output: Product** | Iron scrap from waste tyres/AU U | kg | 380.3 | Co-product allocation estimated at 6% (~$100/t)* |
| | | **Inputs** | | |
| **Input: Materials /Energy** | Tyres | kg | 1,380.3 | |
| **Input: Materials /Energy** | electricity, low voltage, Australian/AU U | MJ | 1,512 | |
| **Input: Materials /Energy** | tap water, at user, Australia/AU U | kg | 207 | |
| **Input: Materials /Energy** | Steel, converter, unalloyed, at plant/RER U/AusSD U | kg | 0.608 | |

| Category | Flow | Unit | Amount | Comments |
|---|---|---|---|---|
| **Input: Materials /Energy** | Lubricating oil, at plant/RER U/AusSD U | kg | 0.015 | |
| | **Outputs** | | | |
| **Output: Emissions to air** | Particulates, < 2.5 um | kg | 0.264 | |
| **Output: Waste water** | Treatment, sewage, to wastewater treatment, class 2/CH U/AusSD U | kg | 207 | |

** Indicative values of co-products have been provided by the Australian Tyre Recyclers Association, November 2018.*

## RECYCLED PLASTICS

Various types of recycled plastic polymers can be used in asphalt products, either mixed in with bitumen to create a modified binder, or the plastics can be added in the asphalt plant. Post-industrial and post-consumer recycled plastics are free from previous environmental burden at the point where they have reached the end-of-waste state, which is at the receiving gate of a plastics recycling plant. Any processing that occurs after that point, such as sorting, washing, and pelletising, is attributed to the secondary material.

## MODULE C: END-OF-LIFE PROCESSES

In module C1, the asphalt is removed from the road through a milling process. Energy use for milling pavement into Reclaimed Asphalt Pavement material is provided in Table 22. The Reclaimed Asphalt Pavement is then loaded into a truck for transport to an intermediate processing facility or asphalt plant for recycling, or to a landfill site for final disposal. The default inventory process and transport distance have been provided in Table 9.

### Table 22. LCI data for milling of asphalt

| Category | Flow | Unit | Amount | Comment |
|---|---|---|---|---|
| **Output: Product** | Reclaimed Asphalt Pavement, at road demolition site/AU U | kg | 1,000 | |
| | **Inputs** | | | |
| **Input: Materials /Energy** | Diesel, burned in building machine/GLO U/AusSD U | L | 0.38 | Milling |
| | tap water, at user, Australia/AU U | kg | 5.4 | Milling |
| | Diesel, burned in building machine/GLO U/AusSD U | L | 0.13 | Screening and front-end loader |

# APPENDIX D. EMISSIONS TO AIR

The default emissions to air for asphalt production are based on data from the United States Environmental Protection Agency (US EPA 2004).

## Emissions at an asphalt plant

Source: United States Environmental Protection Agency (US EPA 2004)

As with most facilities in the mineral products industry, batch mix Hot Mix Asphalt (HMA) plants have two major categories of emissions: ducted sources (those vented to the atmosphere through some type of stack, vent, or pipe), and fugitive sources (those not confined to ducts and vents but emitted directly from the source to the ambient air). Ducted emissions are usually collected and transported by an industrial ventilation system having one or more fans or air movers, eventually to be emitted to the atmosphere through some type of stack. Fugitive emissions result from process and open sources and consist of a combination of gaseous pollutants and PM.

The most significant ducted source of emissions of most pollutants from batch mix HMA plants is the rotary drum dryer. The dryer emissions consist of water (as steam evaporated from the aggregate); PM; products of combustion (carbon dioxide ($CO_2$), nitrogen oxides ($NO_x$), and sulfur oxides ($SO_x$)); carbon monoxide (CO); and small amounts of organic compounds of various species (including volatile organic compounds (VOC), methane ($CH_4$) and hazardous air pollutants (HAP)). The CO and organic compound emissions result from incomplete combustion of the fuel. It is estimated that between 70 and 90 percent of the energy used at HMA plants is from the combustion of natural gas.

Other potential process sources include the hot-side conveying, classifying, and mixing equipment, which are vented either to the primary dust collector (along with the dryer gas) or to a separate dust collection system. The vents and enclosures that collect emissions from these sources are commonly called “fugitive air” or “scavenger” systems.

