Humes

Strength. Performance. Passion.

AUSTRALASIA EPD®
ENVIRONMENTAL PRODUCT DECLARATION

Environmental Product Declaration

Reinforced Concrete Pipe (RCP)
In accordance with ISO 14025 and EN 15804
EPD registration no. S-P-00998 | Version 1.0
Issued 2017-03-23 | Valid until 2022-03-23
Geographical scope: Australia

A Division of Holcim Australia

Contents

Programme information and verification

An Environmental Product Declaration (EPD) is a standardised way of quantifying the potential environmental impacts of a product or system. EPDs are produced according to a consistent set of rules – Product Category Rules (PCR) – that define the requirements within a given product category. These rules are a key part of ISO 14025 as they enable transparency and comparability between EPDs. This EPD provides environmental indicators for Humes steel-reinforced concrete drainage pipes across all pipe production factories in Australia. This EPD is a “cradle-to-gate with options” declaration covering production, distribution, installation, use and end-of-life.

This EPD is verified to be compliant with EN 15804. EPDs of construction products may not be comparable if they do not comply with EN15804. EPDs within the same product category but from different programs or utilising different PCR documents may not be comparable.

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CEN standard EN 15804 served as the core PCR

PCR	PCR 2012:01 Construction Products and Construction Services, Version 2.1, 2017-01-04
PCR review was conducted by	The Technical Committee of the International EPD® System. Chair: Massimo Marino. Contact via info@environdec.com
Independent verification of the declaration and data, according to ISO 14025	☐ EPD process certification (Internal) ☒ EPD verification (External)
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Accredited or approved by	The Australasian EPD® Programme


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About us

Humes Concrete Products (Humes) is a division of Holcim (Australia) Pty Ltd, one of the world's leading suppliers of cement and aggregates. Humes is the largest civil precast concrete manufacturer in Australia, employing over 600 people.

We have a number of factories around Australia however only 10 factories produce spun or dry cast reinforced concrete pipes.

Humes has a long history of engineering precast and prestressed concrete solutions and, after 100 years of manufacture, our product range has never been more diverse, more competitive, or more in-tune with our clients' needs than it is today.

We offer a range of solutions for bridges and platforms, road and rail infrastructure, tunnels and shafts, retaining walls, pipeline systems, water treatment, reuse and detention, and traffic management. We can customise our solutions to ensure they create maximum value for your project, accommodating your site conditions, design requirements and construction factors.

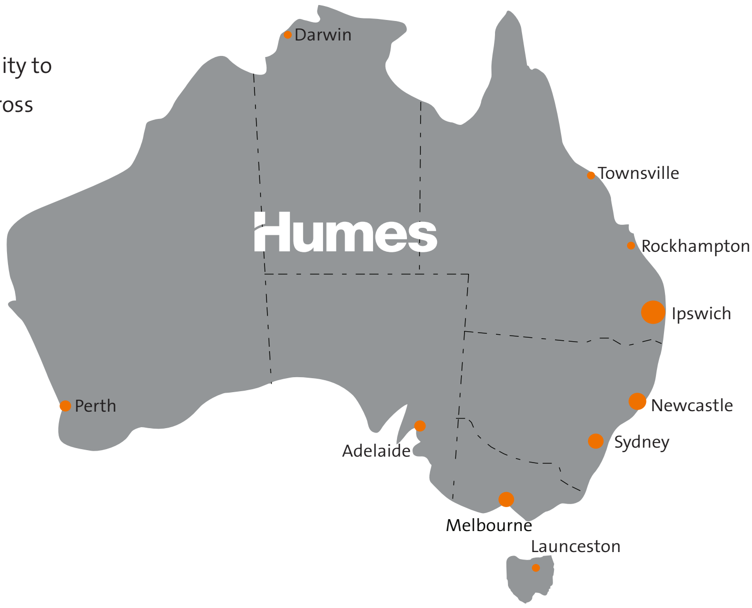
The quality and reliability of Humes' products and services are the foundation of our success. Our ability to deliver to client specifications on major projects across Australia has established Humes as a valuable and reliable partner.

Mission

Humes aims to be the most respected and successfully operated company in our industry, creating value for all of our stakeholders.

As a subsidiary of one of the world's largest cement companies, LafargeHolcim, our vision is to perfect progress as we provide the foundations for society's future. Achieving our mission involves a commitment to the following:

- innovative solutions for our customers
- employees with a passion for performance
- an open and collaborative corporate culture
- a forward-looking organisation
- a culture that promotes sustainable development
- long-term financial performance.



Product description

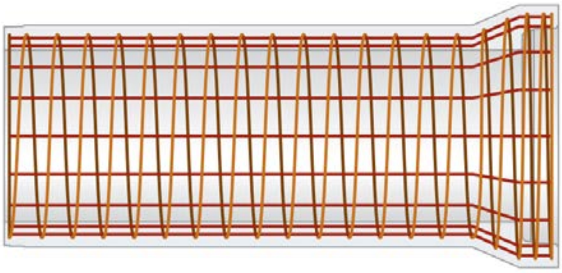
As the leading manufacturer of reinforced concrete pipes (RCPs) and associated precast products in Australia, Humes pipes are available in a wide range of diameters, lengths and with varying strengths.

The product's intended use is for non-pressure stormwater drainage pipelines. In some instances this product will also be suitable for sewerage and pressure pipe applications. Suitability in these conditions is project specific. Further details on product use and design for different applications can be found in Humes' *Concrete pipe reference manual* (see www.humes.com.au).

RCPs are made from coarse and fine aggregates, cement, water, and hard-drawn deformed steel reinforcement. Other material used can include supplementary cementitious materials (SCMs) and chemical admixtures which have varied effects on the concrete depending on the admixture used.

RCPs are manufactured with two basic joint types - Flush Joint (FJ) and Rubber Ring Joint (RRJ). FJ pipes provide an interlocking joint which allows for a small degree of flexibility in the pipeline alignment. RRJ pipes, either belled-socket or in-wall joint depending on the

Figure 2 – Schematic of steel cage in a RRJ concrete pipe



diameter of the pipe and its application, are designed to accommodate change in pipeline alignment and settlement in a pipeline whilst still maintaining a watertight joint.

The majority of Humes' pipe is manufactured in 2.44 metre effective lengths in the DN300 to DN2100 diameter range. Effective length is used to define an RCP's length as the physical length of the pipe includes the overlap of the joint. The standard effective lengths vary slightly at vertical cast factories due to manufacturing limitations. Other lengths and diameters of pipe can be manufactured to suit project requirements. RCPs are available in standard-strength (class 2-4) and super-strength* (class 6-10).

Table 1 – Summary of the reinforced concrete drainage pipe product range

Factory	Rockhampton and Townsville QLD, Sydney NSW, Melbourne VIC, Adelaide SA, Perth WA, Launceston TAS, Darwin NT	Newcastle NSW	Ipswich QLD
Technology	Spun	Vertical cast	
Nominal diameter (mm)	DN300 - DN2100	DN375 - DN1800	DN300 - DN2100
Joint type	RRJ and FJ	RRJ	RRJ and FJ
Effective length	2.44 m	2.34 m	2.34 - 2.44 m

* Super-strength classes are not in the scope of this EPD.

The product as supplied is non-hazardous. The products included in this EPD do not contain any substances of very high concern as defined by European REACH regulation* in concentrations >0.1% (m/m). Dust from this product is classified as Hazardous according to the Approved Criteria for Classifying Hazardous Substances 3rd Edition (NOHSC 2004). Precast concrete products and pipes are classified as non-dangerous goods according to the Australian Code for the Transport of Dangerous Goods by Road and Rail. When concrete products are cut, sawn, abraded or crushed, dust is created which contains crystalline silica, some of which may be respirable (particles small enough to go into the deep parts of the lung when breathed in), and which is hazardous. Exposure through inhalation should be avoided.

RCPs form part of the UN CPC 375 – "Concrete" industry classification and the ANZSIC 2034 – "Concrete Product Manufacturing" product group classification.

Table 2 – Product content

Chemical Name	Proportion	CAS
General Purpose Cement*	11 - 21%	65997-15-1
Aggregates containing crystalline silica† (quartz)	67 - 83%	14808-60-7
Water	<10%	7732-18-5
Fly Ash ‡	<5%	69131-74-8
Steel	1 - 11%	7439-89-6
Admixtures such as hardening accelerators, set accelerators, (super) plasticisers, and special purpose (air detrainers)	<1%	9036-19-5, 68584-22-5, 1310-73-2, 13477-34-4, 540-72-7, 140-07-8, 111-42-2

* Cement in concrete contains traces of Chromium VI (hexavalent).
† Crystalline-silica (quartz) may be a constituent of sand, crushed stone, gravel, blast furnace slag and fly ash used in any particular concrete mix.
‡ Cementitious additives may contain traces of metals.

Technical compliance

Humes' RCPs are manufactured and proof tested to comply with AS/NZS 4058:2007 - Precast concrete pipes (pressure and non-pressure) (SA 2007b). In addition, RCP products have a reference service life (RSL) of 100 years, when manufactured in accordance with AS/NZS 4058:2007 (SA 2007b) and installed in accordance with AS/NZS 3725: Design for Installation of Buried Concrete Pipes (SA 2007c). AS/NZS 4058:2007 also covers performance requirements, e.g. load testing, water tightness, pressure testing, water absorption, etc.

* Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals

Scope of EPD

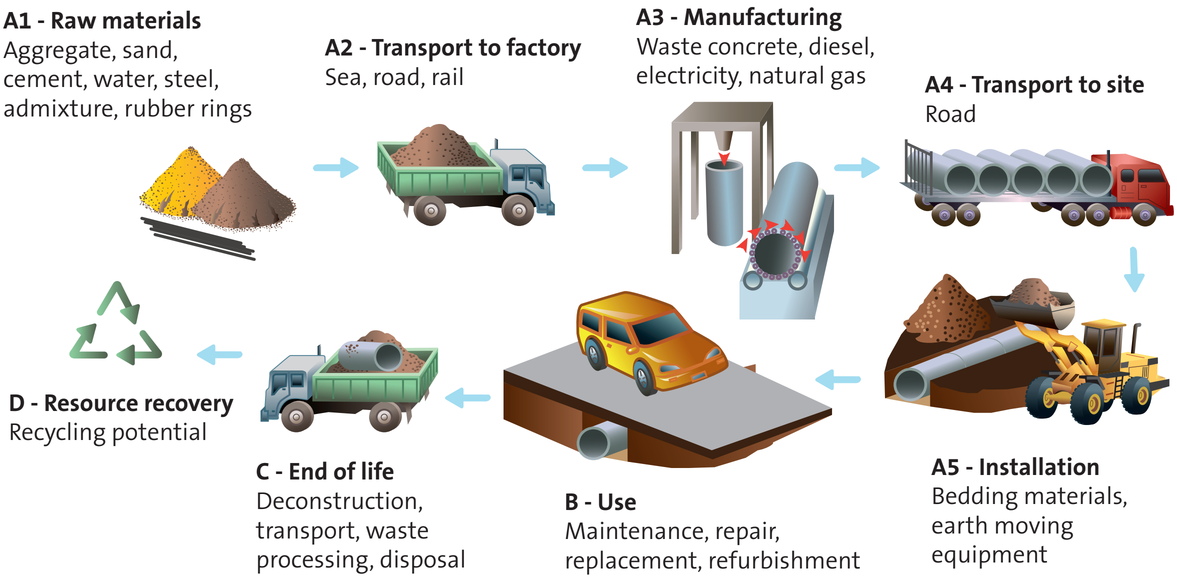
This EPD covers life cycle stages A1-5, B3-4, C1-4 and D. This EPD covers the processes that occur in as many of the product's life cycle stages as could be effectively modelled. Stages B1-2 and B5-7 have not been included.

