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Carbon Abatement Opportunities for Circular Economy

Report to NSW EPA: Final Report (Updated)

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Contents

Glossary of terms and abbreviations

Ash dams	Coal ash is stored by power stations in ash dams
Biochar	Carbon-rich materials (charcoal) produced from the slow pyrolysis of biomass.
C&D	Construction and demolition
C&I	Commercial and industrial
CACC	Carbon abatement cost curve[1].
CDS	Container deposit scheme
CO_{2e}	Carbon dioxide equivalent
Crumb rubber	Powder like product of highly refined rubber, its size is typically less then 1mm.
DECCW	NSW Department of Environment, Climate Change and Water
EAF	Electric Arc Furnace, a furnace used in steel production
EOLT	End-of-life tyres
EPiC	The Environmental Performance in Construction database
Fly Ash	A by-product of coal combustion in power stations
FO	Food organics
FOGO	Food organics and garden organics
Geopolymer cement	A Portland cement replacement, comprising fly ash, slag, waste glass and an activator such as sodium silicate.
GHG	Greenhouse gas
GO	Garden organics
HDPE	High density polyethylene
LDPE	Low density polyethylene
LEBM	Low Emissions Building Materials
Levelised costs	Assessment of average discounted costs over a given period.
LLDPE	Linear low density polyethylene is a blended form of LDPE
MECLA	Materials and Embodied Carbon Leaders' Alliance
MRF	Material recovery facility
MRRI	Major Resource Recovery Infrastructure
MSW	Municipal solid waste
OTR	Off the road tyres, usually used in mining and agriculture applications

[1] In this study, the CACC is a visual tool that identifies the average annual NSW based CO_{2e} emissions reduction of different initiatives and average net cost per tonne of CO_{2e} assessed on a levelized costs basis, over the short to medium term (15 – 20 years).

PIP	Product Improvement Program
Portland cement	Most common type of cement used in concrete. High in embodied carbon.
PP	Polypropylene
Pyrolysis	Heating in the absence of oxygen
RAP	Reclaimed asphalt pavement
SCMs	Supplementary cementitious materials, such as fly ash and slag
Scope 1	Direct greenhouse gas emissions from sources controlled or owned by the reporting organisation.
Scope 2	Indirect emissions associated with energy use (such as electricity, steam, heat or cooling) by the reporting organisation.
Scope 3	All indirect emissions (not in scope 2) that occur in the value chain of the reporting organisation, including upstream and downstream emissions.
Slag	A by-product of steel production
SMART	Centre for Sustainable Materials Research and Technology
SWF	Solid Waste Fuel
TDF	Tyre derived fuel
TfNSW	Transport for NSW
TSA	Tyre Stewardship Australia
The Strategy	NSW's Waste and Sustainable Materials Strategy 2041: Stage 1 2021 – 2027
UNSW	The University of NSW

Executive summary

Introduction

In 2020, the NSW Government has released its *Net Zero Plan Stage 1: 2020 – 2030*. The Plan sets out how carbon emissions will be reduced in NSW by 50% by 2030, as compared to 2005 levels. Sitting alongside the Net Zero Plan is the *Waste and Sustainable Materials Strategy 2041: Stage 1 2021 – 2027* (the Strategy). The Strategy sets out the NSW Government's plan to transition NSW to a circular economy over the next six years. A circular economy seeks to design out materials that end up in landfill or as litter, reuse or repair products before they are thrown out, or recycle materials so they can be used multiple times in manufacturing or construction.

The carbon abatement cost curve

Approach to the analysis

The following materials have been identified as potential priority waste materials for the purpose of developing a carbon abatement cost curve: aluminium; cement/concrete; fly ash (from electricity production); food and garden organics; paper and cardboard; plastics; slag (from steel production); steel; textiles; and tyres.

An initial review of opportunities was then undertaken across these materials, with a focus on:

- current and projected quantities of waste being generated;
- emissions in NSW associated with the production, use or disposal of the materials; and
- opportunities to reducing these emissions.

The review involved consultations with 26 industry stakeholders and materials specialists, focussing on opportunities associated with priority opportunities.

A carbon abatement cost curve is a visual tool that identifies the carbon abatement potential of different initiatives (within or across sectors) and net cost per tonne of CO_{2e} abated over a given time period. The use of the cost effectiveness metric ($/t$CO_{2\text{-}e}$) allows different opportunities to be compared on equivalent terms, providing guidance on where resources can be invested to achieve the greatest impact. The CACC produced for this study assesses average annual emission reductions and average costs. These have been assessed on a levelised costs basis, over a 15 year period.

Numerous opportunities for adoption of circular economy opportunities were identified over the course of discussions with stakeholders or review of the literature. Many of those opportunities were not subsequently assessed and incorporated into the CACC. Reasons for this include insufficient data relating to costs and/or emission reduction potential, likelihood that while emission reductions would be achieved, this would be outside of NSW, and abatement potential being only in the longer term.

Results

Figure ES 1 sets out the Carbon Abatement Cost Curve for circular economy opportunities in NSW. In total, annual emission abatement opportunities of approximately 1.85 million tonnes per annum have been identified, with a weighted average cost of abatement across all opportunities of approximately \$33/ tonne of $CO_{2\text{-}e}$. This represents over 10% of Scope 1 emissions associated with those sectors.

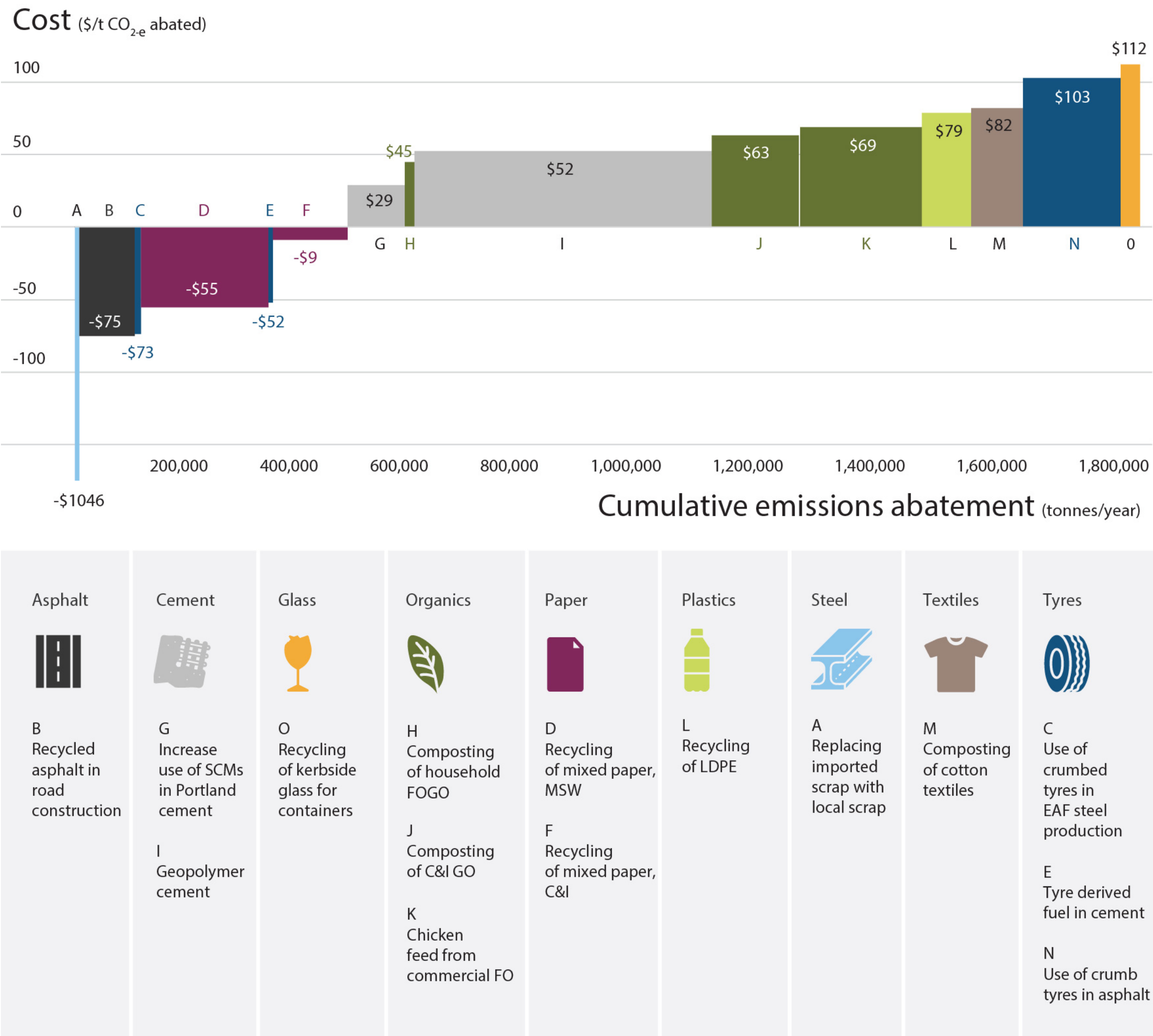

Figure ES 1: Carbon Abatement Cost Curve for circular economy opportunities

The total level of identified abatement is likely to be conservative, especially in the longer term. The total identified abatement and average cost figures hide wide ranges of emissions abatement potential and costs between different abatement opportunities:

- Approximately 26% (473 kilotonnes) of opportunities have negative costs, ranging from -\$1046/tonne to -\$9/tonne, with a weighted average cost of -\$54/ tonne.
- The other 74% of opportunities (1377 kilotonnes) have positive costs, ranging from \$29/ tonne to \$112/ tonne, with a weighted average cost of \$66/ tonne.

There are significant uncertainties associated with potential emission abatement and, in particular, the cost of emission abatement for some of the opportunities. Given these uncertainties, results of the CACC should only be used as guidance for investment in circular economy emissions abatement.

1. Introduction

1.1 Background

In 2020, The NSW Government has released its *Net Zero Plan Stage 1: 2020 – 2030*. The Plan sets out how carbon emissions will be reduced in NSW by 50%[2] by 2030, as compared to 2005 levels. It builds on the Government's *Climate Change Policy Framework*, which outlines the long-term aspiration of achieving Net Zero emissions in NSW by 2050.

Sitting alongside the Net Zero Plan is the *Waste and Sustainable Materials Strategy 2041: Stage 1 2021 – 2027* (the Strategy). The Strategy sets out the NSW Government's plan to transition NSW to a circular economy over the next six years. A circular economy seeks to design out materials that end up in landfill or as litter, reuse or repair products before they are thrown out, or recycle materials so they can be used multiple times in manufacturing or construction (Figure 1).