The emissions to air are partly due to the plant’s fuel combustion. The emissions to air for an asphalt mixture shall be determined based on:

- A plant’s site-level National Pollutant Inventory (NPI) data as reported on the NPI website (http://www.npi.gov.au/). The NPI emissions can be divided by the total production (in tonnes) at a plant to produce the emissions intensity (kg/tonne asphalt), as long as the reporting periods align.
- For substances that are not reported under NPI, calculate emissions based on the drying/heating fuel use (Table 23).
- For substances that are not reported under NPI, and are not listed in Table 23, use default factors (kg/tonne asphalt) that are independent of the drying/heating fuel usage (see Table 24)

**Table 23. Default emissions to air, kg/MJ of fuel combusted**

| Emission to air | Unit | Natural gas* | LPG** | Diesel*** | HFO**** |
|---|---|---|---|---|---|
| **Acetaldehyde** | kg/MJ | 1.92E-09 | 2.69E-09 | 1.31E-09 | 1.52E-07 |
| **Benzo[a]pyrene** | kg/MJ | 2.41E-14 | 1.06E-11 | 6.87E-13 | 2.87E-11 |
| **Benzene** | kg/MJ | 3.09E-10 | 5.41E-07 | 1.57E-07 | 1.62E-07 |
| **Butane** | kg/MJ | 1.56E-09 | 5.37E-06 | 1.51E-06 | 1.57E-06 |
| **Methane** | kg/MJ | 2.95E-05 | 2.94E-06 | 1.95E-06 | 2.73E-06 |
| **Carbon monoxide** | kg/MJ | 4.74E-05 | 1.30E-05 | 2.35E-05 | 1.61E-05 |
| **Carbon dioxide** | kg/MJ | 6.03E-02 | 7.28E-02 | 8.13E-02 | 8.76E-02 |
| **Acetic acid** | kg/MJ | 7.75E-11 | 1.55E-07 | 8.78E-09 | 6.06E-07 |
| **Formaldehyde** | kg/MJ | 1.21E-08 | 1.09E-07 | 6.32E-09 | 4.58E-07 |
| **Mercury** | kg/MJ | 2.19E-10 | 5.69E-10 | 1.53E-09 | 4.30E-10 |
| **Dinitrogen monoxide** | kg/MJ | 2.13E-07 | 2.11E-07 | 7.97E-07 | 1.74E-06 |
| **Nitrogen oxides** | kg/MJ | 1.55E-04 | 6.48E-05 | 9.45E-05 | 1.37E-04 |
| **PAH** | kg/MJ | 3.57E-10 | 1.03E-08 | 5.29E-09 | 1.02E-09 |
| **Particulates, <2.5µm** | kg/MJ | 4.13E-06 | 2.58E-06 | 3.30E-06 | 3.75E-05 |
| **Pentane** | kg/MJ | 1.69E-09 | 2.88E-06 | 1.85E-06 | 1.93E-06 |
| **Propane** | kg/MJ | 1.57E-09 | 4.85E-06 | 1.52E-06 | 1.61E-06 |
| **Propionic acid** | kg/MJ | 3.42E-14 | 2.00E-08 | 8.77E-13 | 7.17E-13 |
| **Sulfur dioxide** | kg/MJ | 1.77E-07 | 3.29E-05 | 9.38E-05 | 4.91E-04 |
| **Dioxins** | kg/MJ | 2.53E-15 | 2.29E-16 | 1.15E-14 | 7.16E-16 |
| **Toluene** | kg/MJ | 3.18E-10 | 3.96E-07 | 2.15E-07 | 2.54E-07 |

* Emission in kg per MJ of natural gas use - from AusLCI (v1.36) process for Natural gas, burned in industrial furnace >100kW/RER U/AusSD/Link U

** Emission in kg per MJ of LPG combustion - from AusLCI (v1.36) process for liquefied petroleum gas, burned in industrial furnace >100kW/RER U/adapted/AU U

*** Emission in kg per MJ of diesel combustion - from AusLCI (v1.36) process for diesel, burned in industrial furnace >100kW/RER U/adapted/AU U