Table 3 – Scope of EPD

Product stage			Construction stage		Use stage							End-of-life stage				Benefits beyond system boundary
Raw materials	Transport	Manufacturing	Transport	Construction\ Installation	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				
✓	✓	✓	✓	✓	MND	MND	✓	✓	MND	MND	MND	✓	✓	✓	✓	✓

Note: ✓ = Module is included in this study, MND = Module not declared

Figure 3 – Product lifecycle of steel reinforced concrete pipes



Product stage

Raw material – Module A1

All raw materials used in the production of RCP comply with the following standards as required by AS 4058 (SA 2007b):

- AS/NZS 3972: General purpose and blended cements (SA 2010)
- AS 3582.1 Supplementary cementitious materials Part 1: Fly Ash (SA 2016)
- AS/NZS 4671 Steel reinforcing materials (SA 2001)
- AS 2758.1 Aggregates and rock for engineering purposes Part 1: Concrete Aggregates (SA 2014)
- AS 1478 Chemical admixtures for concrete, mortar and grout (SA 2000)
- AS 1646 Elastomeric seals for waterworks purposes (SA 2007d)

Transportation – Module A2

Raw materials are typically transported from site via articulated trucks. The impact of transportation is determined from the specific supply sources for each factory in Australia.

Manufacturing – Module A3

The manufacturing process of RCP is typically a centrifugal spun process in the majority of Humes' pipe factories. Concrete is poured inside a spinning mould where the water in the concrete is slowly drawn to the interior of the pipe. Once the mould is filled with concrete the bore of the pipe is smoothed and the compaction process is complete. The manufacturing process for Ipswich and Newcastle dry-cast pipes differs in that the pipe moulds are filled vertically with a much drier concrete mix. Compaction is achieved through either vibration or a compaction roller.

RCP is cured in a curing chamber designed to accelerate the setting and strength gain of the pipes immediately after casting. Once RCPs have cured enough to be handled with lifting equipment, they are transferred to the outdoor yard storage area and continue to cure until they are transported to the installation site.

Construction process stage

Transportation – Module A4

Distribution distances vary from site to site. Transportation to the construction site is based on the weighted average delivery scenario for each group of RCP products. Return-transport is empty.

Transport of imported and surplus materials is also included as per the installation scenarios. The values are expressed per metre of RCP of a particular diameter, regardless of the class of pipe or whether the pipe is made using the spun or dry-cast process. The environmental impacts correlate strongly to the pipe diameter.

Installation – Module A5

The installation of RCPs in a storm-water system is included in the LCA on the basis of typical scenarios. This EPD contains a range of scenarios as the installation scenario can have a significant impact on the environmental profile. Only trench type installation was considered due to the predictability of trench dimensions. The type of support is selected depending on the application (required performance) of the pipeline system. The required strength of a concrete pipe depends on both the load to be carried by the installed pipe, and the supporting ground installation conditions.

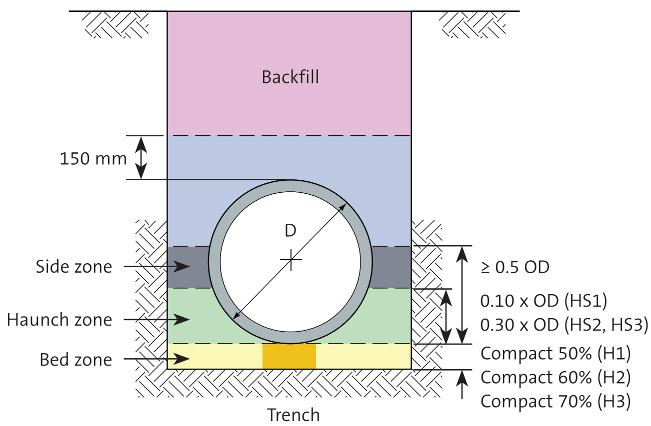
Installation processes include:

- Excavation of the trench
- Placement of bedding materials
- Placement of RCP
- Filling of the trench

Bedding types for pipes are H1, H2, HS1, HS2, HS3, and U. Where U denotes an unsupported fill, H denotes Haunch support, HS denotes Haunch and Side support, and 1, 2, and 3 denotes the level of support (compaction of fill) in the material used. Further details are available in AS/NZS 3725: Design for Installation of Buried Concrete Pipes (SA 2007c).

Further information on trench dimensions for the installation of RCP can be found in Humes' *Concrete pipe reference manual* (see www.humes.com.au).

Figure 4 – Type H and type HS support



Use stage

Pipework which is installed correctly is relatively inert and does not consume energy or water to operate. As such, the life-cycle modules for use (B1), maintenance (B2), refurbishment (B5), operational energy use (B6), and operational water use (B7) are not declared.

Repair and Replacement – Modules B3 and B4

Based on anecdotal evidence, it has been conservatively assumed that 1% of pipes require repair or replacement over the reference service life. This has been split evenly into 0.5% of pipes requiring repair and 0.5% of pipes requiring replacement. The repair scenario involves injecting an epoxy resin into cracks that exceed 30 cm in length and/or are greater than 0.15 mm wide (BCC 2016). Smaller cracks are assumed to re-seal under the natural action of the concrete's autogenous healing process.
The replacement scenario involves impacts associated with all the other life cycle stages: product stage (A1-A3), transport to site (A4), installation (A5), repair (B3) and end-of-life (C1-C4).

End of life stage

At the end of their functional life, RCP pipes can enter into one of the following disposal options:

- left in the ground, abandoned
- left in the ground, re-lined with a plastic HDPE pipe (and thus going into a second life; the re-lining process is considered part of the second life)
- left in the ground, filled with a grout to avoid cave-in
- exhumed and recycled

This EPD covers all four options in the end of life stage so that the reader can select the applicable scenario for their situation.

Deconstruction/Demolition – Module C1

It is assumed that when the pipe is exhumed it is replaced with another new product, the excavation and back-filling of the trench is part of the next pipe's life cycle and is not included in the replaced pipe's end-of-life scenario. Removal of pipes is included.

Transport – Module C2

The transportation includes the discarded pipe to a recycling site or transportation of waste to a final sorting yard or disposal site.

Waste Processing – Module C3

The waste processing includes crushing of waste pipes (recycling) into concrete rubble and steel scrap.

Disposal – Module C4

Waste disposal includes physical pre-treatment and management of the disposal site. For pipes that are left in-ground, emissions from concrete and controlled low strength material (if applicable) waste disposed to landfill are considered. Pipes that are left in the ground are assumed not to need any further waste processing.

Resource recovery stage

Reuse, recovery, recycling potential – Module D

The information in module D includes environmental benefits or loads resulting from recyclable materials leaving a product system. The concrete rubble and steel scrap produced in module C3 can replace natural coarse aggregates (crushed rock) and virgin steel (after further processing), respectively. Module D is only relevant when pipes are exhumed and recycled.

Life cycle assessment (LCA) methodology

Background data

Primary data covers the 2015 calendar year and has been sourced from each of the ten Humes factories that manufacture RCP. Background data is predominantly sourced from AusLCI and the AusLCI shadow database. Data for reinforcing steel wire has been sourced from our supplier's (ARC/OneSteel) EPD (registration number S-P-00855) (OneSteel 2016). Data for admixtures has been sourced from five EPDs published in December 2015 by FEICA (Association of the European Adhesive and Sealant Industry) (FEICA 2015a-e). As a result, the vast majority of the environmental profile of our products is based on life cycle data less than three years old. Background data used is less than 10 years old.

Methodological choices have been applied in line with EN 15804:2012+A1:2013; deviations have been recorded.

Explanation of averages

Humes produces a large number of RCP products, each with unique characteristics (e.g. class, length, diameter, joint type) and composition (concrete composition, steel reinforcement content). After careful consideration of the range of products, it was decided that the best three groupings are based on type of production process (spun / dry-cast), class strength of pipe and geographical region. This particular grouping reduces the variation within each group's environmental profile while providing a clear delineation for users of the EPD. This leads to four groups:

- Spun pipes, class 2/3/4, (NSW/VIC/SA/WA/TAS)
- Spun pipes, class 2/3/4, (QLD/NT)
- Dry-cast pipes, class 2/3/4, (NSW)
- Dry-cast pipes, class 2/3/4, (QLD)

Allocation

The key processes that require allocation are:

- Production of concrete pipes and other precast concrete products: All shared processes are attributed to concrete products based on their mass
- Use of fly ash: all environmental impacts of the power plant have been allocated to the main product: electricity, fly ash has only received the burdens of the transport to our sites.
- Use of steel scrap in reinforcement steel wire: Recycling allocation has followed the polluter pays principle in line with EN 15804 and the PCR. See OneSteel's EPD (S-P-00855) of reinforcing rod and wire (OneSteel 2016).

Cut-off criteria

- The contribution of capital goods (production equipment and infrastructure) and personnel is outside the scope of the LCA, in line with the PCR (Environdec 2017).
- The amount of packaging used for admixtures, rubber rings and mould oil is well below the materiality cut-off and packaging materials and quantities have therefore been estimated only.
- The rubber ring lubricant applied to the socket lead-in for skid joints is excluded from the LCA, as the amount used is negligible.
- Compaction of bedding materials has been excluded from the assessment. Energy consumed for the compactor is below the cut-off (1%) of the installation stage and does not affect the overall environmental performance of the RCPs.

Key assumptions

- The concrete composition of each product is taken from Humes internal operating systems. There are minor differences between sites in the way data are measured and entered into the system. This created a need to manually adjust (harmonise) the concrete compositions by about 2%.
- Water consumption data were not available for the full reporting period at each site, as some water meters have only been installed recently. For each site we have taken the longest period for which water bills are available and divided consumption by the site's total tonnes of concrete output (pipes and other products) during that time period. This gives an average water use per tonne of concrete for each site.
- The scenarios for modules A5, B3 and B4 are based on a set of assumptions (depth of backfill, trench width, distance of imported bedding material, repair epoxy needed, replacement percentage, etc.) that may influence the outcome of the assessment. It is important to understand the scenarios before drawing conclusions based on this EPD.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Life cycle assessment (LCA) results

An LCA serves as the foundation for this EPD. An LCA analyses the production systems of a product. It provides comprehensive evaluations of all upstream and downstream energy inputs and outputs. The results are provided in a form which covers a range of environmental impact categories.

Declared unit

Reinforced concrete pipes are available in various classes (thickness related) and diameters. After considering various options, it became clear that there is no single parameter that allows different pipes to be averaged while presenting impacts across a large part of their life cycle. Therefore we have opted to apply two declared units and group life cycle stages based on whether multiple products can be presented collectively according to their mass or physical dimensions. For modules A1-A4, C1-C4, and D, a large number of permutations have been included based on the following declared unit:

1 tonne of reinforced concrete pipework with a given capacity (class, dimensions and length of pipes shall be specified).

For installation module A5, repair module B3, and replacement module B4 results are expressed per metre of pipe length for a certain diameter, as results per tonne of pipe are not meaningful. As such the following declared unit has been applied to these modules:

1 equivalent metre of reinforced pipework with a given capacity (dimensions and class shall be specified), applied in a 'normal environment' in Australia, with a service life of 100 years.*

This EPD contains a weight conversion factor (tonne/metre) for each pipe to assure the results can be easily converted; e.g. for use in environmental calculators (see Table 28, Table 29, Table 30, and Table 31 for conversion factors).

Table 4 – Environmental indicators

Environmental Indicator	Acronym	Unit	Description
Global Warming Potential	GWP	kg CO_2 eq	Global warming impact of greenhouse gases such as carbon dioxide (CO_2), measured in kg CO_2 equivalents using a global warming potential over a 100-year time horizon.
Ozone Depletion Potential	ODP	kg CFC-11 eq	Relative impact that the product can cause to the stratospheric ozone layer, measured in kg trichlorofluoromethane (CFC-11) equivalents.
Acidification Potential	AP	kg SO_2 eq	Increase of soil and water acidity that the product can cause, measured in kg sulphur dioxide (SO_2) equivalents.
Eutrophication Potential	EP	kg PO_4^{3-} eq	Potential impact of nutrification by nitrogen and phosphorus to aquatic and terrestrial ecosystems, for example through algal blooms, measured in kg phosphate (PO_4^{3-}) equivalents.
Photochemical Ozone Creation Potential	POCP	kg C_2H_4 eq	Also known as summer smog, the potential impact from oxidising of volatile compounds in the presence of nitrogen oxides (NO_x) which frees ozone in the low atmosphere, measured in kg ethene (C_2H_4) equivalents.
Abiotic Depletion Potential (elements)	ADPE	kg Sb eq	Economic impact from the depletion of scarce non-renewable resources such as metals, measured in kg antimony equivalents.
Abiotic Depletion Potential (Fossil Fuels)	ADPF	MJ	Economic impact from depletion of fossil fuel resources such as oil or natural gas, expressed using their net calorific value.