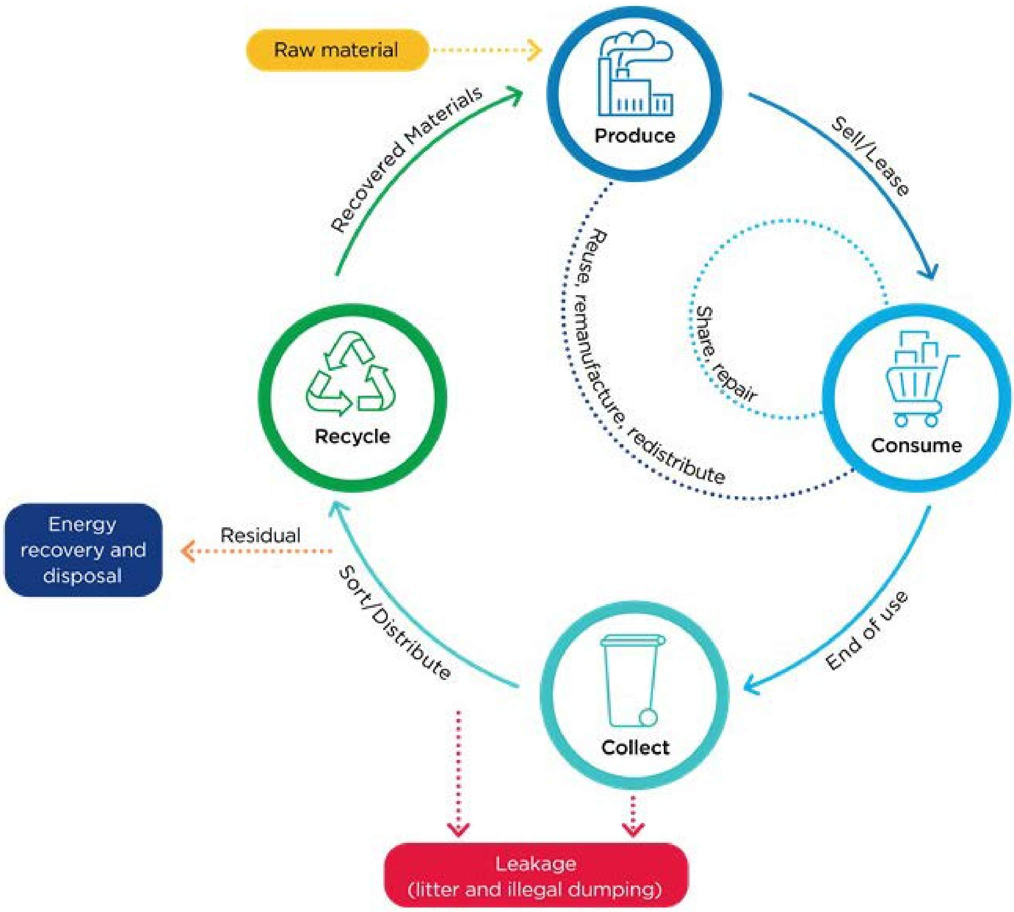

Figure 1: The circular economy

Source: DPIE 2021

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[2] The plan to reduce emissions by 50% by 2030 relative to 2005 has recently been upgraded from an earlier plan to reduce emissions by 35% by 2030.

Adopting circular economy principles also presents opportunities for reducing greenhouse gas emissions. Embodied carbon – that is, the emissions associated with the input materials, manufacture and use of a product or material – are estimated variously to comprise between about 30% and 50% of global greenhouse gas (GHG) emissions (Advancing Net Zero et al. 2019, BCG 2021, Ramboll et al. 2020). Packaging and construction materials, for example, are estimated to have embodied carbon of between 0.1 and 18 kg of emissions ($CO_{2\text{-}e}$) per kg of material if the materials are produced from raw materials. Recycling of these materials or applying innovative production processes to replace traditional inputs with 'waste' inputs has the potential to reduce embodied carbon substantially. For other materials, such as food and garden organics, paper, cardboard and organic textiles, end of life disposal to landfill involves release of substantial GHG emissions. Diverting these materials from landfill for composting, recycling or reuse can also substantially reduce emissions. (Figure 2)

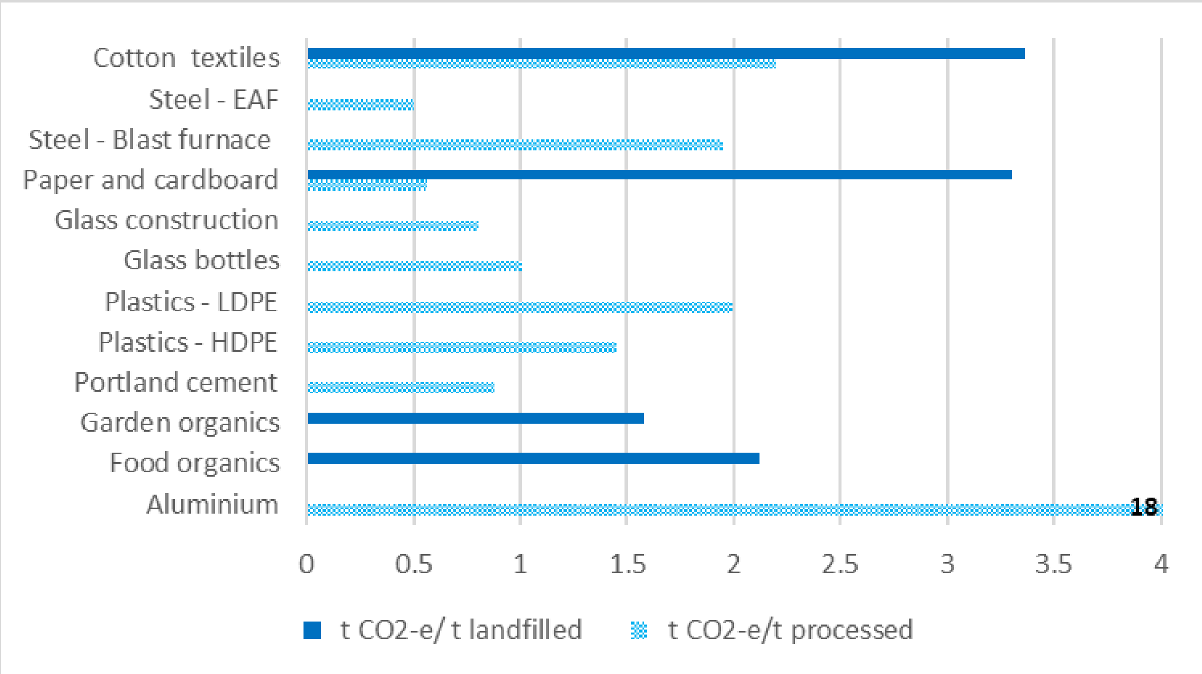

Figure 2: Estimates of carbon emissions associated with the processing or landfill of materials in NSW[3]

Source: Carre et al. 2015; Crawford et al. 2019; DECCW 2010; Sharma and Grant 2015; Marsden Jacob analysis

Transitioning to a circular economy therefore offers the potential to significantly reduce GHG emissions by:

- using recovered materials to displace use of high emission alternatives products or energy sources;
- designing out materials, waste and energy consumption in production processes across the value chain;
- retaining the embodied energy in products and materials by keeping them in use for longer, through

[3] Manufacture emissions only include emissions associated with the production process (Scope 1 and Scope 2). Landfill emissions do not account for recovery of landfill gas, which is factored into assessment of avoided emissions from opportunities associated with organics, paper and textiles.

reuse or recycling; and

- using recovered materials to help add or retain carbon in soil.

1.2 Purpose of the study

To achieve the objective of supporting innovative circular economy approaches that reduce carbon emissions through improved waste and materials management, it is important that government and industry interventions are well targeted at materials and processes that contribute to meeting key objectives of the Waste and Sustainable Materials Strategy[4] and are designed in a manner that:

- delivers on their potential to reduce emissions in the short or medium term;
- catalyses movement towards low embodied carbon across targeted materials, processes and sectors; and
- can help leverage changes more broadly and can achieve other benefits.

To that end, Marsden Jacob was engaged by NSW EPA to develop a carbon abatement cost curve (CACC) for circular economy opportunities and to provide advice on future government and industry actions to help achieve these goals.

This report presents results of the CACC development. The report is structured as follows:

- Section 2 presents and overview of the approach to the CACC analysis and summary of the results of the analysis.
- Section 3 presents further details on individual circular economy opportunities including key assumptions and discussion of potential barriers to realising opportunities.

[4] Objectives include: reducing total waste generated by 10% per person by 2030; having an 80% average recovery rate from all waste streams by 2030; significantly increase the use of recycled content by governments and industry; phasing out problematic and unnecessary plastics by 2025; and halving the amount of organic waste sent to landfill by 2030.

2. The carbon abatement cost curve

2.1 Approach to analysis

2.1.1 Scoping

NSW EPA identified the following as potential priority waste materials for the purpose of developing a carbon abatement cost curve:

- aluminium
- asphalt
- cement/concrete
- fly ash (from electricity production)
- food and garden organics
- paper and cardboard
- plastics
- slag (from steel production)
- steel
- textiles
- tyres.

Additional materials subsequently identified included glass and asphalt. Combined, the industries that are responsible for producing or disposing of these materials generate about 18 million tonnes of NSW Scope 1 emissions each year[5] or about 13.5% of total NSW emissions (Table 1). They are also responsible for about 11 million tonnes of emissions associated with electricity consumption (Scope 2).

Table 1: Estimates of Scope 1 GHG emissions from industries associated with priority materials, kt CO_{2-e}, 2018

Industry/ sector	Scope 1	
	ktonnes	% NSW
Total NSW (all sectors)	**131,685**	**100%**
Relevant industries and sectors	***17,745***	***13.5%***
Textile, Leather, Clothing and Footwear Manufacturing	112	0.1%
Wood, Pulp, Paper and Printing	333	0.3%
Basic Chemical, Polymer and Rubber Product Manufacturing	3,382	2.6%
Non-Metallic Mineral Product Manufacturing	2,812	2.1%
Primary Metal and Metal Product Manufacturing	7,153	5.4%
Solid Waste Collection, Treatment and Disposal	3,351	2.5%
Building Construction	303	0.2%
Heavy and Civil Engineering Construction	300	0.2%

—

5 Excludes the electricity industry, which is responsible for fly ash

Source: NGGI 2018, Marsden Jacob Analysis

An initial review of opportunities was then undertaken across these materials, with a focus on:

- current and projected quantities of waste being generated;
- emissions in NSW associated with the production, use or disposal of the materials; and
- opportunities to reducing these emissions.

Opportunities considered across these materials included (Table 2):

- reuse or recycling;
- use as inputs to innovative production or construction processes;
- redesign of products and structures to reduce their embodied carbon, enhance their life or to enhance recyclability at the end of their useful life; and
- diversion from landfill and reconstitution to assist with adding or retaining soil carbon.

The review involved consultations with 26 industry stakeholders and materials specialists, with discussions centred on:

- material types;
- potential opportunities; and
- emission reductions that could be realised through opportunities; and
- costs associated with the opportunities.

In many cases, multiple potential pathways were identified for each of the materials (Table 2). A key consideration when assessing opportunities, however, was a focus on opportunities that have the potential to abate NSW emissions, especially in the short to medium terms. Consequently, numerous opportunities were not assessed (see section 4).