*** Emission in kg per MJ of HFO combustion - from AusLCI (v1.36) process for Heavy fuel oil, burned in industrial furnace 1MW, non-modulating/RER U/AusSD U

**Table 24. Default asphalt plant emissions to air, kg/tonne asphalt**

| Emission to air | Quantity | Unit | Source |
|---|---|---|---|
| **Acenaphthene** | 4.50E-07 | kg/tonne | US EPA 2004 reported values |
| **Arsenic** | 2.30E-07 | kg/tonne | |
| **Barium** | 7.50E-07 | kg/tonne | |
| **Benzaldehyde** | 6.50E-05 | kg/tonne | |
| **Benzene, ethyl-** | 1.10E-03 | kg/tonne | |
| **Beryllium** | 7.50E-08 | kg/tonne | |
| **Cadmium** | 3.05E-07 | kg/tonne | |
| **Chromium** | 2.85E-07 | kg/tonne | |
| **Chromium VI** | 2.40E-08 | kg/tonne | |
| **Copper** | 1.40E-06 | kg/tonne | |
| **Lead** | 4.45E-07 | kg/tonne | |
| **Manganese** | 3.45E-06 | kg/tonne | |
| **Nickel** | 1.50E-06 | kg/tonne | |
| **Particulates, < 10 µm** | 1.35E-02 | kg/tonne | |
| **Selenium** | 2.45E-07 | kg/tonne | |
| **Xylene** | 1.35E-03 | kg/tonne | |
| **Zinc** | 3.40E-06 | kg/tonne | |

## *UNITED STATES ENVIRONMENTAL PROTECTION AGENCY TABLES*

The US EPA 2004 tables on the following pages show the default emission factors that form the basis for calculating emission factors for asphalt production processes.

Relevant default emissions are indicated with an orange outline:

**Note:** To convert from lb/ton to kg/Mg, multiply by 0.5.

11.1-11 EMISSION FACTORS

Table 11.1-1. PARTICULATE MATTER EMISSION FACTORS FOR BATCH MIX HOT MIX ASPHALT PLANTS[a]

| | Filterable PM | | | | Condensable PM[b] | | | | Total PM | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Process | PM[c] | EMISSION FACTOR RATING | PM-10[d] | EMISSION FACTOR RATING | Inorganic | EMISSION FACTOR RATING | Organic | EMISSION FACTOR RATING | PM[e] | EMISSION FACTOR RATING | PM-10[f] | EMISSION FACTOR RATING |
| Dryer, hot screens, mixer[g] (SCC 3-05-002-45, -46, -47) | | | | | | | | | | | | |
| Uncontrolled | 32[h] | E | 4.5 | E | 0.013[j] | E | 0.0041[j] | E | 32 | E | 4.5 | E |
| Venturi or wet scrubber | 0.12[k] | C | ND | NA | 0.013[m] | B | 0.0041[n] | B | 0.14 | C | ND | NA |
| Fabric filter | 0.025[p] | A | 0.0098 | C | 0.013[m] | A | 0.0041[n] | A | 0.042 | B | 0.027 | C |

[a] Factors are lb/ton of product. SCC = Source Classification Code. ND = no data. NA = not applicable. To convert from lb/ton to kg/Mg, multiply by 0.5.
[b] Condensable PM is that PM collected using an EPA Method 202, Method 5 (analysis of "back-half" or impingers), or equivalent sampling train.
[c] Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.
[d] Particle size data from Reference 23 were used in conjunction with the filterable PM emission factors shown.
[e] Total PM is the sum of filterable PM, condensable inorganic PM, and condensable organic PM.
[f] Total PM-10 is the sum of filterable PM-10, condensable inorganic PM, and condensable organic PM.
[g] Batch mix dryer fired with natural gas, propane, fuel oil, waste oil, and coal. The data indicate that fuel type does not significantly effect PM emissions.
[h] Reference 5.
[j] Although no data are available for uncontrolled condensable PM, values are assumed to be equal to the controlled value measured.
[k] Reference 1, Table 4-19. Average of data from 16 facilities. Range: 0.047 to 0.40 lb/ton. Median: 0.049 lb/ton. Standard deviation: 0.11 lb/ton.
[m] Reference 1, Table 4-19. Average of data from 35 facilities. Range: 0.00073 to 0.12 lb/ton. Median: 0.0042 lb/ton. Standard deviation: 0.024 lb/ton.
[n] Reference 1, Table 4-19. Average of data from 24 facilities. Range: 0.000012 to 0.018 lb/ton. Median: 0.0026 lb/ton. Standard deviation: 0.0042 lb/ton.
[p] Reference 1, Table 4-19. Average of data from 89 facilities. Range: 0.0023 to 0.18 lb/ton. Median: 0.012 lb/ton. Standard deviation: 0.033 lb/ton.