* A 'normal environment' is classified as: an underground environment having negligible influence on the in-service life expectancy of pipe and having a minimum cover to reinforcement complying with AS/NZS 4058:2007 (SA 2007b)

Table 5 – Parameters describing resource use, waste and output flows

Parameter	Acronym	Unit
Parameters describing resource use		
Use of renewable primary energy excluding renewable primary energy resources used as raw materials	PERE	MJ_{NCV}
Use of renewable primary energy resources used as raw materials	PERM	MJ_{NCV}
Total use of renewable primary energy resources	PERT	MJ_{NCV}
Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials	PENRE	MJ_{NCV}
Use of non-renewable primary energy resources used as raw materials	PENRM	MJ_{NCV}
Total use of non-renewable primary energy resources	PENRT	MJ_{NCV}
Use of secondary material	SM	kg
Use of renewable secondary fuels	RSF	MJ_{NCV}
Use of non-renewable secondary fuels	NRSF	MJ_{NCV}
Use of net fresh water	FW	m^3
Waste categories		
Hazardous waste disposed	HWD	kg
Non-hazardous waste disposed	NHWD	kg
Radioactive waste disposed	RWD	kg
Output flows		
Components for re-use	CRU	kg
Materials for recycling	MFR	kg
Materials for energy recovery	MER	kg
Exported energy	EE	MJ

Environmental profiles

Cradle-to-gate (A1-A3)

The cradle-to-gate environmental indicators of each product group are expressed per tonne of average product, for:

- Spun pipes, class 2/3/4, NSW/VIC/SA/WA/TAS (Table 6)
- Spun pipes, class 2/3/4, QLD/NT (Table 7)
- Dry-cast, class 2/3/4, NSW (Table 8)
- Dry-cast, class 2/3/4, QLD (Table 9)

Table 6 – Environmental indicators, modules A1-A3, Spun pipe, NSW/VIC/SA/WA/TAS, per tonne of pipe

Environmental Indicator	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
GWP [kg CO_2 eq]	2.71E+02	2.85E+02	2.92E+02
ODP [kg CFC-11 eq]	2.39E-06	2.10E-06	2.75E-06
AP [kg SO_2 eq]	5.67E-01	5.87E-01	6.77E-01
EP [kg PO_4^{3-} eq]	1.06E-01	1.05E-01	1.20E-01
POCP [kg C_2H_4 eq]	5.94E-02	6.80E-02	7.94E-02
ADPE [kg Sb eq]	1.95E-04	2.57E-04	3.18E-04
ADPF [MJ_{NCV}]	2.41E+03	2.62E+03	2.71E+03
Resource Use	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
PERE [MJ_{NCV}]	7.46E+01	6.67E+01	8.57E+01
PERM [MJ_{NCV}]	0	0	0
PERT [MJ_{NCV}]	7.46E+01	6.67E+01	8.57E+01
PENRE [MJ_{NCV}]	2.44E+03	2.64E+03	2.73E+03
PENRM [MJ_{NCV}]	2.51E-01	6.97E-02	4.90E-02
PENRT [MJ_{NCV}]	2.44E+03	2.64E+03	2.73E+03
SM [kg]	1.26E+01	1.66E+01	2.07E+01
RSF [MJ_{NCV}]	0	0	0
NRSF [MJ_{NCV}]	7.89E-01	1.04E+00	1.29E+00
FW [m^3]	1.93E+00	1.90E+00	1.97E+00
Waste Categories	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
HW [kg]	7.71E-06	9.88E-06	1.22E-05
NHW [kg]	1.20E+01	1.57E+01	1.92E+01
RW [kg]	1.24E-03	1.59E-03	1.96E-03
Output flows	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
CRU [kg]	0	0	0
MFR [kg]	2.52E+01	2.52E+01	2.53E+01
MER [kg]	1.08E-02	1.43E-02	1.77E-02
EE [MJ]	0	0	0

Table 7 – Environmental indicators, modules A1-A3, Spun pipe, QLD/NT, per tonne of pipe

Environmental Indicator	Class 2 pipes	Class 3 pipes	Class 4 pipes
GWP [kg CO_2 eq]	2.28E+02	2.40E+02	2.59E+02
ODP [kg CFC-11 eq]	1.79E-06	1.60E-06	1.77E-06
AP [kg SO_2 eq]	5.18E-01	5.37E-01	5.94E-01
EP [kg PO_4^{3-} eq]	9.26E-02	9.38E-02	1.02E-01
POCP [kg C_2H_4 eq]	5.86E-02	6.52E-02	7.41E-02
ADPE [kg Sb eq]	2.13E-04	2.66E-04	3.10E-04
ADPF [MJ_{NCV}]	1.85E+03	2.16E+03	2.31E+03
Resource Use	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
PERE [MJ_{NCV}]	4.96E+01	6.12E+01	6.89E+01
PERM [MJ_{NCV}]	0	0	0
PERT [MJ_{NCV}]	4.96E+01	6.12E+01	6.89E+01
PENRE [MJ_{NCV}]	1.87E+03	2.17E+03	2.32E+03
PENRM [MJ_{NCV}]	9.09E-01	1.19E-01	5.29E-01
PENRT [MJ_{NCV}]	1.87E+03	2.17E+03	2.32E+03
SM [kg]	1.38E+01	1.72E+01	2.01E+01
RSF [MJ_{NCV}]	0	0	0
NRSF [MJ_{NCV}]	8.61E-01	1.08E+00	1.26E+00
FW [m^3]	2.00E+00	2.21E+00	2.20E+00
Waste Categories	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
HW [kg]	9.09E-06	1.03E-05	1.24E-05
NHW [kg]	1.26E+01	1.60E+01	1.86E+01
RW [kg]	1.47E-03	1.65E-03	2.00E-03
Output flows	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
CRU [kg]	0	0	0
MFR [kg]	2.52E+01	2.52E+01	2.53E+01
MER [kg]	1.18E-02	1.48E-02	1.72E-02
EE [MJ]	0	0	0

Table 8 – Environmental indicators, modules A1-A3, Dry-cast pipe, NSW, per tonne of pipe

Environmental Indicator	Class 2 pipes	Class 3 pipes	Class 4 pipes
GWP [kg CO_2 eq]	2.97E+02	3.34E+02	3.41E+02
ODP [kg CFC-11 eq]	2.65E-06	2.60E-06	2.68E-06
AP [kg SO_2 eq]	7.28E-01	8.35E-01	8.53E-01
EP [kg PO_4^{3-} eq]	1.29E-01	1.40E-01	1.44E-01
POCP [kg C_2H_4 eq]	8.29E-02	1.07E-01	1.08E-01
ADPE [kg Sb eq]	3.48E-04	4.97E-04	4.97E-04
ADPF [MJ_{NCV}]	2.56E+03	2.99E+03	3.04E+03
Resource Use	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
PERE [MJ_{NCV}]	8.45E+01	1.08E+02	1.09E+02
PERM [MJ_{NCV}]	4.16E-01	4.10E-01	4.05E-01
PERT [MJ_{NCV}]	8.49E+01	1.09E+02	1.09E+02
PENRE [MJ_{NCV}]	2.58E+03	3.02E+03	3.07E+03
PENRM [MJ_{NCV}]	6.73E+00	6.64E+00	6.56E+00
PENRT [MJ_{NCV}]	2.59E+03	3.03E+03	3.07E+03
SM [kg]	2.18E+01	3.16E+01	3.16E+01
RSF [MJ_{NCV}]	0	0	0
NRSF [MJ_{NCV}]	1.36E+00	1.97E+00	1.97E+00
FW [m^3]	1.85E+00	1.99E+00	2.00E+00
Waste Categories	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
HW [kg]	4.96E-05	5.49E-05	5.44E-05
NHW [kg]	2.22E+01	3.09E+01	3.09E+01
RW [kg]	4.76E-03	5.65E-03	5.62E-03
Output flows	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
CRU [kg]	0	0	0
MFR [kg]	2.53E+01	2.54E+01	2.54E+01
MER [kg]	1.87E-02	2.71E-02	2.71E-02
EE [MJ]	0	0	0

Table 9 – Environmental indicators, modules A1-A3, Dry-cast pipe, QLD, per tonne of pipe

Environmental Indicator	Class 2 pipes	Class 3 pipes	Class 4 pipes
GWP [kg CO_2 eq]	1.96E+02	2.16E+02	2.37E+02
ODP [kg CFC-11 eq]	1.51E-06	1.51E-06	1.50E-06
AP [kg SO_2 eq]	4.91E-01	5.46E-01	6.07E-01
EP [kg PO_4^{3-} eq]	9.43E-02	1.01E-01	1.08E-01
POCP [kg C_2H_4 eq]	4.77E-02	5.92E-02	7.20E-02
ADPE [kg Sb eq]	1.60E-04	2.31E-04	3.10E-04
ADPF [MJ_{NCV}]	1.68E+03	1.90E+03	2.15E+03
Resource Use	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
PERE [MJ_{NCV}]	4.79E+01	5.94E+01	7.22E+01
PERM [MJ_{NCV}]	0	0	0
PERT [MJ_{NCV}]	4.79E+01	5.94E+01	7.22E+01
PENRE [MJ_{NCV}]	1.70E+03	1.92E+03	2.16E+03
PENRM [MJ_{NCV}]	2.50E+00	2.49E+00	2.47E+00
PENRT [MJ_{NCV}]	1.70E+03	1.92E+03	2.16E+03
SM [kg]	1.03E+01	1.49E+01	2.01E+01
RSF [MJ_{NCV}]	0	0	0
NRSF [MJ_{NCV}]	6.46E-01	9.33E-01	1.26E+00
FW [m^3]	1.67E+00	1.74E+00	1.82E+00
Waste Categories	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
HW [kg]	9.80E-06	1.25E-05	1.55E-05
NHW [kg]	1.02E+01	1.43E+01	1.89E+01
RW [kg]	1.60E-03	2.03E-03	2.51E-03
Output flows	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
CRU [kg]	0	0	0
MFR [kg]	2.51E+01	2.52E+01	2.53E+01
MER [kg]	8.86E-03	1.28E-02	1.72E-02
EE [MJ]	0	0	0

Variation (A1-A3) per impact category

The variations of results in modules A1-A3 are presented in Table 10.