Table 2: Circular economy pathways for priority materials considered

<table>
<tr><th></th><th colspan="4">Circular economy pathway</th><th></th></tr>
<tr><th>Material</th><th>Reuse or recycle</th><th>Waste inputs to innovative production or construction processes</th><th>Redesign of products or structures</th><th>Add or retain soil carbon</th><th>Notes</th></tr>
<tr><td>Aluminium</td><td>x</td><td></td><td>x</td><td></td><td rowspan="2">- Energy savings in production process through recycling or reuse</td></tr>
<tr><td>Steel</td><td>x</td><td></td><td>x</td><td></td></tr>
<tr><td>Asphalt</td><td>x</td><td></td><td>x</td><td></td><td>- Recycle
- Use of innovative materials top replace bitumen, aggregates or sand</td></tr>
<tr><td>Cement</td><td>x</td><td>x</td><td>x</td><td></td><td>- Geopolymer cement
- Re-use as aggregate in concrete
- Recycling as landscaping material</td></tr>
<tr><td>Glass</td><td>x</td><td>x</td><td></td><td></td><td rowspan="2">- Energy savings in production through recycling or reuse
- Potential input in production of geopolymer cement or in roads</td></tr>
<tr><td>Plastics</td><td>x</td><td>x</td><td>x</td><td></td></tr>
<tr><td>Fly ash</td><td></td><td>x</td><td></td><td></td><td rowspan="2">- Use in geopolymer cement production offers potential for energy savings and reduced process emissions</td></tr>
<tr><td>Slag</td><td></td><td>x</td><td></td><td></td></tr>
<tr><td>Food and garden Organics</td><td>x</td><td>x</td><td></td><td>x</td><td>- Diversion for composting reduces landfill methane and enhances soil carbon
- Also, potential energy source</td></tr>
<tr><td>Paper/ cardboard</td><td>x</td><td></td><td>x</td><td>x</td><td rowspan="2">- Reduces loss of biomass and soil carbon
- Energy savings in production process through recycling
- Reduced methane emissions when diverted from landfill
- Composting for retention of carbon in soil</td></tr>
<tr><td>Textiles</td><td>x</td><td></td><td>x</td><td>x</td></tr>
<tr><td>Tyres</td><td>x</td><td>x</td><td>x</td><td></td><td>- Re-treading
- Use in asphalt
- Pyrolysis
- Tyre derived fuels</td></tr>
</table>

2.1.2 Approach to the carbon abatement cost curve

A carbon abatement cost curve (sometimes referred to as a marginal abatement cost curve) is a visual tool that identifies the carbon abatement potential of different initiatives (within or across sectors) and net cost per tonne of $CO_{2\text{-}e}$ abated over a given time period. A diagram outlining how to interpret the carbon abatement cost curve developed for this study is shown in Figure 3. The use of the cost effectiveness metric ($/t$CO_{2\text{-}e}$) allows different opportunities to be compared on equivalent terms, providing guidance on where resources can be invested to achieve the greatest impact.

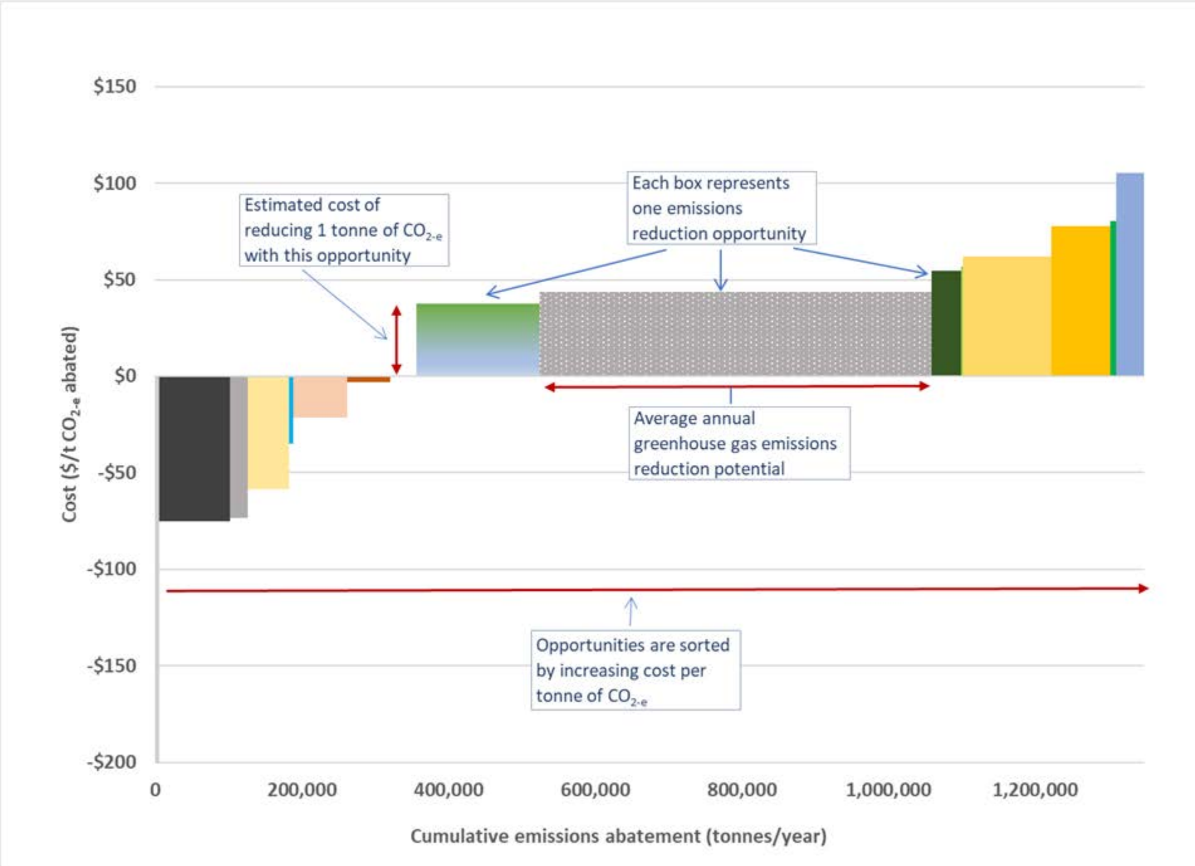

Figure 3: How to interpret the CACC

Source: Marsden Jacob after Climate Works 2010

2.1.3 Methodology for assessing inputs to the carbon abatement cost curve

The CACC produced for this study assesses average annual emission reductions and levelised costs. Levelised costing involves assessing discounted costs and emissions abatement over a given period (in this case 15 years for all options), applying the same discount rate to both costs and emissions. This enables opportunities to be compared on an equivalent basis. Three steps were taken for each opportunity to complete the levelised cost analysis:

1. The estimated quantity of GHG emissions that can potentially be abated through the opportunity relative to the baseline (i.e. emissions in the absence of the abatement opportunity), over 15 years expressed in tonnes $CO_{2\text{-}e}$[6]. This in turn required estimation of:
   - unit emissions associated with an established process, including (where relevant and material) production (Scope 1 and Scope 2), transport and disposal emissions (Scope 3);
   - equivalent unit emissions (Scope 1, Scope 2 and Scope 3[7]) associated with the relevant recycling, reuse or substitution process;
   - where relevant, current production in NSW of the relevant material using the established process;
   - the feasibility and extent of replacing the existing process with the alternative process, considering available supply and realistic recovery rate or availability of the waste material; and
   - ensuring that there is no double counting by adjusting for any quantity of waste material that has been identified for application through a lower cost opportunity.

   For the levelized cost analysis, avoided emissions were assessed over 15 years, with discounting applied to produce a present value of avoided emissions over 15 years.

   Annual emission abatement was assessed as the annual average over 15 years for each opportunity.
2. The cost of achieving that quantity of abatement relative to the baseline was assessed considering all costs over 15 years including capital and operating costs. Discounting was then applied to produce a present value of costs over 15 years (either positive or negative).
3. Finally, the levelised cost of each opportunity, expressed in $/tonne of $CO_{2\text{-}e}$ abated, was calculated by the dividing the present value of the 15 years of emissions abatement into the present value of costs over the same period.

Applying this approach, emission abatement and costs were estimated for 15 opportunities across nine materials.

2.1.4 Opportunities not assessed

Numerous opportunities for adoption of circular economy opportunities were identified in discussions with stakeholders or in reviewing the literature. Many of those opportunities were not subsequently incorporated into the CACC. Reasons for this include insufficient data relating to costs and/or emission reduction potential, likelihood that while emission reductions would be achieved these would be outside of NSW, and abatement potential being only in the longer term. Exclusion of these opportunities from the analysis is not necessarily an indication that they are not worthy of

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[6] Note, the estimated average annual emission reductions were assessed based on an estimate of realistic achievable reductions taking account of supply, technical and logistical considerations in the short to medium term (i.e. next 15-20 years).

[7] In some cases, Scope 2 and Scope 3 emissions intensities were not estimated for the established and alternative processes if differences between the two processes were considered to be immaterial. Where differences in Scope 2 emissions were identified as being material, adjustments were made to account for an expected reduction in emissions intensity of electricity supply in NSW over time.

further consideration to assess their potential to reduce GHG emissions or to meet other circular economy objectives. Further discussion of opportunities not assessed is provided in section 4.

2.1.5 Data sources

Data necessary to quantify each of the opportunities was drawn from:

- a range of waste and lifecycle analysis databases including:
  - NSW EPA's Waste Projections Model;
  - the Environmental Performance in Construction (EPiC) database;
  - NSW Department of Planning Industry & Environment's Low Emissions Building Materials (LEBM) Program energy and emissions model;
  - National Greenhouse Gas Inventory;
- Major Resource Recovery Infrastructure (MRRI) and Product Improvement Program (PIP) grant applications;
- numerous reports on embodied carbon and lifecycle emissions including Carre et al. (2015) and DECCW (2010); and
- consultations with key waste, construction, and manufacturing stakeholders, notably members of the Materials and Embodied Carbon Leaders' Alliance (MECLA).

2.1.6 Uncertainties

There are significant uncertainties associated with potential emission abatement and, in particular, the cost of emission abatement for some of the opportunities. The level of uncertainty associated with costs are identified with each of the opportunities (see following section). Given these uncertainties, results of the CACC should only be used as guidance for investment in circular economy emissions abatement.

2.2 Results

2.2.1 Overview

Figure 4 sets out the Carbon Abatement Cost Curve for circular economy opportunities in NSW. In total, annual emission abatement opportunities of approximately 1.85 million tonnes per annum have been identified, with a weighted average cost of abatement across all opportunities of approximately \$33/ tonne of $CO_{2\text{-}e}$. This represents over 10% of Scope 1 emissions associated with those sectors.

It is important to note that the total level of identified abatement is likely to be conservative, especially in the longer term. Abatement opportunities have been assessed on estimates of waste that can realistically be recovered and utilised for identified opportunities in NSW over the next 15 years, and don't necessarily reflect the potential for reducing emissions in the longer term.