** Fabric filter is standard technology on most Australian asphalt plants*

Table 11.1-2. SUMMARY OF PARTICLE SIZE DISTRIBUTION FOR BATCH MIX DRYERS, HOT SCREENS, AND MIXERS[a]

EMISSION FACTOR RATING: E

| Particle Size, µm[b] | Cumulative Mass Less Than or Equal to Stated Size (%)[c] | | Emission Factors, lb/ton | |
|---|---|---|---|---|
| | Uncontrolled[d] | Fabric Filter | Uncontrolled[d] | Fabric Filter |
| 1.0 | ND | 30[e] | ND | 0.0075[e] |
| 2.5 | 0.83 | 33[e] | 0.27 | 0.0083[e] |
| 5.0 | 3.5 | 36[e] | 1.1 | 0.0090[e] |
| 10.0 | 14 | 39[f] | 4.5 | 0.0098[f] |
| 15.0 | 23 | 47[e] | 7.4 | 0.012[e] |

[a] Emission factor units are lb/ton of HMA provided. Rounded to two significant figures. SCC 3-05-002-45, -46, -47. ND = no data available. To convert from lb/ton to kg/Mg, multiply by 0.5.
[b] Aerodynamic diameter.
[c] Applies only to the mass of filterable PM.
[d] References 23, Table 3-36. The emission factors are calculated using the particle size data from this reference in conjunction with the filterable PM emission factor shown in Table 11.1-1.
[e] References 23, Page J-61. The emission factors are calculated using the particle size data from this reference in conjunction with the filterable PM emission factor shown in Table 11.1-1.
[f] References 23-24. The emission factors are calculated using the particle size data from these references in conjunction with the filterable PM emission factor shown in Table 11.1-1.

Table 11.1-5. EMISSION FACTORS FOR CO, $CO_2$, $NO_x$, AND $SO_2$ FROM BATCH MIX HOT MIX ASPHALT PLANTS[a]

| Process | CO[b] | EMISSION FACTOR RATING | $CO_2$[c] | EMISSION FACTOR RATING | $NO_x$ | EMISSION FACTOR RATING | $SO_2$[c] | EMISSION FACTOR RATING |
|---|---|---|---|---|---|---|---|---|
| Natural gas-fired dryer, hot screens, and mixer (SCC 3-05-002-45) | 0.40 | C | 37[d] | A | 0.025[e] | D | 0.0046[f] | E |
| No. 2 fuel oil-fired dryer, hot screens, and mixer (SCC 3-05-002-46) | 0.40 | C | 37[d] | A | 0.12[g] | E | 0.088[h] | E |
| Waste oil-fired dryer, hot screens, and mixer (SCC 3-05-002-47) | 0.40 | C | 37[d] | A | 0.12[g] | E | 0.088[h] | E |
| Coal-fired dryer, hot screens, and mixer[j] (SCC 3-05-002-98) | ND | NA | 37[d] | A | ND | NA | 0.043[k] | E |

[a] Emission factor units are lb per ton of HMA produced. SCC = Source Classification Code. ND = no data available. NA = not applicable. To convert from lb/ton to kg/Mg, multiply by 0.5.

[b] References 24, 34, 46-47, 49, 161, 204, 215-217, 282, 370, 378, 381. The CO emission factors represent normal plant operations without scrutiny of the burner design, operation, and maintenance. Information is available that indicates that attention to burner design, periodic evaluation of burner operation, and appropriate maintenance can reduce CO emissions. Data for dryers firing natural gas, No. 2 fuel oil, and No. 6 fuel oil were combined to develop a single emission factor because the magnitude of emissions was similar for dryers fired with these fuels.