Table 10 – Range in LCA results (modules A1-A3)

Spun pipes (NSW/VIC/SA/WA/TAS)						
Environmental Indicator	Class 2		Class 3		Class 4	
	min	max	min	max	min	max
GWP [kg CO_2 eq]	-17%	9%	-16%	10%	-20%	19%
ODP [kg CFC-11 eq]	-15%	0%	-5%	2%	-27%	0%
AP [kg SO_2 eq]	-21%	12%	-16%	16%	-30%	15%
EP [kg PO_4^{3-} eq]	-19%	6%	-13%	12%	-26%	7%
POCP [kg C_2H_4 eq]	-23%	25%	-19%	24%	-36%	31%
ADPE [kg Sb eq]	-36%	45%	-27%	34%	-50%	47%
ADPF [MJ_{NCV}]	-17%	9%	-17%	8%	-23%	19%
Spun pipes (QLD/NT)						
Environmental Indicator	Class 2		Class 3		Class 4	
	min	max	min	max	min	max
GWP [kg CO_2 eq]	-16%	18%	-19%	12%	-27%	17%
ODP [kg CFC-11 eq]	-21%	0%	-15%	0%	-23%	0%
AP [kg SO_2 eq]	-21%	15%	-20%	12%	-29%	18%
EP [kg PO_4^{3-} eq]	-18%	13%	-19%	11%	-27%	13%
POCP [kg C_2H_4 eq]	-26%	20%	-21%	10%	-34%	24%
ADPE [kg Sb eq]	-33%	33%	-23%	10%	-40%	34%
ADPF [MJ_{NCV}]	-14%	21%	-21%	5%	-28%	15%
Dry-cast pipes (NSW)						
Environmental Indicator	Class 2		Class 3		Class 4	
	min	max	min	max	min	max
GWP [kg CO_2 eq]	-10%	14%	-11%	12%	-19%	22%
ODP [kg CFC-11 eq]	-1%	4%	0%	0%	-3%	3%
AP [kg SO_2 eq]	-12%	15%	-12%	14%	-21%	25%
EP [kg PO_4^{3-} eq]	-8%	12%	-9%	10%	-16%	18%
POCP [kg C_2H_4 eq]	-19%	21%	-19%	22%	-31%	37%
ADPE [kg Sb eq]	-28%	28%	-25%	28%	-39%	48%
ADPF [MJ_{NCV}]	-13%	15%	-13%	15%	-22%	26%
Dry-cast pipes (QLD)						
Environmental Indicator	Class 2		Class 3		Class 4	
	min	max	min	max	min	max
GWP [kg CO_2 eq]	-5%	14%	-8%	11%	-15%	13%
ODP [kg CFC-11 eq]	0%	0%	0%	0%	0%	0%
AP [kg SO_2 eq]	-6%	16%	-9%	12%	-17%	14%
EP [kg PO_4^{3-} eq]	-4%	10%	-6%	8%	-11%	9%
POCP [kg C_2H_4 eq]	-12%	33%	-17%	22%	-28%	24%
ADPE [kg Sb eq]	-22%	60%	-27%	34%	-40%	34%
ADPF [MJ_{NCV}]	-7%	18%	-10%	13%	-18%	16%

Transport to site (A4)

Table 11 and Table 12 present the environmental indicators associated with transport of the pipes to construction sites. Transport scenarios are based on Humes' actual supply logistics for each site in 2015.

Table 11 – Environmental indicators, module A4, Spun pipe NSW/VIC/SA/WA/TAS, per tonne of pipe

Environmental Indicator	Class 2 pipes	Class 3 pipes	Class 4 pipes
GWP [kg CO_2 eq]	3.55E+01	4.63E+01	4.62E+01
ODP [kg CFC-11 eq]	4.40E-06	5.75E-06	5.73E-06
AP [kg SO_2 eq]	1.73E-01	2.25E-01	2.25E-01
EP [kg PO_4^{3-} eq]	3.63E-02	4.75E-02	4.73E-02
POCP [kg C_2H_4 eq]	3.75E-02	4.90E-02	4.88E-02
ADPE [kg Sb eq]	4.11E-08	5.37E-08	5.35E-08
ADPF [MJ_{NCV}]	4.74E+02	6.19E+02	6.17E+02
Resource Use	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
PERE [MJ_{NCV}]	4.14E-01	5.40E-01	5.38E-01
PERM [MJ_{NCV}]	0	0	0
PERT [MJ_{NCV}]	4.14E-01	5.40E-01	5.38E-01
PENRE [MJ_{NCV}]	5.15E+02	6.73E+02	6.71E+02
PENRM [MJ_{NCV}]	0	0	0
PENRT [MJ_{NCV}]	5.15E+02	6.73E+02	6.71E+02
SM [kg]	0	0	0
RSF [MJ_{NCV}]	0	0	0
NRSF [MJ_{NCV}]	0	0	0
FW [m^3]	7.06E-02	9.22E-02	9.19E-02
Waste Categories	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
HW [kg]	0	0	0
NHW [kg]	5.08E-03	6.64E-03	6.61E-03
RW [kg]	0	0	0
Output flows	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
CRU [kg]	0	0	0
MFR [kg]	0	0	0
MER [kg]	0	0	0
EE [MJ]	0	0	0

Table 12 – Environmental indicators, module A4, Spun pipe QLD/NT, per tonne of pipe

Environmental Indicator	Class 2 pipes	Class 3 pipes	Class 4 pipes
GWP [kg CO_2 eq]	3.15E+01	6.25E+01	4.79E+01
ODP [kg CFC-11 eq]	3.91E-06	7.75E-06	5.94E-06
AP [kg SO_2 eq]	1.53E-01	3.04E-01	2.33E-01
EP [kg PO_4^{3-} eq]	3.23E-02	6.40E-02	4.90E-02
POCP [kg C_2H_4 eq]	3.34E-02	6.61E-02	5.06E-02
ADPE [kg Sb eq]	3.65E-08	7.23E-08	5.54E-08
ADPF [MJ_{NCV}]	4.21E+02	8.35E+02	6.40E+02
Resource Use	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
PERE [MJ_{NCV}]	3.68E-01	7.28E-01	5.58E-01
PERM [MJ_{NCV}]	0	0	0
PERT [MJ_{NCV}]	3.68E-01	7.28E-01	5.58E-01
PENRE [MJ_{NCV}]	4.58E+02	9.07E+02	6.95E+02
PENRM [MJ_{NCV}]	0	0	0
PENRT [MJ_{NCV}]	4.58E+02	9.07E+02	6.95E+02
SM [kg]	0	0	0
RSF [MJ_{NCV}]	0	0	0
NRSF [MJ_{NCV}]	0	0	0
FW [m^3]	6.28E-02	1.24E-01	9.52E-02
Waste Categories	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
HW [kg]	0	0	0
NHW [kg]	4.52E-03	8.95E-03	6.86E-03
RW [kg]	0	0	0
Output flows	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
CRU [kg]	0	0	0
MFR [kg]	0	0	0
MER [kg]	0	0	0
EE [MJ]	0	0	0

Table 13 – Environmental indicators, module A4, Dry-cast pipe NSW, per tonne of pipe

Environmental Indicator	Class 2 pipes	Class 3 pipes	Class 4 pipes
GWP [kg CO_2 eq]	3.92E+01	3.92E+01	3.92E+01
ODP [kg CFC-11 eq]	4.87E-06	4.87E-06	4.87E-06
AP [kg SO_2 eq]	1.91E-01	1.91E-01	1.91E-01
EP [kg PO_4^{3-} eq]	4.02E-02	4.02E-02	4.02E-02
POCP [kg C_2H_4 eq]	4.15E-02	4.15E-02	4.15E-02
ADPE [kg Sb eq]	4.54E-08	4.54E-08	4.54E-08
ADPF [MJ_{NCV}]	5.24E+02	5.24E+02	5.24E+02
Resource Use	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
PERE [MJ_{NCV}]	4.57E-01	4.57E-01	4.57E-01
PERM [MJ_{NCV}]	0	0	0
PERT [MJ_{NCV}]	4.57E-01	4.57E-01	4.57E-01
PENRE [MJ_{NCV}]	5.70E+02	5.70E+02	5.70E+02
PENRM [MJ_{NCV}]	0	0	0
PENRT [MJ_{NCV}]	5.70E+02	5.70E+02	5.70E+02
SM [kg]	0	0	0
RSF [MJ_{NCV}]	0	0	0
NRSF [MJ_{NCV}]	0	0	0
FW [m^3]	7.80E-02	7.80E-02	7.80E-02
Waste Categories	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
HW [kg]	0	0	0
NHW [kg]	5.62E-03	5.62E-03	5.62E-03
RW [kg]	0	0	0
Output flows	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
CRU [kg]	0	0	0
MFR [kg]	0	0	0
MER [kg]	0	0	0
EE [MJ]	0	0	0

Table 14 – Environmental indicators, module A4, Dry-cast pipe QLD, per tonne of pipe

Environmental Indicator	Class 2 pipes	Class 3 pipes	Class 4 pipes
GWP [kg CO_2 eq]	2.95E+01	2.95E+01	2.95E+01
ODP [kg CFC-11 eq]	3.66E-06	3.66E-06	3.66E-06
AP [kg SO_2 eq]	1.44E-01	1.44E-01	1.44E-01
EP [kg PO_4^{3-} eq]	3.02E-02	3.02E-02	3.02E-02
POCP [kg C_2H_4 eq]	3.12E-02	3.12E-02	3.12E-02
ADPE [kg Sb eq]	3.42E-08	3.42E-08	3.42E-08
ADPF [MJ_{NCV}]	3.94E+02	3.94E+02	3.94E+02
Resource Use	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
PERE [MJ_{NCV}]	3.44E-01	3.44E-01	3.44E-01
PERM [MJ_{NCV}]	0	0	0
PERT [MJ_{NCV}]	3.44E-01	3.44E-01	3.44E-01
PENRE [MJ_{NCV}]	4.29E+02	4.29E+02	4.29E+02
PENRM [MJ_{NCV}]	0	0	0
PENRT [MJ_{NCV}]	4.29E+02	4.29E+02	4.29E+02
SM [kg]	0	0	0
RSF [MJ_{NCV}]	0	0	0
NRSF [MJ_{NCV}]	0	0	0
FW [m^3]	5.87E-02	5.87E-02	5.87E-02
Waste Categories	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
HW [kg]	0	0	0
NHW [kg]	4.23E-03	4.23E-03	4.23E-03
RW [kg]	0	0	0
Output flows	**Class 2 pipes**	**Class 3 pipes**	**Class 4 pipes**
CRU [kg]	0	0	0
MFR [kg]	0	0	0
MER [kg]	0	0	0
EE [MJ]	0	0	0

Installation of pipes (A5)

The following tables show the environmental indicators associated with installation processes on the construction site. As indicated in the section titled Construction Process Stage, six different bedding types have been analysed in the LCA. The environmental impacts of H1 bedding are provided hereafter, based on the following scenarios and assumptions:

- Two CCTV inspections take place to examine installation works.
- The depth of backfill is 1.0 metre.
- Imported sand is used for the bed zone (100%), haunch zone (75%) and side zones (50%). Excavated material is used to complement the haunch zone (25%) and side zones (50%).
  - Sand is imported over 50 kilometres, using a 16-28 tonne truck
- Compaction densities for these three zones are:
  - 2.21 t/m³ (U, H1 and HS1 bedding types)
  - 2.34 t/m³ (H2 and HS2 bedding types)
  - 2.47 t/m³ (HS3 bedding types)
- The trench volume multiplied by a factor of two to account for the excavation and filling of the trench material, is used to determine energy consumption by the excavator. The excavator digs the trench, adds bedding materials, lays the RCPs and fills the trench.

Table 15 – Environmental indicators, installation module A5, bedding type H1, per effective metre of pipe

Environmental Indicator	DN300	DN375	DN450	DN525	DN600	DN675	DN750	DN825
GWP [kg CO_2 eq]	5.07E+00	6.42E+00	7.99E+00	9.27E+00	1.11E+01	1.30E+01	1.48E+01	1.71E+01
ODP [kg CFC-11 eq]	5.69E-07	7.25E-07	9.08E-07	1.06E-06	1.27E-06	1.50E-06	1.71E-06	1.98E-06
AP [kg SO_2 eq]	2.64E-02	3.34E-02	4.15E-02	4.81E-02	5.73E-02	6.74E-02	7.64E-02	8.80E-02
EP [kg PO_4^{3-} eq]	5.66E-03	7.14E-03	8.87E-03	1.03E-02	1.22E-02	1.44E-02	1.63E-02	1.88E-02
POCP [kg C_2H_4 eq]	4.64E-03	5.93E-03	7.44E-03	8.71E-03	1.04E-02	1.24E-02	1.41E-02	1.63E-02
ADPE [kg Sb eq]	8.18E-08	9.84E-08	1.16E-07	1.26E-07	1.45E-07	1.65E-07	1.78E-07	1.99E-07
ADPF [MJ_{NCV}]	6.71E+01	8.50E+01	1.06E+02	1.23E+02	1.47E+02	1.73E+02	1.96E+02	2.27E+02
Resource Use	**DN300**	**DN375**	**DN450**	**DN525**	**DN600**	**DN675**	**DN750**	**DN825**
PERE [MJ_{NCV}]	3.08E-01	3.73E-01	4.42E-01	4.87E-01	5.63E-01	6.43E-01	7.01E-01	7.89E-01
PERM [MJ_{NCV}]	0	0	0	0	0	0	0	0
PERT [MJ_{NCV}]	3.08E-01	3.73E-01	4.42E-01	4.87E-01	5.63E-01	6.43E-01	7.01E-01	7.89E-01
PENRE [MJ_{NCV}]	7.25E+01	9.18E+01	1.14E+02	1.33E+02	1.59E+02	1.87E+02	2.13E+02	2.45E+02
PENRM [MJ_{NCV}]	0	0	0	0	0	0	0	0
PENRT [MJ_{NCV}]	7.25E+01	9.18E+01	1.14E+02	1.33E+02	1.59E+02	1.87E+02	2.13E+02	2.45E+02
SM [kg]	0	0	0	0	0	0	0	0
RSF [MJ_{NCV}]	0	0	0	0	0	0	0	0
NRSF [MJ_{NCV}]	0	0	0	0	0	0	0	0
FW [m³]	2.78E-01	3.33E-01	3.91E-01	4.25E-01	4.87E-01	5.53E-01	5.97E-01	6.67E-01
Waste Categories	**DN300**	**DN375**	**DN450**	**DN525**	**DN600**	**DN675**	**DN750**	**DN825**
HW [kg]	0	0	0	0	0	0	0	0
NHW [kg]	3.52E-03	4.26E-03	5.05E-03	5.56E-03	6.43E-03	7.34E-03	8.01E-03	9.01E-03
RW [kg]	0	0	0	0	0	0	0	0
Output flows	**DN300**	**DN375**	**DN450**	**DN525**	**DN600**	**DN675**	**DN750**	**DN825**
CRU [kg]	0	0	0	0	0	0	0	0
MFR [kg]	0	0	0	0	0	0	0	0
MER [kg]	0	0	0	0	0	0	0	0
EE [MJ]	0	0	0	0	0	0	0	0