Moreover, many opportunities have not been quantified due to lack of information or technical and environmental concerns (see section 4).

The total identified abatement and average cost figures hide wide ranges of emissions abatement potential and costs between different abatement opportunities:

- Approximately 26% (473 kilotonnes) of opportunities have negative costs, ranging from -$1046/tonne to -$9/tonne, with a weighted average cost of -$54/ tonne.
- The other 74% of opportunities (1377 kilotonnes) have positive costs, ranging from $29/ tonne to $112/ tonne, with a weighted average cost of $66/ tonne.

As detailed in Table 3, abatement opportunities vary substantially between individual opportunities. Noteworthy examples include:

- The three largest opportunities, in terms of emissions abatement potential, are:
  - the widespread take-up of geopolymer cement using waste fly ash, slag and glass (516 kt)
  - development of commercial food organics for chicken feedstock (213 kt)
  - recycling of mixed paper from C&I sources (221 kt).

  These three opportunities comprise about 40% of all identified abatement potential. Their estimated weighted average cost of abatement is $40/tonne.
- By contrast, many of the low cost opportunities have relatively limited abatement potential. The three opportunities with the lowest estimated cost have the potential of reducing emissions by just 114 kt (6% of all identified abatement opportunities).

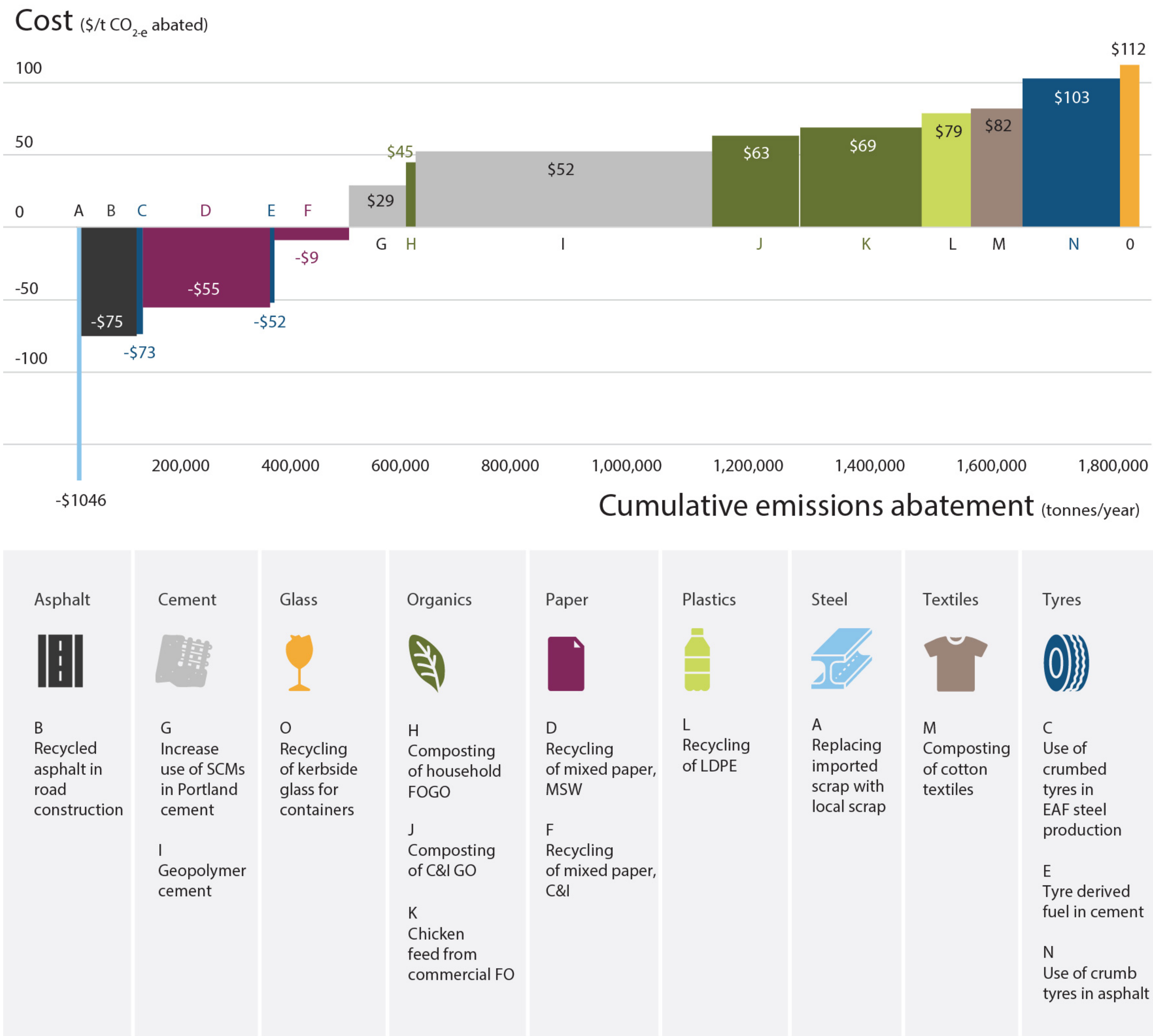


Figure 4: Carbon Abatement Cost Curve for circular economy opportunities

Table 3: Circular economy opportunities, further details

Material	Descriptor	CO_2 avoided tonnes/year	Cost ($/t) Central	High	Low
Steel	Replacing imported scrap with local scrap	6,401	**-1046**	-495	-1613
Asphalt	Recycled asphalt in road construction	96,148	**-75**	106	-166
Tyres	Use of crumb tyres in EAF steel production	12,090	**-73**	45	-133
Paper	Recycling of mixed paper, C&I	221,190	**-55**	-33	-77
Tyres	Tyre derived fuel use in cement	7,993	**-52**	**-31**	**-73**
Paper	Recycling of mixed paper, MSW	129,642	**-9**	-3	-14
Cement/fly ash/slag	Increased use of SCMs in Portland cement	98,587	**29**	**37**	**20**
Organics	Composting of household FOGO	17,237	**45**	69	20
Cement/fly ash/slag	Geopolymer cement	516,411	**52**	**68**	**36**
Organics	Composting of C&I GO	151,836	**63**	98	29
Organics	Chicken feed from commercial FO	213,376	**69**	126	-23
Plastics	Recycling of LDPE	85,972	**79**	42	97
Textiles	Composting of cotton textiles	90,222	**82**	109	62
Tyres/asphalt	Use of crumb tyres in asphalt	168,564	**103**	**257**	**-77**
Glass	Recycling of kerbside glass for containers	34,753	**112**	157	45
Total		**1,850,422**	**33**	78	-13

Factors driving emissions abatement potential and costs across the opportunities are discussed further in section 3.

2.2.2 Uncertainties

As detailed in Table 3, there are significant uncertainties associated with costs of abatement – for individual opportunities and averaged across all opportunities. Overall, the average weighted cost of abatement, has been estimated at $33/tonne across all opportunities. As indicated in Figure 5Table 3: Circular economy opportunities, further details, uncertainties with costs estimates mean this average could feasibly be as high as $78/tonne or as low as -$13/tonne, but more likely lies between $3/ tonne and $33/tonne.

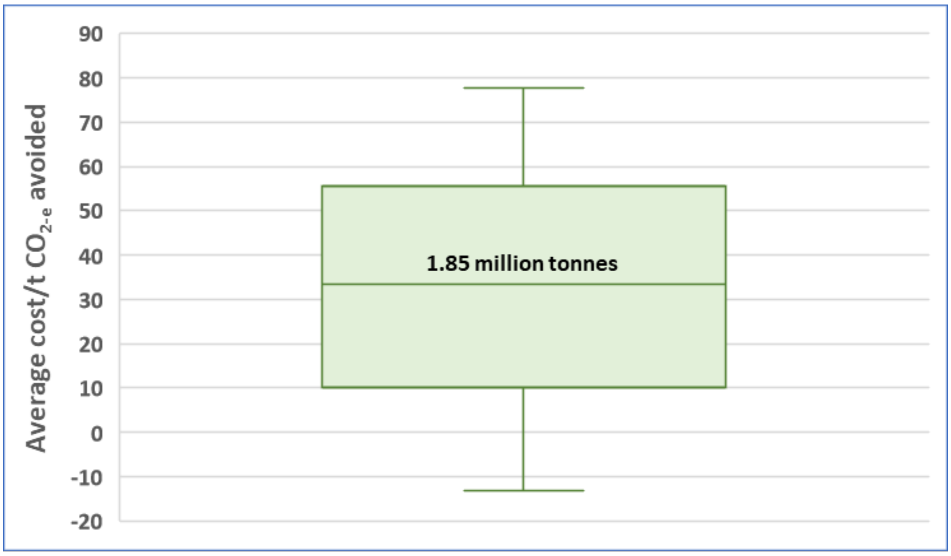


Figure 5: Weighted average cost of abatement, showing ranges of uncertainty

Ranges of uncertainty for costs vary significantly between opportunities:

- many of the lower cost options have high ranges of uncertainty - greater than +/-50%
- some of the higher cost opportunities have lower ranges of uncertainty - less than +/-30%.

The major factors driving uncertainty with costs include:

- limited information on the costs of abatement provided by stakeholders or available through databases and the literature;
- sometimes inconsistent cost information provided by applicants for PIP or MRI grants; or
- for low abatement opportunities in particular, abatement cost estimates varying significantly with relatively small changes to key assumptions.

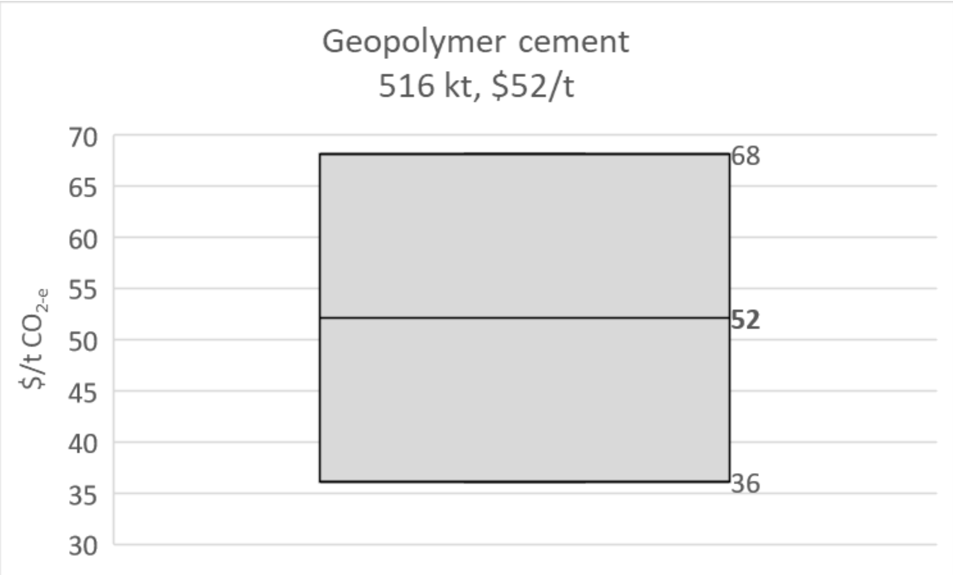
Some of these factors are discussed further in the following section.