[c] Emissions of $CO_2$ and $SO_2$ can also be estimated based on fuel usage and the fuel combustion emission factors (for the appropriate fuel) presented in AP-42 Chapter 1. The $CO_2$ emission factors are an average of all available data, regardless of the dryer fuel (emissions were similar from dryers firing any of the various fuels). Based on data for drum mix facilities, 50 percent of the fuel-bound sulfur, up to a maximum (as $SO_2$) of 0.1 lb/ton of product, is expected to be retained in the product, with the remainder emitted as $SO_2$.

[d] Reference 1, Table 4-20. Average of data from 115 facilities. Range: 6.9 to 160 lb/ton. Median: 32 lb/ton. Standard deviation: 22 lb/ton.

[e] References 24, 34, 46-47.

[f] References 46-47.

[g] References 49, 226.

[h] References 49, 226, 228, 385.

[j] Dryer fired with coal and supplemental natural gas or fuel oil.

[k] Reference 126.

Table 11.1-6. EMISSION FACTORS FOR TOC, METHANE, AND VOC FROM BATCH MIX HOT MIX ASPHALT PLANTS[a]

| Process | TOC[b] | EMISSION FACTOR RATING | $CH_4$[c] | EMISSION FACTOR RATING | VOC[d] | EMISSION FACTOR RATING |
|---|---|---|---|---|---|---|
| Natural gas-fired dryer, hot screens, and mixer (SCC 3-05-002-45) | 0.015[e] | D | 0.0074 | D | 0.0082 | D |
| No. 2 fuel oil-fired dryer, hot screens, and mixer (SCC 3-05-002-46) | 0.015[e] | D | 0.0074 | D | 0.0082 | D |
| No. 6 fuel oil-fired dryer, hot screens, and mixer (SCC 3-05-002-47) | 0.043[f] | E | 0.0074 | D | 0.036 | E |

[a] Emission factor units are lb per ton of HMA produced. SCC = Source Classification Code. ND = no data available. NA = not applicable. To convert from lb/ton to kg/Mg, multiply by 0.5.
[b] TOC equals total hydrocarbons as propane, as measured with an EPA Method 25A or equivalent sampling train plus formaldehyde.
[c] References 24, 46-47, 49. Factor includes data from natural gas- and No. 6 fuel oil-fired dryers. Methane measured with an EPA Method 18 or equivalent sampling train.
[d] The VOC emission factors are equal to the TOC factors minus the methane emission factors; differences in values reported are due to rounding.
[e] References 24, 46-47, 155.
[f] Reference 49.

Table 11.1-9. EMISSION FACTORS FOR ORGANIC POLLUTANT EMISSIONS FROM BATCH MIX HOT MIX ASPHALT PLANTS[a]

| Process | Pollutant | | Emission Factor, lb/ton | Emission Factor Rating | Ref. Nos. |
|---|---|---|---|---|---|
| | CASRN | Name | | | |
| Natural gas- or No. 2 fuel oil-fired dryer, hot screens, and mixer with fabric filter (SCC 3-05-002-45,-46) | Non-PAH Hazardous Air Pollutants[b] | | | | |
| | 75-07-0 | Acetaldehyde | 0.00032 | E | 24,34 |
| | 71-43-2 | Benzene | 0.00028 | D | 24,34,46, 382 |
| | 100-41-4 | Ethylbenzene | 0.0022 | D | 24,46,47,49 |
| | 50-00-0 | Formaldehyde | 0.00074 | D | 24,34,46,47,49,226,382 |
| | 106-51-4 | Quinone | 0.00027 | E | 24 |
| | 108-88-3 | Toluene | 0.0010 | D | 24,34,46,47 |
| | 1330-20-7 | Xylene | 0.0027 | D | 24,46,47,49 |
| | | Total non-PAH HAPs | 0.0075 | | |