Table 15 – Continued

Environmental Indicator	DN900	DN1050	DN1200	DN1350	DN1500	DN1650	DN1800	DN1950	DN2100
GWP [kg CO_2 eq]	2.02E+01	2.65E+01	3.22E+01	4.25E+01	5.17E+01	5.97E+01	6.88E+01	7.94E+01	9.16E+01
ODP [kg CFC-11 eq]	2.35E-06	3.08E-06	3.76E-06	4.91E-06	6.00E-06	6.94E-06	8.02E-06	9.27E-06	1.07E-05
AP [kg SO_2 eq]	1.04E-01	1.36E-01	1.66E-01	2.16E-01	2.63E-01	3.04E-01	3.50E-01	4.03E-01	4.66E-01
EP [kg PO_4^{3-} eq]	2.22E-02	2.90E-02	3.53E-02	4.60E-02	5.60E-02	6.47E-02	7.45E-02	8.59E-02	9.92E-02
POCP [kg C_2H_4 eq]	1.94E-02	2.55E-02	3.11E-02	4.07E-02	4.97E-02	5.76E-02	6.65E-02	7.70E-02	8.89E-02
ADPE [kg Sb eq]	2.32E-07	2.91E-07	3.44E-07	5.01E-07	5.90E-07	6.64E-07	7.43E-07	8.27E-07	9.50E-07
ADPF [MJ_{NCV}]	2.68E+02	3.51E+02	4.28E+02	5.64E+02	6.87E+02	7.93E+02	9.14E+02	1.05E+03	1.22E+03
Resource Use	**DN900**	**DN1050**	**DN1200**	**DN1350**	**DN1500**	**DN1650**	**DN1800**	**DN1950**	**DN2100**
PERE [MJ_{NCV}]	9.19E-01	1.17E+00	1.38E+00	1.97E+00	2.34E+00	2.64E+00	2.97E+00	3.33E+00	3.83E+00
PERM [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
PERT [MJ_{NCV}]	9.19E-01	1.17E+00	1.38E+00	1.97E+00	2.34E+00	2.64E+00	2.97E+00	3.33E+00	3.83E+00
PENRE [MJ_{NCV}]	2.91E+02	3.80E+02	4.64E+02	6.10E+02	7.43E+02	8.58E+02	9.89E+02	1.14E+03	1.32E+03
PENRM [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
PENRT [MJ_{NCV}]	2.91E+02	3.80E+02	4.64E+02	6.10E+02	7.43E+02	8.58E+02	9.89E+02	1.14E+03	1.32E+03
SM [kg]	0	0	0	0	0	0	0	0	0
RSF [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
NRSF [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
FW [m^3]	7.73E-01	9.71E-01	1.14E+00	1.68E+00	1.97E+00	2.21E+00	2.47E+00	2.75E+00	3.16E+00
Waste Categories	**DN900**	**DN1050**	**DN1200**	**DN1350**	**DN1500**	**DN1650**	**DN1800**	**DN1950**	**DN2100**
HW [kg]	0	0	0	0	0	0	0	0	0
NHW [kg]	1.05E-02	1.33E-02	1.58E-02	2.28E-02	2.70E-02	3.05E-02	3.43E-02	3.84E-02	4.42E-02
RW [kg]	0	0	0	0	0	0	0	0	0
Output flows	**DN900**	**DN1050**	**DN1200**	**DN1350**	**DN1500**	**DN1650**	**DN1800**	**DN1950**	**DN2100**
CRU [kg]	0	0	0	0	0	0	0	0	0
MFR [kg]	0	0	0	0	0	0	0	0	0
MER [kg]	0	0	0	0	0	0	0	0	0
EE [MJ]	0	0	0	0	0	0	0	0	0

Table 16 – Impacts of installation, per metre, average across all pipe diameters, relative

Environmental Indicator	H1	H2	HS1	HS2	HS3	U
GWP [kg CO_2 eq]	100%	123%	125%	132%	135%	73%
ODP [kg CFC-11 eq]	100%	120%	122%	128%	130%	77%
AP [kg SO_2 eq]	100%	121%	123%	129%	131%	76%
EP [kg PO_4^{3-} eq]	100%	120%	122%	128%	130%	77%
POCP [kg C_2H_4 eq]	100%	121%	124%	129%	132%	76%
ADPE [kg Sb eq]	100%	151%	143%	166%	175%	44%
ADPF [MJ_{NCV}]	100%	123%	125%	132%	134%	74%

This EPD provides the environmental impacts of installation type H1 only. However this EPD recognises that there are many installation types and that the impacts in alternative types can vary significantly. The relative impacts across all pipe diameters and all environmental indicators can be calculated by using the relative impacts in Table 16. By multiplying the relevant factor by the impact indicators in Table 15, the resultant impact for module A5 can be determined for each installation type. The use of these indicators still assumes a depth of backfill of 1.0 metre.

The depth of backfill of 1.0 metre covers almost all minimum depth requirements for compaction devices (CPAA 2007). In practice, the depth of trench is variable with on-site circumstances and project requirements. This can have a significant effect on the results of module A5. Therefore, comparing the installation results to other LCAs or EPDs should only be done when the same scenario has been modelled.

Installation of pipes on site (A5) – Rubber rings

Table 17 and Table 18 present the environmental impacts of rubber rings used for RRJ pipes. The results are based on an average ring for RRJ pipes. The variation between different rings is within ±10%, with the exception of ADPE. The abiotic depletion potential (elements) of synthetic rubber (used for dry-cast pipes in Queensland) is three orders of magnitude higher than that of natural rubber.

Table 17– Environmental indicators, installation module A5, rubber rings for RRJ pipes, all locations, per effective metre of pipe

Environmental Indicator	DN300	DN375	DN450	DN525	DN600	DN675	DN750	DN825
GWP [kg CO_2 eq]	2.37E-01	3.15E-01	4.07E-01	6.31E-01	8.36E-01	1.04E+00	1.37E+00	1.43E+00
ODP [kg CFC-11 eq]	8.14E-08	1.02E-07	1.32E-07	2.06E-07	2.65E-07	3.16E-07	4.48E-07	4.63E-07
AP [kg SO_2 eq]	6.00E-04	7.70E-04	9.95E-04	1.55E-03	2.01E-03	2.43E-03	3.37E-03	3.48E-03
EP [kg PO_4^{3-} eq]	9.46E-05	1.24E-04	1.60E-04	2.49E-04	3.28E-04	4.03E-04	5.42E-04	5.62E-04
POCP [kg C_2H_4 eq]	7.00E-05	9.92E-05	1.28E-04	1.98E-04	2.72E-04	3.49E-04	4.31E-04	4.51E-04
ADPE [kg Sb eq]	6.64E-07	1.41E-06	1.81E-06	2.74E-06	4.42E-06	6.57E-06	6.00E-06	6.47E-06
ADPF [MJ_{NCV}]	4.35E+00	5.92E+00	7.70E+00	1.19E+01	1.60E+01	2.01E+01	2.55E+01	2.66E+01
Resource Use	**DN300**	**DN375**	**DN450**	**DN525**	**DN600**	**DN675**	**DN750**	**DN825**
PERE [MJ_{NCV}]	1.14E-01	1.52E-01	1.97E-01	3.05E-01	4.06E-01	5.04E-01	6.64E-01	6.90E-01
PERM [MJ_{NCV}]	0	0	0	0	0	0	0	0
PERT [MJ_{NCV}]	1.14E-01	1.52E-01	1.97E-01	3.05E-01	4.06E-01	5.04E-01	6.64E-01	6.90E-01
PENRE [MJ_{NCV}]	4.98E+00	6.69E+00	8.63E+00	1.34E+01	1.79E+01	2.23E+01	2.91E+01	3.03E+01
PENRM [MJ_{NCV}]	0	0	0	0	0	0	0	0
PENRT [MJ_{NCV}]	4.98E+00	6.69E+00	8.63E+00	1.34E+01	1.79E+01	2.23E+01	2.91E+01	3.03E+01
SM [kg]	0	0	0	0	0	0	0	0
RSF [MJ_{NCV}]	0	0	0	0	0	0	0	0
NRSF [MJ_{NCV}]	0	0	0	0	0	0	0	0
FW [m^3]	2.84E-03	4.12E-03	5.30E-03	8.18E-03	1.14E-02	1.48E-02	1.79E-02	1.87E-02
Waste Categories	**DN300**	**DN375**	**DN450**	**DN525**	**DN600**	**DN675**	**DN750**	**DN825**
HW [kg]	0	0	0	0	0	0	0	0
NHW [kg]	6.86E-03	8.61E-03	1.11E-02	1.73E-02	2.22E-02	2.64E-02	3.77E-02	3.89E-02
RW [kg]	0	0	0	0	0	0	0	0
Output flows	**DN300**	**DN375**	**DN450**	**DN525**	**DN600**	**DN675**	**DN750**	**DN825**
CRU [kg]	0	0	0	0	0	0	0	0
MFR [kg]	0	0	0	0	0	0	0	0
MER [kg]	0	0	0	0	0	0	0	0
EE [MJ]	0	0	0	0	0	0	0	0