There are also uncertainties with abatement potential for each of the opportunities. For most opportunities ranges of uncertainty are about +/- 25%, mainly reflecting uncertainties about the emissions intensity of established production processes versus alternative processes and materials or the potential for the established processes to be replaced with alternative processes and materials.

3. Details of individual opportunities

3.1 Opportunities associated with use of waste materials in production of cement

3.1.1 Geopolymer cement using fly ash, slag, waste glass



Overview

An estimated 1.4 million tonnes of Portland cement are currently produced in NSW (BZE 2017, CIF 2020, Yin et al. 2020), producing 1.35 million tonnes of CO_{2-e}, direct and indirect. This supplies about 50% of the demand for cement in the State, with remainder being imported from overseas or interstate as clinker or finished Portland cement.

The main stage of cement making involves the production of clinker, which involves transforming limestone (calcium carbonate - $CaCO_3$) into lime (CaO). This releases carbon dioxide (CO_2) as a waste product. The process accounts for about 55% of the direct and indirect carbon emissions associated with cement making. Another 27% of emissions are associated with coal used to heat the kilns for the clinker production process. Portland cement production in turn accounts for over 90% of the emissions associated with concrete production.

Replacing Portland cement with geopolymer cement that comprises a mix of fly ash, slag, waste glass and an activator such as sodium silicate, can largely eliminate the process and energy emissions associated with Portland cement.

Discussions with the construction industry for this project indicate that geopolymer cement outperforms or performs as well as Portland cement in many applications, including concrete piping exposed to high acidity, such as sewer pipes and tunnels, structural foundations in acidic soils and marine environments. This is supported by the literature (e.g., Aldred and Day, 2012, BZE 2017). In total, geopolymer cement could replace Portland cement in at least 50% of applications in the short to medium term and potentially most applications in the longer term, once more testing and proof of performance has been undertaken for these other activities.

Key issues

Availability of fly ash

Discussions with power station operators indicate that the supply of fly ash is not an issue in the short term, with 'run of station'[8] fly ash from the Bayswater power station and, to a lesser extent Mt Piper and Vales Point power stations, being significantly greater than current and future demand is likely to require. In the medium term however, with the expected closure of power stations, supply will need to be met through stockpiled fly ash. Assessing the availability of run of station fly ash given likely closure dates, indicates that by 2028 stockpiled fly ash will need to be accessed to meet potential demand and that reliance on stockpiled fly ash is likely to increase to about 70% of required supply by 2033. Relying on these stockpiles is likely to be substantially more expensive than using run of station supplies. This will significantly increase the cost of producing geopolymer cement in the future.

Cost of geopolymer cement

Separate sources indicate that the cost of producing geopolymer cement is currently between 5% and 10% greater than Portland cement when relying on run of station fly ash. Wagner's geopolymer cement was quoted in 2017 as being around 10-15% greater than traditional cement (BZE 2017). Cost differences relate to differences in costs of material inputs and, in part, reflect a lack of production scale. Construction industry stakeholders suggest the current cost differential is now about 5-10%. However, as previously noted, increased reliance on stockpiled fly ash is likely to increase the cost of geopolymer cement in the medium term. For this analysis, we have estimated the cost of geopolymer cement will be closer to 20% greater than Portland cement by the early 2030s, in the absence of any further reductions in production costs. Assessed over the long term however, once durability and longevity are taken into account, geopolymer cement could prove to be more cost effective than Portland cement for a number of applications.

Standards

Demand for geopolymer cement appears not to be an issue, with construction industry stakeholders indicating that, due to the quality and durability of the product, they will be comfortable with using geopolymer cement in many applications once supply is assured and there is a standard specification. Although handbooks and guidelines on the use of geopolymer concrete have been published by some organisations including Standards Australia (see Berndt et al. 2017 and Shayan 2016), the lack of a standard specification continues to be a barrier to the widespread uptake of geopolymer concrete, with current national and state standards and codes limiting concrete to a

[8] Fly ash produced from current, ongoing operations of the power station. This contrasts with very large, buried stockpiles of fly ash that have built up over time.

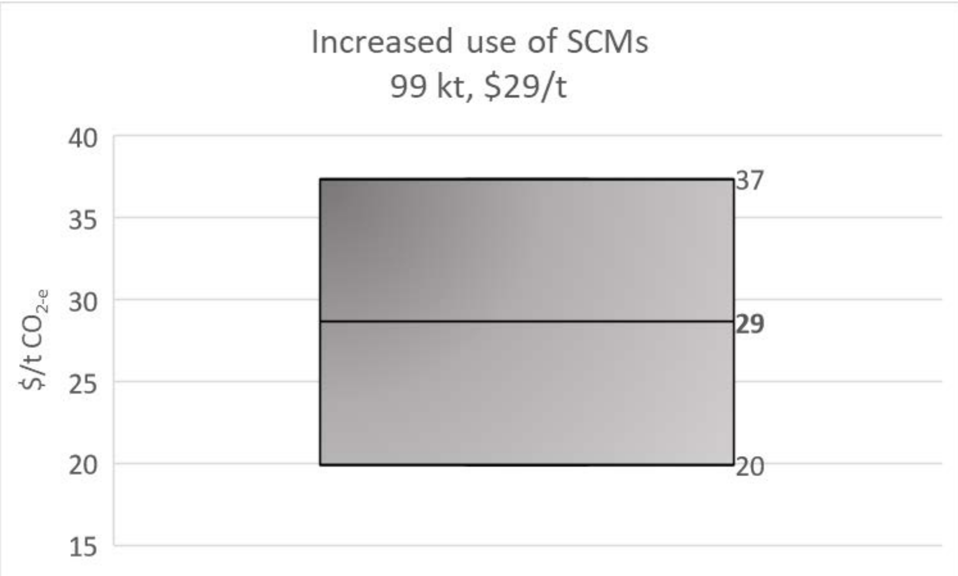
Portland cement-based binder. Discussions may need to be held with the appropriate industry regulators including TfNSW to rectify this situation.

Assumptions

Variable	Value
Annual production of Portland cement in NSW	1.4 million tonnes
Emissions from cement production and supply	1.35 million tonnes
Emissions intensity of Portland cement (includes 12% fly ash)	0.97 (t CO_{2-e}/ t cement) – 55% process emissions – 27% energy emissions – 11% electricity emissions[9] – 7% transport emissions
Emissions intensity of geopolymer cement	0.23 (t CO_{2-e}/ t cement)
Replacement of Portland cement with geopolymer cement	50%
Cost of geopolymer cement relative to Portland cement (averaged over 15 years)	+16%

Source: Alfred and Day 2012; BZE 2017; Boral 2021; CIF 2020; Crawford et al. 2019; Sharma and Grant 2015; VDZ 2020; Yin et al. 2020; stakeholder information; Marsden Jacob analysis

3.1.2 Increase supplementary cementitious materials (SCMs)



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9 Note, electricity emissions will be largely unaffected by replacing Portland cement with geopolymer cement. Electricity-related emissions associated with cement production are likely to fall substantially over the next 15 years for both Portland and geopolymer cement.

Overview

Australian and NSW product standards currently allow for supplementary cementitious materials (SCMs), such as fly ash and slag, to be used in the production of Portland cement. Stakeholders and literature indicate that the production of Portland cement in NSW currently comprises approximately 12% fly ash (Yin et al. 2020). Literature (e.g., BZE 2017, VDZ 2020) and discussions with stakeholders indicate that the use of SCMs could be increased substantially without compromising the integrity of the cement. Indeed, Portland cement based concrete products now available in Australia contain up to 50% reduction in Portland cement composition (Boral 2021). The Australian Standard for General Purpose and Blended Cements (AS 3792) does not limit the amount of fly ash in high blend cement, provided the fly ash meets the AS 3582.1 specification (supplementary cementitious materials for use with Portland cement – Fly ash). Transport for NSW (TfNSW) however, limits fly ash content to 40%.

Any increase in the use of SCMs will reduce process and energy emissions by effectively 100% in proportionate terms.

Key issues

We have assumed an increase to the maximum allowable 40% of fly ash, which stakeholders have also indicated should be technically feasible. Fly ash and other SCM content could potentially be increased by more than this, however there is some uncertainty as to whether and how difficult it will be to amend the industry standard to allow for an increase including greater use of slag. Discussions will need to be held with the appropriate industry regulators including TfNSW. Moreover, although increasing SCMs has a low cost at present (less than 5% greater than general purpose Portland cement when utilising run of station ash), costs will increase in the future when fly ash needs to be sourced from stockpiled ash.

Noting, the geopolymer opportunity discussed in the previous section, and comments from construction stakeholders indicating that high blend cements will not necessarily be suitable for all applications, we have conservatively assumed 25% replacement of general purpose Portland cement with high blend SCM cement.

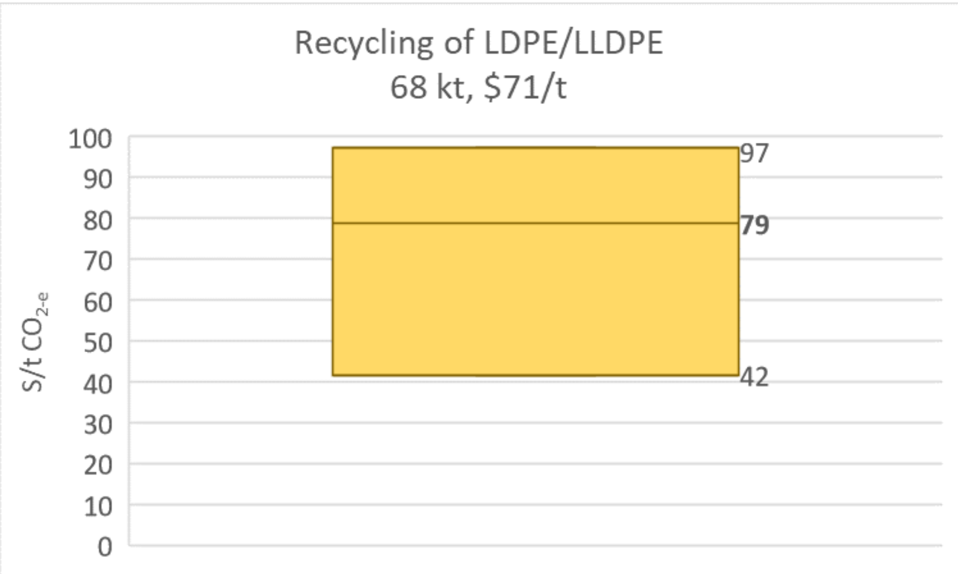
Assumptions

Variable	Value
Annual production of Portland cement in NSW	1.4 million tonnes
Emissions from cement production	1.35 million tonnes
Emissions intensity of Portland cement	0.97 (t $CO_{2\text{-}e}$/ t cement)
Current fly ash content of cement	12%
Fly ash and other SCM content with opportunity	Up to 40%
Replacement of general purpose Portland cement with high blend SCM cement	25%
Emissions intensity of Portland cement with opportunity	0.73 (t $CO_{2\text{-}e}$/ t cement)
Impact of opportunity on production cost of Portland cement	+3%

Source: Alfred and Day 2012; BZE 2017; Boral 2021; CIF 2020; Crawford et al. 2019; Sharma and Grant 2015; VDZ 2020; Yin et al. 2020; stakeholder information; Marsden Jacob analysis

3.2 Opportunities associated with recycling of plastics

3.2.1 Increased recycling of LDPE and LLDPE



Overview

Low density polyethylene (LDPE) and linear low density polyethylene (LLDPE) are used in a range of applications including bags (produce, heavier boutique bags and garbage bags), squeeze bottles, container lids, shrink wrap, toys and coatings for wire, and cable coverings. Consumption and disposal of LDPE/LLDPE in NSW is currently about 108,000 tonnes per year of which only about 7,500 tonnes (7%) are recycled. A substantial proportion of this material (70%) is consumer packaging that can feasibly be recovered (Envisage Works 2021). Total production of LDPE and LLDPE in NSW is currently about 170,000 tonnes.