| | | | | | |
|---|---|---|---|---|---|
| | | PAH HAPs | | | |
| | 91-57-6 | 2-Methylnaphthalene[c] | 7.1x10$^{-5}$ | D | 24,47,49 |
| | 83-32-9 | Acenaphthene[c] | 9.0x10$^{-7}$ | D | 34,46,226 |
| | 208-96-8 | Acenaphthylene[c] | 5.8x10$^{-7}$ | D | 34,46,226 |
| | 120-12-7 | Anthracene[c] | 2.1x10$^{-7}$ | D | 34,46,226 |
| | 56-55-3 | Benzo(a)anthracene[c] | 4.6x10$^{-9}$ | E | 46,226 |
| | 50-32-8 | Benzo(a)pyrene[c] | 3.1x10$^{-10}$ | E | 226 |
| | 205-99-2 | Benzo(b)fluoranthene[c] | 9.4x10$^{-9}$ | D | 34,46,226 |
| | 191-24-2 | Benzo(g,h,i)perylene[c] | 5.0x10$^{-10}$ | E | 226 |
| | 207-08-9 | Benzo(k)fluoranthene[c] | 1.3x10$^{-8}$ | E | 34,226 |
| | 218-01-9 | Chrysene[c] | 3.8x10$^{-9}$ | E | 46,226 |
| | 53-70-3 | Dibenz(a,h)anthracene[c] | 9.5x10$^{-11}$ | E | 226 |
| | 206-44-0 | Fluoranthene[c] | 1.6x10$^{-7}$ | D | 34,46,47,226 |
| | 86-73-7 | Fluorene[c] | 1.6x10$^{-6}$ | D | 34,46,47,226 |
| | 193-39-5 | Indeno(1,2,3-cd)pyrene[c] | 3.0x10$^{-10}$ | E | 226 |
| | 91-20-3 | Naphthalene | 3.6x10$^{-5}$ | D | 34,46,47,49,226 |
| | 85-01-8 | Phenanthrene[c] | 2.6x10$^{-6}$ | D | 34,46,47,226 |
| | 129-00-0 | Pyrene[c] | 6.2x10$^{-8}$ | D | 34,46,226 |
| | | Total PAH HAPs | 0.00011 | | |
| | | Total HAPs | 0.0076 | | |
| | | Non-HAP organic compounds | | | |
| | 100-52-7 | Benzaldehyde | 0.00013 | E | 24 |
| | 78-84-2 | Butyraldehyde/ isobutyraldehyde | 3.0x10$^{-5}$ | E | 24 |
| | 4170-30-3 | Crotonaldehyde | 2.9x10$^{-5}$ | E | 24 |
| | 66-25-1 | Hexanal | 2.4x10$^{-5}$ | E | 24 |
| | | Total non-HAPs | 0.00019 | | |

Table 11.1-11. EMISSION FACTORS FOR METAL EMISSIONS FROM BATCH MIX HOT MIX ASPHALT PLANTS[a]

| Process | Pollutant | Emission Factor, lb/ton | Emission Factor Rating | Reference Numbers |
|---|---|---|---|---|
| Dryer, hot screens, and mixer[b] (SCC 3-05-002-45,-46,-47) | Arsenic[c] | 4.6x10$^{-7}$ | D | 34, 40, 226 |
| | Barium | 1.5x10$^{-6}$ | E | 24 |
| | Beryllium[c] | 1.5x10$^{-7}$ | E | 34, 226 |
| | Cadmium[c] | 6.1x10$^{-7}$ | D | 24, 34, 226 |
| | Chromium[c] | 5.7x10$^{-7}$ | D | 24, 34, 226 |
| | Hexavalent chromium[c] | 4.8x10$^{-8}$ | E | 34, 226 |
| | Copper | 2.8x10$^{-6}$ | D | 24, 34, 226 |
| | Lead[c] | 8.9x10$^{-7}$ | D | 24, 34, 226 |
| | Manganese[c] | 6.9x10$^{-6}$ | D | 24, 34, 226 |
| | Mercury[c] | 4.1x10$^{-7}$ | E | 34, 226 |
| | Nickel[c] | 3.0x10$^{-6}$ | D | 24, 34, 226 |
| | Selenium[c] | 4.9x10$^{-7}$ | E | 34, 226 |
| | Zinc | 6.8x10$^{-6}$ | D | 24, 34, 226 |

[a] Emission factor units are lb/ton of HMA produced. Emissions controlled by a fabric filter. SCC = Source Classification Code. To convert from lb/ton to kg/Mg, multiply by 0.5.