Table 17 – Continued

Environmental Indicator	DN900	DN1050	DN1200	DN1350	DN1500	DN1650	DN1800	DN1950	DN2100
GWP [kg CO_2 eq]	1.75E+00	2.43E+00	2.42E+00	3.05E+00	3.73E+00	4.33E+00	5.38E+00	5.92E+00	6.27E+00
ODP [kg CFC-11 eq]	5.69E-07	7.90E-07	7.92E-07	1.01E-06	1.23E-06	1.44E-06	1.80E-06	1.99E-06	2.11E-06
AP [kg SO_2 eq]	4.28E-03	5.94E-03	5.94E-03	7.57E-03	9.21E-03	1.07E-02	1.34E-02	1.48E-02	1.57E-02
EP [kg PO_4^{3-} eq]	6.89E-04	9.57E-04	9.56E-04	1.21E-03	1.48E-03	1.71E-03	2.13E-03	2.35E-03	2.49E-03
POCP [kg C_2H_4 eq]	5.50E-04	7.62E-04	7.59E-04	9.38E-04	1.15E-03	1.33E-03	1.64E-03	1.80E-03	1.89E-03
ADPE [kg Sb eq]	7.78E-06	1.07E-05	1.05E-05	1.17E-05	1.49E-05	1.64E-05	1.95E-05	2.06E-05	2.10E-05
ADPF [MJ_{NCV}]	3.25E+01	4.49E+01	4.48E+01	5.63E+01	6.88E+01	7.96E+01	9.84E+01	1.08E+02	1.14E+02
Resource Use	**DN900**	**DN1050**	**DN1200**	**DN1350**	**DN1500**	**DN1650**	**DN1800**	**DN1950**	**DN2100**
PERE [MJ_{NCV}]	8.46E-01	1.17E+00	1.17E+00	1.47E+00	1.80E+00	2.09E+00	2.59E+00	2.86E+00	3.02E+00
PERM [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
PERT [MJ_{NCV}]	8.46E-01	1.17E+00	1.17E+00	1.47E+00	1.80E+00	2.09E+00	2.59E+00	2.86E+00	3.02E+00
PENRE [MJ_{NCV}]	3.71E+01	5.15E+01	5.14E+01	6.46E+01	7.90E+01	9.14E+01	1.14E+02	1.25E+02	1.32E+02
PENRM [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
PENRT [MJ_{NCV}]	3.71E+01	5.15E+01	5.14E+01	6.46E+01	7.90E+01	9.14E+01	1.14E+02	1.25E+02	1.32E+02
SM [kg]	0	0	0	0	0	0	0	0	0
RSF [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
NRSF [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
FW [m^3]	2.28E-02	3.16E-02	3.14E-02	3.86E-02	4.76E-02	5.46E-02	6.72E-02	7.35E-02	7.72E-02
Waste Categories	**DN900**	**DN1050**	**DN1200**	**DN1350**	**DN1500**	**DN1650**	**DN1800**	**DN1950**	**DN2100**
HW [kg]	0	0	0	0	0	0	0	0	0
NHW [kg]	4.78E-02	6.64E-02	6.66E-02	8.53E-02	1.04E-01	1.21E-01	1.51E-01	1.67E-01	1.78E-01
RW [kg]	0	0	0	0	0	0	0	0	0
Output flows	**DN900**	**DN1050**	**DN1200**	**DN1350**	**DN1500**	**DN1650**	**DN1800**	**DN1950**	**DN2100**
CRU [kg]	0	0	0	0	0	0	0	0	0
MFR [kg]	0	0	0	0	0	0	0	0	0
MER [kg]	0	0	0	0	0	0	0	0	0
EE [MJ]	0	0	0	0	0	0	0	0	0

Table 18– Environmental indicators, installation module A5, rubber rings for FJ pipes, QLD, per effective metre of pipe

Environmental Indicator	DN300	DN375	DN450	DN525	DN600	DN675	DN750	DN825
GWP [kg CO_2 eq]	6.73E-01	7.80E-01	9.36E-01	1.16E+00	1.20E+00	1.34E+00	1.50E+00	1.70E+00
ODP [kg CFC-11 eq]	2.51E-07	2.91E-07	3.49E-07	4.31E-07	4.46E-07	5.00E-07	5.59E-07	6.33E-07
AP [kg SO_2 eq]	1.80E-03	2.08E-03	2.50E-03	3.08E-03	3.19E-03	3.58E-03	4.00E-03	4.53E-03
EP [kg PO_4^{3-} eq]	2.73E-04	3.16E-04	3.80E-04	4.69E-04	4.85E-04	5.44E-04	6.07E-04	6.88E-04
POCP [kg C_2H_4 eq]	1.76E-04	2.04E-04	2.45E-04	3.02E-04	3.12E-04	3.50E-04	3.91E-04	4.43E-04
ADPE [kg Sb eq]	8.81E-09	1.02E-08	1.23E-08	1.51E-08	1.57E-08	1.76E-08	1.96E-08	2.22E-08
ADPF [MJ_{NCV}]	1.32E+01	1.52E+01	1.83E+01	2.26E+01	2.34E+01	2.62E+01	2.92E+01	3.31E+01
Resource Use	**DN300**	**DN375**	**DN450**	**DN525**	**DN600**	**DN675**	**DN750**	**DN825**
PERE [MJ_{NCV}]	3.21E-01	3.71E-01	4.46E-01	5.50E-01	5.69E-01	6.39E-01	7.13E-01	8.08E-01
PERM [MJ_{NCV}]	0	0	0	0	0	0	0	0
PERT [MJ_{NCV}]	3.21E-01	3.71E-01	4.46E-01	5.50E-01	5.69E-01	6.39E-01	7.13E-01	8.08E-01
PENRE [MJ_{NCV}]	1.39E+01	1.61E+01	1.93E+01	2.38E+01	2.46E+01	2.76E+01	3.08E+01	3.49E+01
PENRM [MJ_{NCV}]	0	0	0	0	0	0	0	0
PENRT [MJ_{NCV}]	1.39E+01	1.61E+01	1.93E+01	2.38E+01	2.46E+01	2.76E+01	3.08E+01	3.49E+01
SM [kg]	0	0	0	0	0	0	0	0
RSF [MJ_{NCV}]	0	0	0	0	0	0	0	0
NRSF [MJ_{NCV}]	0	0	0	0	0	0	0	0
FW [m^3]	6.82E-03	7.90E-03	9.48E-03	1.17E-02	1.21E-02	1.36E-02	1.52E-02	1.72E-02
Waste Categories	**DN300**	**DN375**	**DN450**	**DN525**	**DN600**	**DN675**	**DN750**	**DN825**
HW [kg]	0	0	0	0	0	0	0	0
NHW [kg]	2.13E-02	2.46E-02	2.96E-02	3.65E-02	3.77E-02	4.23E-02	4.73E-02	5.36E-02
RW [kg]	0	0	0	0	0	0	0	0
Output flows	**DN300**	**DN375**	**DN450**	**DN525**	**DN600**	**DN675**	**DN750**	**DN825**
CRU [kg]	0	0	0	0	0	0	0	0
MFR [kg]	0	0	0	0	0	0	0	0
MER [kg]	0	0	0	0	0	0	0	0
EE [MJ]	0	0	0	0	0	0	0	0

Table 18 – Continued

Environmental Indicator	**DN900**	**DN1050**	**DN1200**	**DN1350**	**DN1500**	**DN1650**	**DN1800**	**DN1950**	**DN2100**
GWP [kg CO_2 eq]	1.84E+00	2.18E+00	3.22E+00	3.77E+00	4.29E+00	4.63E+00	5.29E+00	5.82E+00	6.34E+00
ODP [kg CFC-11 eq]	6.86E-07	8.13E-07	1.20E-06	1.41E-06	1.60E-06	1.73E-06	1.97E-06	2.17E-06	2.36E-06
AP [kg SO_2 eq]	4.90E-03	5.81E-03	8.60E-03	1.01E-02	1.14E-02	1.23E-02	1.41E-02	1.55E-02	1.69E-02
EP [kg PO_4^{3-} eq]	7.45E-04	8.84E-04	1.31E-03	1.53E-03	1.74E-03	1.88E-03	2.14E-03	2.36E-03	2.57E-03
POCP [kg C_2H_4 eq]	4.80E-04	5.69E-04	8.42E-04	9.86E-04	1.12E-03	1.21E-03	1.38E-03	1.52E-03	1.66E-03
ADPE [kg Sb eq]	2.41E-08	2.85E-08	4.22E-08	4.94E-08	5.61E-08	6.06E-08	6.92E-08	7.62E-08	8.30E-08
ADPF [MJ_{NCV}]	3.59E+01	4.26E+01	6.30E+01	7.37E+01	8.37E+01	9.04E+01	1.03E+02	1.14E+02	1.24E+02
Resource Use	**DN900**	**DN1050**	**DN1200**	**DN1350**	**DN1500**	**DN1650**	**DN1800**	**DN1950**	**DN2100**
PERE [MJ_{NCV}]	8.75E-01	1.04E+00	1.54E+00	1.80E+00	2.04E+00	2.20E+00	2.52E+00	2.77E+00	3.02E+00
PERM [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
PERT [MJ_{NCV}]	8.75E-01	1.04E+00	1.54E+00	1.80E+00	2.04E+00	2.20E+00	2.52E+00	2.77E+00	3.02E+00
PENRE [MJ_{NCV}]	3.78E+01	4.49E+01	6.64E+01	7.77E+01	8.82E+01	9.52E+01	1.09E+02	1.20E+02	1.30E+02
PENRM [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
PENRT [MJ_{NCV}]	3.78E+01	4.49E+01	6.64E+01	7.77E+01	8.82E+01	9.52E+01	1.09E+02	1.20E+02	1.30E+02
SM [kg]	0	0	0	0	0	0	0	0	0
RSF [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
NRSF [MJ_{NCV}]	0	0	0	0	0	0	0	0	0
FW [m^3]	1.86E-02	2.21E-02	3.26E-02	3.82E-02	4.34E-02	4.69E-02	5.35E-02	5.90E-02	6.42E-02
Waste Categories	**DN900**	**DN1050**	**DN1200**	**DN1350**	**DN1500**	**DN1650**	**DN1800**	**DN1950**	**DN2100**
HW [kg]	0	0	0	0	0	0	0	0	0
NHW [kg]	5.80E-02	6.88E-02	1.02E-01	1.19E-01	1.35E-01	1.46E-01	1.67E-01	1.84E-01	2.00E-01
RW [kg]	0	0	0	0	0	0	0	0	0
Output flows	**DN900**	**DN1050**	**DN1200**	**DN1350**	**DN1500**	**DN1650**	**DN1800**	**DN1950**	**DN2100**
CRU [kg]	0	0	0	0	0	0	0	0	0
MFR [kg]	0	0	0	0	0	0	0	0	0
MER [kg]	0	0	0	0	0	0	0	0	0
EE [MJ]	0	0	0	0	0	0	0	0	0

Repair of pipes (B3)

Table 19 presents the environmental impacts of the repair process based on the following scenarios and assumptions:

- Three CCTV inspections take place (over the 100 year RSL).
- One crack per 200 metres of pipe exceeds 30 cm in length and/or is greater than 0.15 mm wide (BCC 2016), and therefore requires repair.
    - We estimate 125 grams of epoxy resin is required per repair.
    - An additional 75 grams of epoxy resin is included to account for waste.
    - 3 litres of fresh water is used per repair for cleaning of the surface.

Table 19 – Environmental indicators, repair module B3, per effective metre of pipe

Environmental Indicator	Repair (All pipes)
GWP [kg CO_2 eq]	7.59E-03
ODP [kg CFC-11 eq]	5.42E-11
AP [kg SO_2 eq]	1.67E-05
EP [kg PO_4^{3-} eq]	2.59E-06
POCP [kg C_2H_4 eq]	1.28E-05
ADPE [kg Sb eq]	2.55E-08
ADPF [MJ_{NCV}]	1.37E-01
Resource Use	**Repair (All pipes)**
PERE [MJ_{NCV}]	4.94E-03
PERM [MJ_{NCV}]	4.60E-04
PERT [MJ_{NCV}]	5.40E-03
PENRE [MJ_{NCV}]	1.23E-01
PENRM [MJ_{NCV}]	2.11E-02
PENRT [MJ_{NCV}]	1.44E-01
SM [kg]	0
RSF [MJ_{NCV}]	0
NRSF [MJ_{NCV}]	0
FW [m^3]	4.73E-05
Waste Categories	**Repair (All pipes)**
HW [kg]	1.52E-06
NHW [kg]	4.17E-04
RW [kg]	2.63E-06
Output flows	**Repair (All pipes)**
CRU [kg]	0
MFR [kg]	0
MER [kg]	0
EE [MJ]	0

Replacement of pipes (B4)

Given the large number of possible permutations associated with type of RCP, class, size, joint type (rubber rings), bedding type and end-of-life scenarios, it is considered too complicated to present the environmental impacts of replacement for each possible permutation. Instead, in order to account for replacement add 0.5% of the combined indicators from the product stage (A1-A3), transportation module (A4), installation module (A5), repair module (B3) and the end-of-life stage (C1-C4).

If a different percentage of replacement is more appropriate for a specific project, e.g. due to faulty installation of pipes, then apply the relevant percentage.