Production of HDPE and PP from raw materials currently has an average emission factor of about 1.8 tonnes CO_{2-e}/ tonne of product. Replacing raw materials with recycled resin in the production process can reduce net emissions (including Scope 1, 2 and 3 emissions) by about 50%. (Carre et al. 2015, DECCW 2010)

Key Issues

Recovering HDPE will require substantial additional investment in sorting and recycling infrastructure capacity in NSW, as well as incurring ongoing operating costs. The total net cost over 15 years (after allowing for increased revenue) is estimated to be approximately $6.8 million in NPV terms.

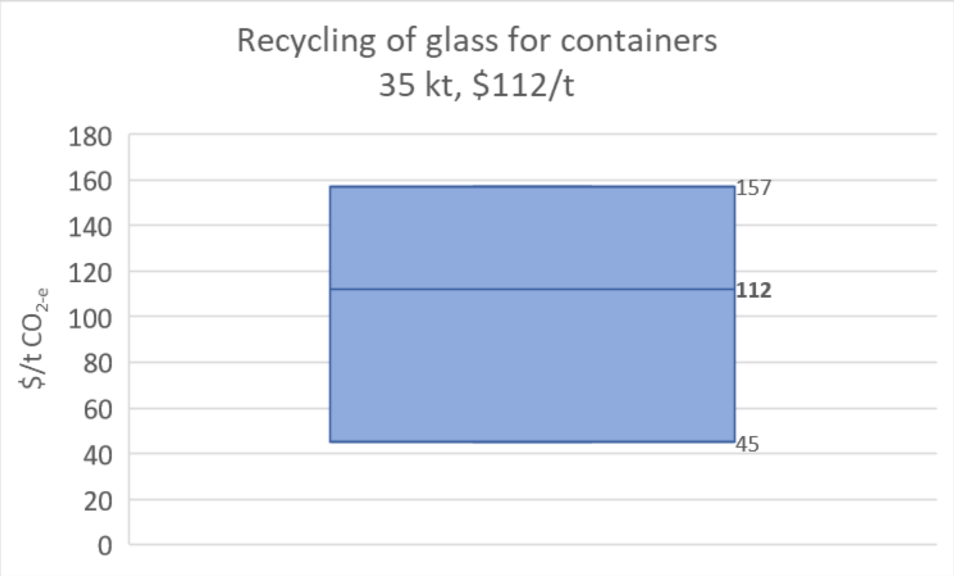
Assumptions

Variable	Value
Annual production of LDPE/LLDPE in NSW	170,000 tonnes
Annual disposal of LDPE/LLDPE in NSW	108,400 tonnes
Current recycling rate of LDPE/LLDPE	7,500 tonnes
Current recycling rate of LDPE/LLDPE	7%
Maximum feasible recovery rate, given current technology and behaviour	90%
Feasible additional recovery of LDPE/LLDPE	97,560 tonnes
Emissions intensity of LDPE/LLDPE plastics production using raw materials (including Scope 1, 2 and 3)	1.8 t CO_{2-e}/ t plastic
Emissions intensity of LDPE/LLDPE plastics production (using recycled materials)	0.9 t CO_{2-e}/ t plastic
Additional cost of production	$ 79/ tonne

Source: *Carre et al, 2015; DECCW 2010; Envisage Works 2021; Hamilton et al. 2019; NSW EPA waste projections model; Schandl et al. 2020; stakeholder information, Marsden Jacob analysis*

3.3 Opportunities associated with recycling of glass

3.3.1 Increased recycling of glass for beverage containers



Overview

Approximately 420,000 tonnes of glass containers reach end-of-life in NSW each year[10]. Of this total, an estimated 110,000 tonnes are recovered as cullet for recycling back into containers in NSW, with the remainder being either disposed to landfill (138,000 tonnes), recovered for use in other applications, such as road base, or recycled outside of NSW (Envisage Works et al. 2021). The recycling rate of containers in NSW has increased in recent years, driven by the introduction of a container deposit scheme (CDS) and investment in glass beneficiation capacity. However, consumption and disposal of containers to landfill is also projected to increase in the future.

Production of beverage containers in NSW is currently undertaken through a single facility in Penrith, which has a capacity of about 220,000 tonnes per annum (SRU 2019, Envisage Works et al. 2021). Upon purchase of the facility from Owens-Illinois in 2020, Visy indicated that it intends to increase recycled content in its glass container production from about 33% across its Australian facilities to about 66%[11]. The technically feasible maximum recycled content in glass container manufacture is about 80% (SRU 2019).

Production of container glass from raw materials currently has an average emission factor of about 1.0 tonnes $CO_{2\text{-}e}$/ tonne of product (including processing and transport emissions - Carre et al. 2015). Replacing raw materials with recycled glass in the production process will reduce net emissions (including processing and transport emissions) by greater than 50% to less than 0.5 tonnes $CO_{2\text{-}e}$/ tonne of product.

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10 NSW EPA waste projections model

11 *Visy acquires glass manufacturing business*, media release, 16 July 2020

Key Issues

As previously noted there has been an increase in the use of recycled content in glass container manufacturing in NSW in recent years. Given public commitments by Visy, this trend could continue. Furthermore, there appears to be capacity in existing facilities to increase recycled content in glass containers beyond 66%. Further increases in use of recycled cullet beyond those already committed are likely to require some additional investment in beneficiation capacity in NSW and associated operating costs. Additionally, increasing recycled content in containers (whether manufactured in NSW or elsewhere) is likely to require other initiatives to improve glass recovery by consumers. These could include education behaviour change programs or changes to kerbside services, such as the introduction of a separate glass kerbside bin.

There is significant uncertainty about the net cost of additional infrastructure and programs. This uncertainty is reflected in the wide range of potential costs presented for this opportunity. Nevertheless, significant net costs are likely overall, even after accounting for the value of recovered glass.

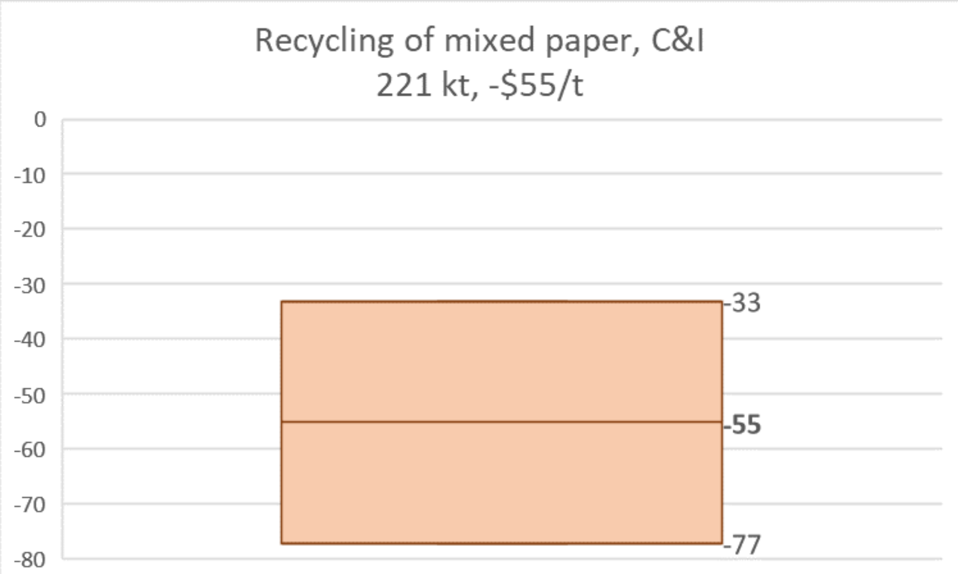
Assumptions

Variable	Value
Annual disposal of glass containers to landfill in NSW	137,700 tonnes
Annual production of beverage containers in NSW	220,000 tonnes
Current use of cullet in production of containers	110,800 tonnes
Maximum feasible use of cullet in glass container manufacturing	80%
Feasible additional recovery of container glass in NSW	66,000 tonnes
Emissions intensity of glass container production (using raw materials)	1.01 t $CO_{2\text{-}e}$/ t glass
Emissions intensity of glass container production (using recycled materials)	0.47 t $CO_{2\text{-}e}$/ t glass
Additional cost of production	$ 59/ tonne

Source: Carre et al, 2015; DECCW 2010; Envisage Works et al 2021; NSW EPA waste projections model; Schandl et al. 2020; SRU 2019; stakeholder information; Marsden Jacob analysis

3.4 Opportunities associated with recycling of paper and cardboard

3.4.1 Increased recycling of mixed paper, C&I



Overview

Production of paper and cardboard in NSW at present is about 2.25 million tonnes, of which about 1.5 million tonnes (67%) are recycled paper, the other 0.75 million tonnes being sourced from predominantly virgin fibre[12].

Approximately 565,000 tonnes (annual average) of mixed paper and cardboard is likely to be disposed to landfill each year from C&I sources over the next 10 years. This represents about 61% of all paper and cardboard that will be disposed to landfill in NSW[13]. Sorting and contamination removal at material recovery facilities (MRFs), and other sorting infrastructure, results in material losses however, estimated to be in the order of 15-20%. This material is landfilled. Moreover, even with minimal contamination, production of recycled paper entails losses, estimated to be greater than 17% (Industry Edge 2021, stakeholder data). This material is also landfilled. Production of recycled paper, therefore, will typically involve process losses of about 35% overall. This means that although an average of 565,000 tonnes of C&I paper could be redirected each year to replacing virgin fibre paper production, this will only replace about 368,000 tonnes of virgin fibre paper production or 49% of total virgin fibre paper production of 750,000 tonnes.