[b] Natural gas-, propane-, No. 2 fuel oil-, or waste oil-/drain oil-/No. 6 fuel oil-fired dryer. For waste oil-/drain oil-/No. 6 fuel oil-fired dryer, use a lead emission factor of 1.0x10$^{-5}$ lb/ton (References 177 and 321, Emission factor rating: E) in lieu of the emission factor shown.

[c] Arsenic, beryllium, cadmium, chromium, hexavalent chromium, lead, manganese, mercury, nickel, and selenium are HAPs as defined in the 1990 CAAA.

# APPENDIX E. REUSE, RECYCLING, RECOVERY ALLOCATION

Guidance to allocation of reuse, recycling and recovery processes is provided in the General Programme Instructions (GPI v4; section A.5.2 ALLOCATION OF WASTE) (IEPDS 2021).

Key aspects of the GPI, including sections of GPI v3.1 (IEPDS 2019b), are included in this appendix to assist LCA practitioners in determining the end-of-waste boundary for waste/secondary materials.

For waste being recycled or reused, the environmental impact of processes until the end-of-waste state shall be attributed to the product system generating the waste. Processes after the end-of-waste state, if any, shall be attributed to the product system using the recycled/reused material flow (recycled materials are thereafter considered secondary materials). Internal scraps that are recycled within a manufacturing process shall not be considered as an input of secondary material.

The methodological choices have been set according to the polluter pays principle (PPP). This principle was adopted by the OECD in 1972 as an economic principle for allocating the costs of pollution control:

> *"[T]he principle to be used for allocating costs of pollution prevention and control measures to encourage rational use of scarce environmental resources and to avoid distortions in international trade and investment…this principle means that the polluter should bear the expenses of carrying out the above-mentioned measures decided by public authorities to ensure that the environment is in an acceptable state. In other words, the cost of these measures should be reflected in the cost of goods and services which cause pollution in production and/or consumption".*

The following figures from (IEPDS 2019b) provide further guidance:

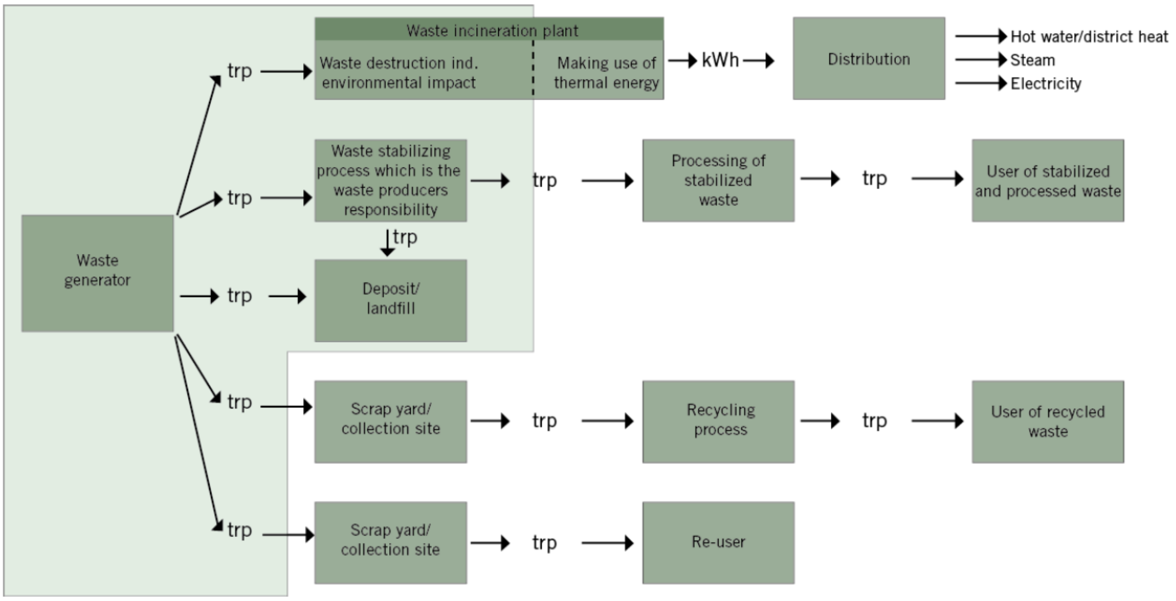


*Figure 4.* The "PP allocation method" illustrated for the various types of waste treatment options included in different process stages. The area in green indicates the environmental impact that shall be carried by the waste generator