Deconstruction/demolition (C1)

The environmental impacts of the deconstruction/demolition module are presented in Table 20 based on the following scenarios:

- No demolition processes or impacts have been associated with pipes that are left in ground, re-lined with plastic or filled with grout.
- Fuel use for a hydraulic excavator has been included in relation to exhuming pipes. We assume that the lifting of 1 tonne of RCP requires as much energy as moving 1 m^3 of material with an excavator.
- When pipes are exhumed, the processes and impacts associated with digging of the trench are attributed to the new pipe system that is put in place of the exhumed system.
- No demolition processes or impacts have been associated with removing rubber rings.

Table 20 – Environmental indicators, end-of-life module C1, per tonne of pipe

Environmental Indicator	Left in ground	Re-lined w/ plastic pipe	Filled with grout	Exhumed and recycled
GWP [kg CO_2 eq]	0	0	0	4.78E-01
ODP [kg CFC-11 eq]	0	0	0	6.13E-08
AP [kg SO_2 eq]	0	0	0	3.80E-03
EP [kg PO_4^{3-} eq]	0	0	0	8.26E-04
POCP [kg C_2H_4 eq]	0	0	0	4.44E-04
ADPE [kg Sb eq]	0	0	0	7.33E-10
ADPF [MJ_{NCV}]	0	0	0	6.53E+00
Resource Use	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
PERE [MJ_{NCV}]	0	0	0	9.18E-03
PERM [MJ_{NCV}]	0	0	0	0
PERT [MJ_{NCV}]	0	0	0	9.18E-03
PENRE [MJ_{NCV}]	0	0	0	7.14E+00
PENRM [MJ_{NCV}]	0	0	0	0
PENRT [MJ_{NCV}]	0	0	0	7.14E+00
SM [kg]	0	0	0	0
RSF [MJ_{NCV}]	0	0	0	0
NRSF [MJ_{NCV}]	0	0	0	0
FW [m^3]	0	0	0	1.24E-03
Waste Categories	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
HW [kg]	0	0	0	0
NHW [kg]	0	0	0	0
RW [kg]	0	0	0	0
Output flows	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
CRU [kg]	0	0	0	0
MFR [kg]	0	0	0	0
MER [kg]	0	0	0	0
EE [MJ]	0	0	0	0

Transport (C2)

The environmental impacts of the transport of waste to a waste-processor are presented in Table 21 based on the following scenarios:

- No transport processes or impacts have been associated with pipes that are left in ground, re-lined with plastic or filled with grout.
- Pipes that are exhumed are transported to a recycling centre (crushing plant): We assume that transport occurs over 50 km one way, using a 20-28t truck.
- We assume that rubber rings (attached to the exhumed pipes) are transported to landfill over 50 km one way, using a 20-28t truck.

Table 21 – Environmental indicators, end-of-life module C2, per tonne of pipe

Environmental Indicator	Left in ground	Re-lined w/ plastic pipe	Filled with grout	Exhumed and recycled
GWP [kg CO_2 eq]	0	0	0	6.42E+00
ODP [kg CFC-11 eq]	0	0	0	7.97E-07
AP [kg SO_2 eq]	0	0	0	3.12E-02
EP [kg PO_4^{3-} eq]	0	0	0	6.58E-03
POCP [kg C_2H_4 eq]	0	0	0	6.79E-03
ADPE [kg Sb eq]	0	0	0	7.44E-09
ADPF [MJ_{NCV}]	0	0	0	8.58E+01
Resource Use	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
PERE [MJ_{NCV}]	0	0	0	7.49E-02
PERM [MJ_{NCV}]	0	0	0	0
PERT [MJ_{NCV}]	0	0	0	7.49E-02
PENRE [MJ_{NCV}]	0	0	0	9.33E+01
PENRM [MJ_{NCV}]	0	0	0	0
PENRT [MJ_{NCV}]	0	0	0	9.33E+01
SM [kg]	0	0	0	0
RSF [MJ_{NCV}]	0	0	0	0
NRSF [MJ_{NCV}]	0	0	0	0
FW [m^3]	0	0	0	1.28E-02
Waste Categories	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
HW [kg]	0	0	0	0
NHW [kg]	0	0	0	9.20E-04
RW [kg]	0	0	0	0
Output flows	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
CRU [kg]	0	0	0	0
MFR [kg]	0	0	0	0
MER [kg]	0	0	0	0
EE [MJ]	0	0	0	0

Waste Processing (C3)

The environmental impacts of the waste processing module are presented in Table 22 based on the following scenarios:

- No waste processing processes or impacts have been associated with pipes that are left in ground, re-lined with plastic or filled with grout.
- Pipes that have been exhumed are crushed. The resulting concrete rubble and steel scrap are separated and become available as secondary materials.
- No waste processing processes or impacts have been associated with rubber rings as these were sent to landfill in C2. The effects of landfilling rubber rings are included in C4.

Table 22 – Environmental indicators, end-of-life module C3, per tonne of pipe

Environmental Indicator	Left in ground	Re-lined w/ plastic pipe	Filled with grout	Exhumed and recycled
GWP [kg CO_2 eq]	0	0	0	1.19E-02
ODP [kg CFC-11 eq]	0	0	0	4.40E-10
AP [kg SO_2 eq]	0	0	0	3.67E-05
EP [kg PO_4^{3-} eq]	0	0	0	4.48E-06
POCP [kg C_2H_4 eq]	0	0	0	8.87E-06
ADPE [kg Sb eq]	0	0	0	1.93E-09
ADPF [MJ_{NCV}]	0	0	0	1.80E-01
Resource Use	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
PERE [MJ_{NCV}]	0	0	0	2.02E-03
PERM [MJ_{NCV}]	0	0	0	0
PERT [MJ_{NCV}]	0	0	0	2.02E-03
PENRE [MJ_{NCV}]	0	0	0	1.83E-01
PENRM [MJ_{NCV}]	0	0	0	0
PENRT [MJ_{NCV}]	0	0	0	1.83E-01
SM [kg]	0	0	0	0
RSF [MJ_{NCV}]	0	0	0	0
NRSF [MJ_{NCV}]	0	0	0	0
FW [m^3]	0	0	0	6.79E-05
Waste Categories	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
HW [kg]	0	0	0	0
NHW [kg]	0	0	0	2.34E-05
RW [kg]	0	0	0	0
Output flows	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
CRU [kg]	0	0	0	0
MFR [kg]	0	0	0	1.00E+03
MER [kg]	0	0	0	0
EE [MJ]	0	0	0	0

Disposal (C4)

The environmental indicators of the disposal module are presented in Table 23 based on the following scenarios:

- Pipes that are left in ground are assumed to have been disposed of, as if they end up in a landfill site. Concrete is a fairly inert material however AusLCI data for cement in landfill shows a small amount of phosphate may be emitted to water, contributing to eutrophication. This was used as a proxy for the cement content in the concrete left behind (conservatively set at 175 kg / tonne RCP).
- The impacts of the grout for the filled with grout scenario are included in this module;
  - Production of the grout and transport to the abandoned pipeline (assumed using a 3.5-16t truck, 50 km one way distance) is included.
  - On average, approximately 1.125 m^3 (±25%) of grout is required per tonne of pipe (average for DN300 – DN1050 pipes).
- Rubber rings left in ground are assumed to have similar impacts as rubber sent to landfill (although no methane emissions are captured).
- Rubber rings exhumed with pipes are assumed to end up in landfill, where the rubber decomposes.

Table 23 – Environmental indicators, end-of-life module C4, per tonne of pipe

Environmental Indicator	Left in ground	Re-lined w/ plastic pipe	Filled with grout	Exhumed and recycled
GWP [kg CO_2 eq]	0	0	1.12E+02	4.58E+00
ODP [kg CFC-11 eq]	0	0	3.70E-06	4.09E-10
AP [kg SO_2 eq]	0	0	3.17E-01	1.79E-03
EP [kg PO_4^{3-} eq]	0	0	6.04E-02	4.57E-04
POCP [kg C_2H_4 eq]	0	0	6.54E-02	4.11E-02
ADPE [kg Sb eq]	0	0	1.36E-06	-1.82E-11
ADPF [MJ_{NCV}]	0	0	7.77E+02	-3.70E+00
Resource Use	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
PERE [MJ_{NCV}]	0	0	4.86E+00	-1.52E-01
PERM [MJ_{NCV}]	0	0	0	0
PERT [MJ_{NCV}]	0	0	4.86E+00	-1.52E-01
PENRE [MJ_{NCV}]	0	0	8.07E+02	-3.70E+00
PENRM [MJ_{NCV}]	0	0	0	0
PENRT [MJ_{NCV}]	0	0	8.07E+02	-3.70E+00
SM [kg]	0	0	0	0
RSF [MJ_{NCV}]	0	0	0	0
NRSF [MJ_{NCV}]	0	0	0	0
FW [m^3]	0	0	5.63E-01	-5.72E-04
Waste Categories	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
HW [kg]	0	0	0	0
NHW [kg]	1.00E+03	0	3.07E+03	2.71E+00
RW [kg]	0	0	0	0
Output flows	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
CRU [kg]	0	1.00E+03	0	0
MFR [kg]	0	0	0	0
MER [kg]	0	0	0	0
EE [MJ]	0	0	0	0

Other environmental information

Recyclability potentials (Module D)

The environmental impacts and benefits beyond the system boundary (module D) are presented in Table 24 based on the following scenarios and assumptions:

- Per tonne of RCP that is exhumed and recycled at end-of-life, 950 kg of crushed rock production is avoided.
- Furthermore, for module D calculations, one tonne of RCP is assumed to contain 20 kg steel reinforcement. Per tonne of RCP that is recycled, 20 kg of scrap is collected for conversion in steel production. This is a conservative estimate.
  - This 20 kg of scrap is assumed to be transported over 250 km (one-way) by truck to an electric arc furnace.
  - The generic recycling rate for steel reinforcement (89%), as mentioned in our supplier's EPD, is considered applicable to RCP (reinforcement) recycling, thereby enabling the use of the module D figures as published (per mass unit) in (OneSteel 2016).

Table 24 – Environmental indicators, end-of-life module D, per tonne of pipe

Environmental Indicator	Left in ground	Re-lined w/ plastic pipe	Filled with grout	Exhumed and recycled
GWP [kg CO_2 eq]	0	0	0	-2.24E+01
ODP [kg CFC-11 eq]	0	0	0	2.19E-07
AP [kg SO_2 eq]	0	0	0	-5.01E-02
EP [kg PO_4^{3-} eq]	0	0	0	-5.63E-03
POCP [kg C_2H_4 eq]	0	0	0	-8.17E-03
ADPE [kg Sb eq]	0	0	0	-5.43E-06
ADPF [MJ_{NCV}]	0	0	0	-2.47E+02
Resource Use	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
PERE [MJ_{NCV}]	0	0	0	2.53E+00
PERM [MJ_{NCV}]	0	0	0	0.00E+00
PERT [MJ_{NCV}]	0	0	0	2.53E+00
PENRE [MJ_{NCV}]	0	0	0	-2.35E+02
PENRM [MJ_{NCV}]	0	0	0	0.00E+00
PENRT [MJ_{NCV}]	0	0	0	-2.35E+02
SM [kg]	0	0	0	0
RSF [MJ_{NCV}]	0	0	0	0
NRSF [MJ_{NCV}]	0	0	0	0
FW [m^3]	0	0	0	-1.31E+00
Waste Categories	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
HW [kg]	0	0	0	1.24E-04
NHW [kg]	0	0	0	-4.96E-02
RW [kg]	0	0	0	4.00E-03
Output flows	**Left in ground**	**Re-lined w/ plastic pipe**	**Filled with grout**	**Exhumed and recycled**
CRU [kg]	0	0	0	0
MFR [kg]	0	0	0	0
MER [kg]	0	0	0	0
EE [MJ]	0	0	0	0

How to calculate the life cycle impact of a product

Table 25 – Where to find corresponding environmental indicators, resource use, and pipe weight factors