Producing paper from virgin fibre currently results in emissions of about 0.6 tonnes $CO_{2\text{-}e}$/ tonne of product. This includes processing and transport emissions (Carre et al. 2015, DECCW 2010). Production of recycled paper involves somewhat higher emissions (0.9 tonnes $CO_{2\text{-}e}$/ tonne of product), due to significant emissions associated with transport, collection and sorting processes. Every tonne of paper that is diverted from landfill through recycling processes will also reduce

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12 Production occurs at four major facilities - Visy in Tumut and Smithfield, ABC in Wetherill, and Opal in Botany (Industry Edge 2020, 2021).

13 NSW EPA waste data projections

emissions by about 1.9 tonnes[14]. After allowing for recycling losses however, the net effect of substituting virgin fibre paper production with recycled paper production is to reduce emissions by about 0.6 tonnes CO_{2-e}/ tonne paper.

Key Issues

A key barrier to increasing paper and cardboard recycling is contamination in the source material, with contamination rates of less than 0.5% being needed to avoid significant impacts on paper quality and/or costs or production. Investment in improved sorting infrastructure will significantly reduce the problem of contamination, significantly increasing prospects for the recovered material replacing virgin material in paper production. Net costs of this investment are likely to be negative over a period of about 15 years after allowing for the value of recovered material.

Market difficulties, relating to the willingness of producers to buy recovered paper for remanufacturing remains another key barrier to increasing recycling. Virgin fibre is similar in cost to recycled fibre, but recycling can affect strength and durability of paper. Some purchasers of paper products may therefore be reluctant to use recycled paper, especially in some packaging applications. Promotion of recycled paper, through policies such as government procurement, will be important to helping overcome this barrier.

Paper disposed to landfill from C&I sources are projected to result in annual emissions of 1.4 million tonnes of CO_{2-e} over the next 10 years. Increasing the recycling of paper will reduce only a fraction of those emissions. Given this, seeking additional pathways for avoiding disposal of paper to landfill – both for paper that is being disposed directly to landfill and paper and pulp that is a by-product of the recycling and production processes – is another key issue that will need to be examined. Options include composting and waste to energy systems (including anaerobic digestion). These options have not been assessed for this analysis due to uncertainties about their technical feasibility and/or other, non-greenhouse, environmental concerns associated with their application. Analysis of organics opportunities however (see section 3.5) suggest that composting is likely to be a substantially more cost-effective option than waste to energy.

Assumptions

Variable	Value
Annual production of paper from virgin fibre, NSW	754,000 tonnes
Annual disposal of C&I mixed paper to landfill, NSW	565,850 tonnes
Material losses in the recycling process	35%
Annual recovery of C&I paper for recycling (technically feasible)	367,803 tonnes
Emissions intensity of paper production using virgin fibre (including processing, transport and disposal)	2.52 t CO_{2-e}/ t paper

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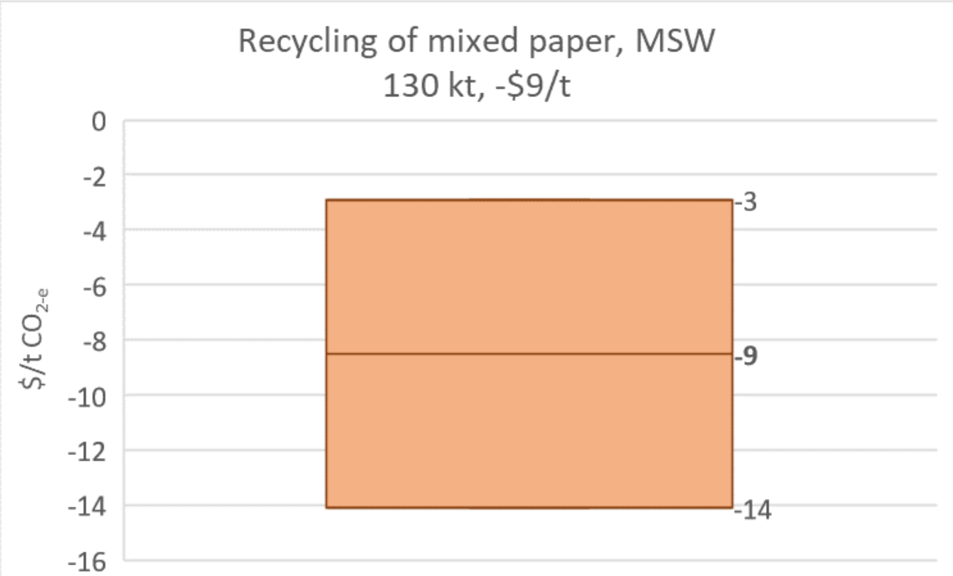
14 The 'gross' emission factor of paper disposed to landfill is about 3.3 tonnes CO_{2-e}/tonne disposed but after accounting for landfill gas recovery, estimated at about 42.6% in NSW, actual emissions are about 1.9 tonnes CO_{2-e}/tonne disposed.

Variable	Value
Emissions intensity of paper production using recycled fibre (including transport, sorting, transport, processing and disposal of recycle wastage)	1.92 t $CO_{2\text{-}e}$/ t paper[15]
Additional cost of recovery	-$55/ tonne

Source: Carre et al, 2015; DECCW 2010; DISER 2020, 2021; Envisage Works et al 2021; Industry Edge 2021; NSW EPA waste projections model; Schandl et al. 2020; SRU 2019; stakeholder information, Marsden Jacob analysis

3.4.2 Increased recycling of mixed paper, MSW



Overview

An estimated 332,000 tonnes (annual average) of mixed paper and cardboard is likely to be disposed to landfill each year from MSW sources over the next 10 years. After allowing for losses in the recycling process, this could replace approximately 216,000 tonnes of virgin fibre paper production.

As with C&I paper recycling, replacing virgin fibre paper production with recycled paper will result in a net reduction in emissions of about 0.6 t $CO_{2\text{-}e}$/ tonne paper.

Key Issues

Investment in improved sorting infrastructure will significantly reduce the problem of contamination in MSW waste paper, increasing the prospect for the recovered material replacing virgin material in paper production. The net cost of this investment is likely to be greater, on per unit cost basis, than C&I investment however, reflecting generally greater levels of contamination in MSW. Even so, net costs are likely to be negative even after allowing for the value of recovered material.

15 Note, this value includes landfill gas recovery, estimated at 42.6% for NSW

As with C&I waste paper, market difficulties relating to the willingness of purchasers of paper products to use recycled paper, remains a key barrier to increasing the production of recycled paper.

Paper disposed to landfill from MSW sources are projected to result in annual emissions of 0.8 million tonnes of CO_{2-e} over the next 10 years. Increasing the recycling of paper will reduce only a fraction of those emissions. As with C&I paper therefore, seeking additional pathways for avoiding disposal of paper to landfill is another key issue that will need to be examined.

Assumptions

Variable	Value
Annual production of paper from virgin fibre, NSW	754,000 tonnes
Annual disposal of MSW mixed paper to landfill, NSW	331,650 tonnes
Material losses in the recycling process	35%
Annual recovery of MSW paper for recycling (technically feasible)	215,573 tonnes
Emissions intensity of paper production using virgin fibre (including processing, transport and disposal)	2.52 t CO_{2-e}/ t paper
Emissions intensity of paper production using recycled fibre (including transport, sorting, transport, processing and disposal of recycle wastage)	1.92 t CO_{2-e}/ t paper[16]
Additional cost of recovery	-$9/ tonne

Source: Carre et al, 2015; DECCW 2010; DISER 2020, 2021; Envisage Works et al 2021; Industry Edge 2021; NSW EPA waste projections model; Schandl et al. 2020; SRU 2019; stakeholder information, Marsden Jacob analysis

3.5 Opportunities associated with the recovery of organics

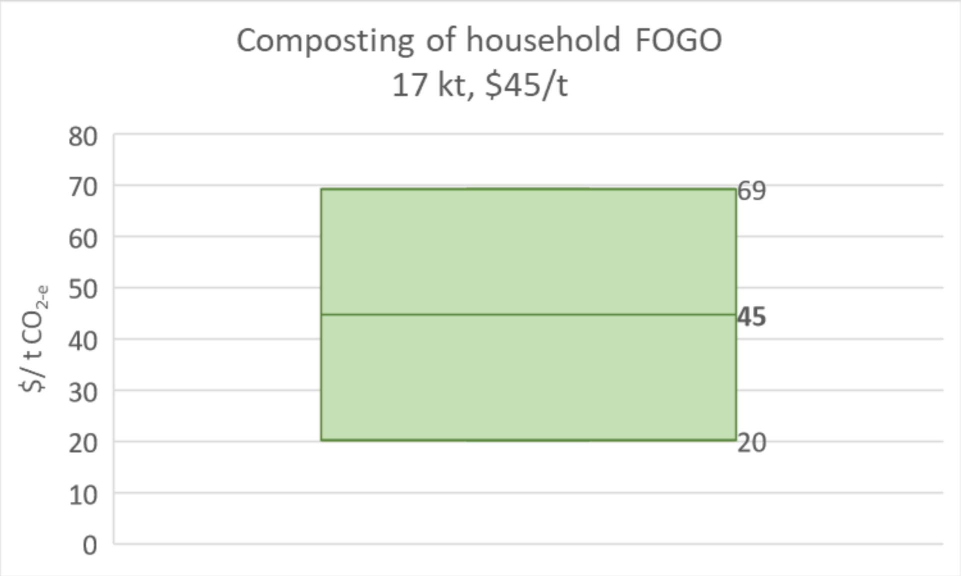
A range of options to achieve reduced carbon emissions across the different sources of organic waste. In each case, the lowest cost approach was included. The range of costs (low/central/high) associated with each waste stream reflects the costs for the identified process. In particular, anaerobic digestion processes were not as cost effective as expansion of existing composting facilities.

With regards to organic waste collected in ‘normal’ domestic garbage (‘red bin’), we did not identify any approach to separate organic waste from other waste that was costed. The analysis below therefore does not include organic waste from domestic garbage bins.

In considering the impact of alternative treatment of organic waste, a significant reduction in carbon emissions is achieved through diversion from landfill.

16 Note, this value includes landfill gas recovery, estimated at 42.6% for NSW

3.5.1 Recovery from MSW bin/FOGO



Overview

In 2019-20, some 746,490 tonnes of domestic-source organics were recycled from 765,184 tonnes collected. Opportunities to reduce the remaining 17,387 tonnes still being sent to landfill are available to expand existing facilities to process greater volumes of domestic FOGO.

Key issues

Cost

However, the average costs associated with these expansions are significantly affected by throughput. A halving of throughput could increase average cost two-fold.