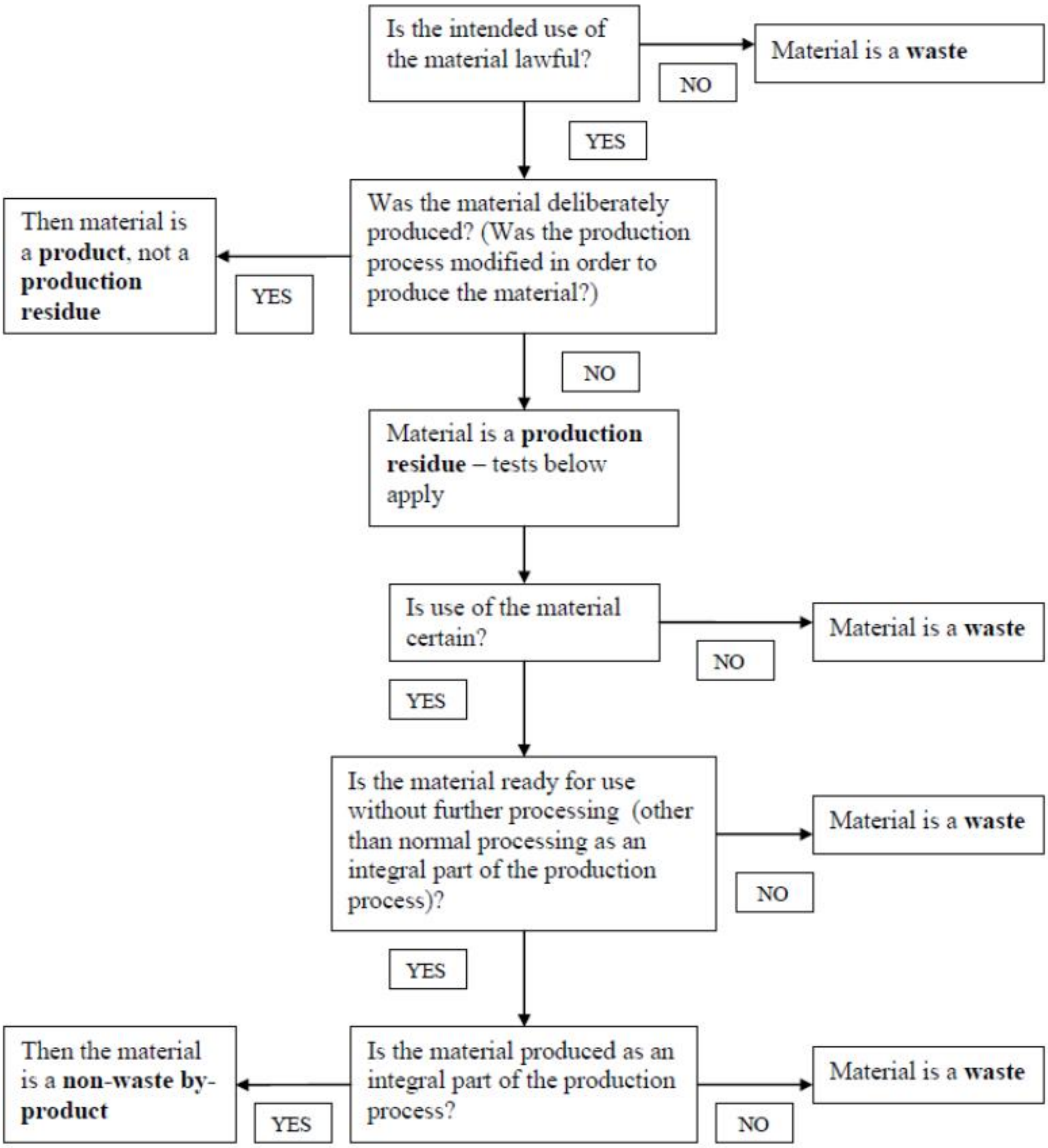


*Figure 5.* Decision tree for definition of waste and by-product. Adopted from Commission of the European Communities, 2007. Communication from the Commission to the Council and the European Parliament on the Interpretative Communication on Waste and By-products.