Stage module	Environmental indicators	Page	Unit	Multiplication factor
A1-A3	Table 6 Table 7 Table 8 Table 9	16 17 18 19	per tonne	Pipe weight (t/m)
A4	Table 11 Table 12 Table 13	21 21 23	per tonne	Pipe weight (t/m)
A5	Table 14 Table 15 Table 16	24 25 26	per metre	1
A5 (rings)	Table 17 Table 18	27 29	per metre	1
B3	Table 19	31	per metre	1
B4	0.5% of the combined impact from other life cycle stages	n/a	per metre	1
C1	Table 20	32	per tonne	Pipe weight (t/m)
C2	Table 21	33	per tonne	Pipe weight (t/m)
C3	Table 22	34	per tonne	Pipe weight (t/m)
C4	Table 23	35	per tonne	Pipe weight (t/m)
D	Table 24	36	per tonne	Pipe weight (t/m)
Pipe weight factors	Table 28 Table 29 Table 30 Table 31	39 39 40 40	tonnes per metre	N/A

Example 1

Size: DN375 **Manufacturing Location:** Melbourne, VIC

Class: 2 **Installation scenario:** Type U (Unsupported)

Joint: RRJ **End of life scenario:** Pipes left in ground

Table 26 – Example 1, Calculation of GWP per effective metre of pipe

Stage module	GWP [kg CO_2 eq]	Unit	Multiplication factor	Result per metre of pipe
A1-A3	2.71E+02	per tonne	0.13*	3.52E+01
A4	3.55E+01	per tonne	0.13	4.62E+00
A5	6.42E+00	per metre	1 x 73%†	4.69E+00
A5 (rings)	3.15E-01	per metre	1	3.15E-01
B3	7.59E-03	per metre	1	7.59E-03
B4	0	per metre	1	2.11E-01‡
C1	0	per tonne	0.13	0
C2	0	per tonne	0.13	0
C3	0	per tonne	0.13	0
C4	0	per tonne	0.13	0
D	0	per tonne	0.13	0
Total				**45.1 kg CO_2 eq per effective metre**

* Pipe weight per effective metre for spun pipe, class 2, DN375, RRJ joint manufactured in Victoria is 0.13 tonnes per effective metre (see Table 28)
† Correction for bedding type U (see Table 16)
‡ Calculated as 0.5% of the sum of all other life cycle stages (see p.32 for detailed explanation)

Example 2

Size: DN1500 **Manufacturing Location:** Sydney, NSW

Class: 4 **Installation scenario:** Type HS2

Joint: RRJ **End of life scenario:** Pipes exhumed and recycled

Length of pipeline: 1450 metres
As per Example 1, the greenhouse gas emmissions per effective metre is calculated. The emissions are also applied to the entire length of the pipeline.

Table 27 – Example 2, Calculation of GWP per effective metre of pipe

Stage module	GWP [kg CO_2 eq]	Unit	Multiplication factor	GWP [kg CO_2 eq] per metre of pipe	Length of pipeline [metres]	GWP [kg CO_2 eq] for the total length of pipeline
A1-A3	2.92E+02	per tonne	1.60*	4.67E+02	1450	6.77E+05
A4	4.62E+01	per tonne	1.60	7.39E+01		1.07E+05
A5	5.17E+01	per metre	1 x 132%†	6.82E+01		9.90E+04
A5 (rings)	3.73E+00	per metre	1	3.73E+00		5.41E+03
B3	7.59E-03	per metre	1	7.59E-03		1.10E+01
B4	0	per metre	1	3.16E+00‡		4.58E+03
C1	4.78E-01	per tonne	1.60	7.65E-01		1.11E+03
C2	6.42E+00	per tonne	1.60	1.03E+01		1.49E+04
C3	1.19E-02	per tonne	1.60	1.90E-02		2.76E+01
C4	4.58E+00	per tonne	1.60	7.33E+00		1.06E+04
D	-2.24E+01	per tonne	1.60	-3.58E+01		-5.20E+04
Total				**599 kg CO_2 eq per effective metre**		**868 tonnes CO_2 eq**

* Pipe weight per effective metre for spun pipe, class 4, DN1500, RRJ joint manufactured in NSW is 1.60 tonnes per effective metre (see Table 28)
† Correction for bedding type HS2 (see Table 16)
‡ Calculated as 0.5% of the sum of all other life cycle stages (see p.32 for detailed explanation)

Product specification

The following tables are provided so the environmental impact can be calculated for a specific product. The value in the table represents the product's weight per linear metre of concrete pipe in tonnes so that the results of the LCA can be converted to:

1 equivalent metre of reinforced pipework with a given capacity (class, dimensions and mass shall be specified), applied in a 'normal environment' in Australia, with a service life of 100 years.

Table 28 – Product specification, Spun pipe, NSW/VIC/SA/WA/TAS, tonnes per effective metre

Diameter	RRJ			FJ		
	Class 2	Class 3	Class 4	Class 2	Class 3	Class 4
DN300	0.09	0.09	0.09	0.08	0.08	0.08
DN375	0.13	0.13	0.13	0.12	0.12	0.12
DN450	0.18	0.18	0.18	0.17	0.17	0.17
DN525	0.21	0.24	0.25	0.19	0.19	0.23
DN600	0.26	0.29	0.29	0.23	0.23	0.26
DN675	0.32	0.35	0.35	0.28	0.29	0.32*
DN750	0.39	0.44	0.44	0.34	0.34	0.39
DN825	0.43	0.50	0.50	0.39	0.39	0.46
DN900	0.58	0.59	0.59	0.45	0.49	0.52
DN1050	0.76	0.79	0.85	0.58	0.71	0.75
DN1200	0.91	0.91	1.07	0.73†	0.83	0.93
DN1350	1.01	1.02	1.23	0.89	0.98	1.11
DN1500	1.47	1.47	1.60	0.99	1.11	1.33
DN1650	1.60	1.62	1.89	1.19	1.35	1.57
DN1800	1.87	1.87	2.18	1.42	1.57	1.82‡
DN1950	2.27	2.28	2.42	1.73	1.85	2.13
DN2100	2.61	2.63	2.67	2.11	2.33	2.67

* Melbourne, VIC, DN675, class 4, † Adelaide, SA, DN1200, class 2, FJ and ‡ Perth, WA, DN1800, class 4, FJ are considered outlier and not included in scope

Table 29 – Product specification, Spun pipe, QLD/NT, tonnes per effective metre

Diameter	RRJ			FJ		
	Class 2	Class 3	Class 4	Class 2	Class 3	Class 4
DN300	–	–	–	–	–	–
DN375	0.13	0.13	0.13	0.12	0.12	0.12
DN450	0.18	0.18	0.18	0.17	0.17	0.17
DN525	0.21	0.24	0.25	0.19	0.19	0.23
DN600	0.26	0.29	0.29	0.23	0.23	0.26
DN675	0.33	0.35	0.35	0.28	0.29	0.32
DN750	0.39	0.39	0.45	0.34	0.34	0.39
DN825	0.43	0.50	0.57	0.39	0.39	0.50
DN900	0.59	0.59	0.60	0.45	0.49	0.52
DN1050	0.78	0.80	0.84	0.59	0.70	0.75
DN1200	0.91	0.91	1.09	0.73	0.81	0.93
DN1350	1.11	–	1.25	0.89	0.98	1.11
DN1500	1.47	–	1.60	0.99	1.11	1.47
DN1650	–	1.62	1.89	1.27	1.38	1.57
DN1800	1.87	–	2.18	1.41	1.57	1.80
DN1950	2.28	–	–	1.76*	1.85	2.13
DN2100	2.61	–	1.89	2.11	2.33	2.67

* Darwin, NT, DN1950, class 2, FJ considered outlier and is not included in scope

Table 30 – Product specification, Dry-cast pipe, NSW, tonnes per effective metre

Diameter	RRJ			FJ		
	Class 2	Class 3	Class 4	Class 2	Class 3	Class 4
DN300	–	–	–	–	–	–
DN375	0.14	–	0.14	–	–	–
DN450	0.19	–	0.19	–	–	–
DN525	0.22	–	0.23	–	–	–
DN600	0.29	–	0.32	–	–	–
DN675	0.36	0.36	0.43	–	–	–
DN750	0.43	0.43	0.44	–	–	–
DN825	0.48	0.48	0.51	–	–	–
DN900	0.59	0.59	0.61	–	–	–
DN1050	0.74	0.76	0.76	–	–	–
DN1200	0.93	1.11	1.11	–	–	–
DN1350	1.11	1.11	–	–	–	–
DN1500	1.34	1.33	1.72	–	–	–
DN1650	–	–	–	–	–	–
DN1800	1.97	1.97	1.96	–	–	–
DN1950	–	–	–	–	–	–
DN2100	–	–	–	–	–	–

Table 31 – Product specification, Dry-cast pipe, QLD, tonnes per effective metre

Diameter	RRJ			FJ		
	Class 2	Class 3	Class 4	Class 2	Class 3	Class 4
DN300	0.15	0.15	0.15	0.14	0.14	0.14
DN375	0.18	0.18	0.19	0.16	0.16	0.17
DN450	0.23	0.23	0.23	0.21	0.21	0.21
DN525	0.28	0.28	0.28	0.26	0.26	0.26
DN600	0.34	0.34	0.34	0.31	0.31	0.31
DN675	0.40	0.40	0.40	0.36	0.36	0.37
DN750	0.48	0.48	0.48	0.43	0.43	0.44
DN825	0.56	0.56	0.57	0.50	0.50	0.51
DN900	0.63	0.64	0.64	0.57	0.57	0.58
DN1050	1.06	1.06	1.07	1.02	1.02	1.03
DN1200	1.34	1.34	1.34	1.28	1.29	1.29
DN1350	1.63	1.64	1.65	1.43	1.44	1.45
DN1500	1.96	1.96	1.97	1.58	1.59	1.60
DN1650	2.33	2.34	2.34	2.29	2.29	2.34
DN1800	2.73	2.73	2.74	2.67	2.68	2.74
DN1950	3.14	3.15	3.16	3.11	3.12	3.16
DN2100	3.58	3.59	3.60	3.56	3.57	3.60

References

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FEICA 2015b	EPD of Reactive resins based on epoxy resin, aqueous/unfilled, IBU EPD Declaration number EPD-FEI-20150299-IBG1-EN, issued 14-12-2015, based on EN15804 and PCR for Reaction resin products EPD owner: FEICA - Association of the European Adhesive and Sealant Industry
FEICA 2015c	EPD of Reactive resins based on epoxy resin, filled and/or aqueous with high content of filler, IBU EPD Declaration number EPD-FEI-20150300-IBG1-EN, issued 14-12-2015, based on EN15804 and PCR for Reaction resin products EPD owner: FEICA - Association of the European Adhesive and Sealant Industry
FEICA 2015d	EPD of Reactive resins based on epoxy resin, unfilled/solvent-free with high content of reactive diluent, IBU EPD Declaration number EPD-FEI-20150301-IBG1-EN, issued 14-12-2015, based on EN15804 and PCR for Reaction resin products EPD owner: FEICA - Association of the European Adhesive and Sealant Industry
FEICA 2015e	EPD of Reactive resins based on epoxy resin, filled and/or aqueous with low content of filler, IBU EPD Declaration number EPD-FEI-20150302-IBG1-EN, issued 14-12-2015, based on EN15804 and PCR for Reaction resin products EPD owner: FEICA - Association of the European Adhesive and Sealant Industry
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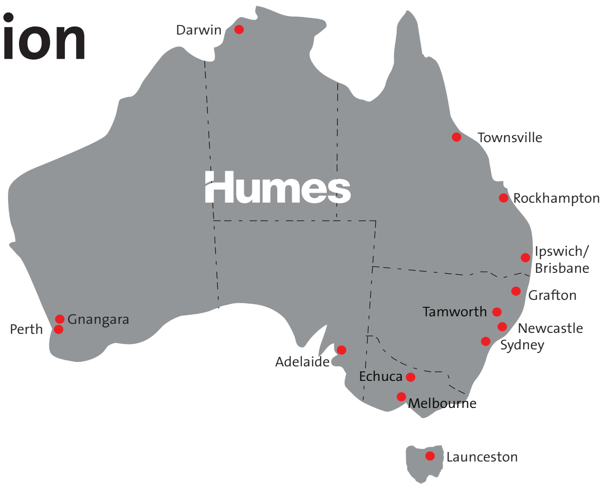

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