Demand

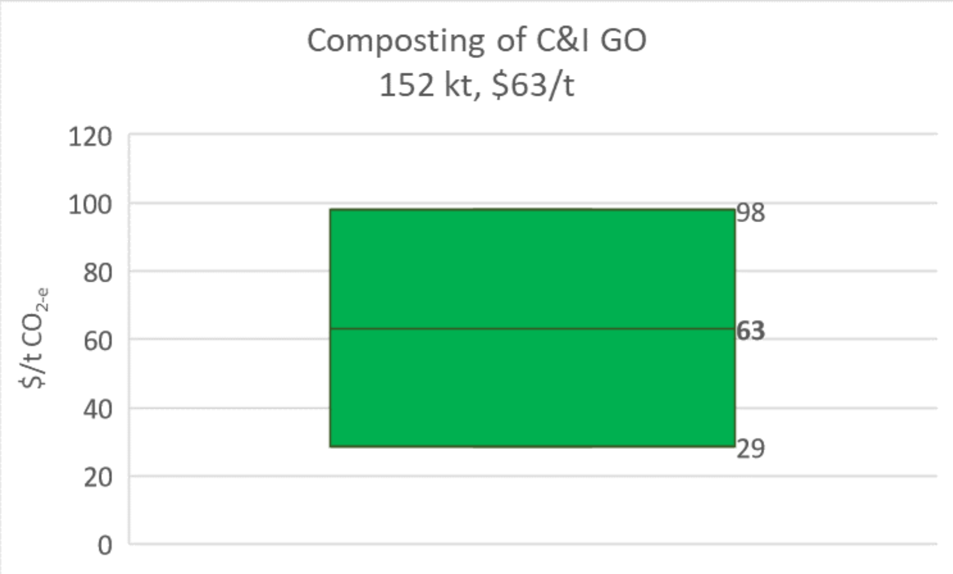
The expansion represents a small increase in the volume of mulch and soil conditioner which would have limited impact on the markets for these products.

Major assumptions

Variable	Value
Assumed available domestic FOGO (green bins)	17,387 t
Emissions from landfill	0.945 t CO_{2-e} / t waste
Carbon sequestered / tonne of compost	0.046 t CO_{2-e}
Levelised cost of expanded capacity	$20-$70/t waste

Source: NSW EPA Waste Projection model 1.4, stakeholder consultations

3.5.2 Mixed domestic and C&I



Overview

Existing FOGO processing operations can expand their facilities to take on more waste from domestic and C&I sources. We have used cost estimates for these processes as a proxy for take-up of C&I FOGO waste. There are opportunities that can use food only waste from C&I sources and these are described in the next section. While the central estimate of costs for the C&I food option is similar to this option, there may be significant downside to the costs. We have therefore estimated the reduction in emissions as applying to only C&I garden waste to landfill.[17]

Key issues

Cost of collection

Costs associated with collection reflect the volumes associated with all C&I FOGO. To the extent that volumes are now separate (GO or FO only) then the collection cost may be prohibitive.

To extent that C&I GO waste could be collected with domestic FOGO, these volumes could be allocated to the previous process.

Demand

The end product provides a bulking supplement to other compost outputs. Analysis suggests demand is increasing for supply and price for speciality composts.

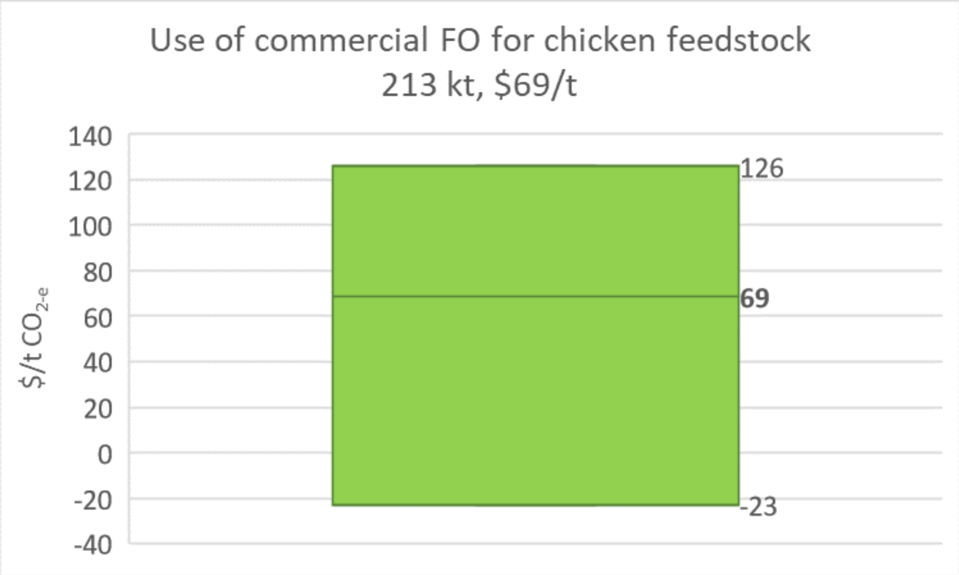
[17] This also excludes emissions associated with C&I timber sent to landfill.

Major assumptions

Variable	Value
Indicative volume (C&I GO)	159,000t
Net emissions from landfill	0.909 t CO_{2-e} / t landfill
Carbon sequestered / tonne of compost	0.046 t CO_{2-e}
Cost of expansion of facilities compared with landfill	$60/ t input

Source: NSW EPA Waste Projection model 1.4, stakeholder consultations

3.5.3 Use of commercial FO for chicken feedstock



Overview

Significant volumes of feed for livestock are supplied in Australia every year. These existing processes generate approximately 1.2t CO_{2-e} per tonne of feed supplied. This option focuses on the replacement of grain chicken feed with feed made partially from C&I food waste. The option provides lower CO_{2-e} generation as well as diverts waste from landfill.

The volumes of feed required in Australia for layer hens appear to exceed Australia's production of C&I food waste significantly. In addition, the process could also supply other livestock (meat chickens, aquaculture). Similarly, it is unlikely that demand for feed will constrain the take-up of C&I food waste in NSW.

The process uses heat treatment, dewatering, and blending to produce a homogeneous animal feed product. In addition, to feed, the process also generates fertiliser and water.

Key issues

Comparative production costs

Limited sources indicate that the production cost for existing producers of chicken feed is significantly higher than those for the option. However, costs of collection of C&I food waste may exceed the difference between the two processes.

Importantly, a significant proportion of feed mills are located in other States. We have therefore, conservatively estimated that NSW supplies half of its own chicken feed demand.

Capital investment for each operation is minor.

Demand

The product developed under the option provides similar or better nutrient outcomes for livestock compared with existing feeds. We have assumed that capacity can be expanded to use the existing C&I food sent to landfill. As this is a very new process, we have assumed it will only be able to be used for half of the existing C&I FO waste stream.

Major assumptions

Variable	Value
Emissions from grain input production	1.2t CO_2 / t produced
Emissions from food waste input production	0.05 t CO_2 / t produced
Proportion of grain input sourced from NSW	50%
Proportion of waste diverted	50%
Emissions from food to landfill	1.2 t CO_2 / t food waste
Input of food waste	1 t feed / 2 tonnes food waste input
Cost of waste chicken feed production relative to grain feed	commercial-in-confidence
Tonnes of $CO_{2\text{-}e}$ of C&I waste diverted (max)	213,400

Source: NSW EPA Waste Projection model 1.4, stakeholder consultations

3.6 Opportunities associated with the recovery of textiles

3.6.1 Composting of cotton textiles

Overview

An estimated 236,000 tonnes of textiles are currently being disposed to landfill each year including 137,000 tonnes from households. This total is likely to increase by 26% over the next 20 years to over 297,000 tonnes, linked to the continued growth in textiles consumption associated with the 'fast fashion' industry (ACTA 2021). At present, most textiles consumed in NSW are imported. Emissions associated with the production of textiles, therefore occur predominantly overseas. The disposal of textiles made from natural fibres, however, generates substantial greenhouse gas emissions from landfill methane. Unit emissions are estimated to be approximately 1.2 t CO_{2-e}/ tonne for all textile waste in NSW (natural and artificial fibres) after allowing for landfill gas recovery (Marsden Jacob analysis drawing on DISER, 2020 and 2021). Unit emissions of cotton textiles are estimated to be approximately 1.9 t CO_{2-e}/ tonne of waste.

An estimated 17% of textiles disposed in NSW are cotton textiles. Research currently being conducted in Queensland for Cotton Australia indicates that diverting the cotton from landfill, shredding it and mixing it with other C&I organic waste can produce medium to high grade compost suitable for a number of farming applications.

Key Issues

Difficulty of ensuring a reliable supply and the costs associated with collection are key barriers to implementing this option. Estimates for this study indicate that the net cost of composting cotton textiles is likely to be approximately $89/tonne, with collection costs being a major cost component. Significant thought will need to be given therefore, to design of collection systems in ways that can minimise costs.

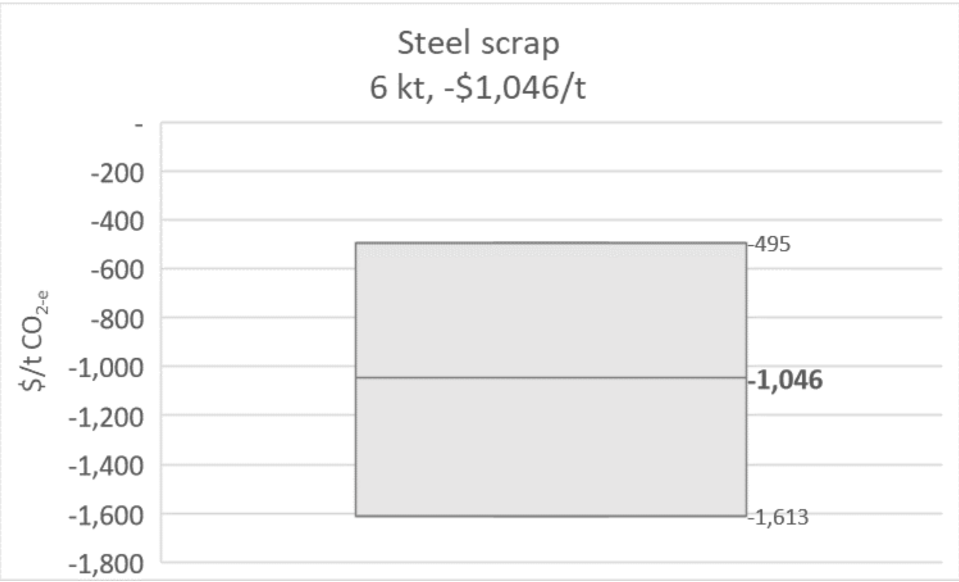
Another significant cost is likely to be associated with sorting and pre-processing, involving the removal of non-cotton component for the textiles. Cotton industry stakeholders indicate that nearly all 'cotton' clothes are mixed fibre comprising artificial fibre components, such as elastics, that will need to be removed to ensure successful composting.

Assumptions

Variable	Value
Estimated annual disposal of cotton textiles to landfill, NSW (averaged over the next 20 years)	45,965 tonnes
Potential recovery rate of cotton suitable for composting	80%
Potential annual diversion of cotton textiles from landfill to composting	36,772 tonnes
Emissions intensity of landfilling cotton textiles	1.9 t CO_{2-e}/ t cotton textile
Emissions intensity of composting	0.02 t CO_{2-e}/ t cotton textile
Net cost of composting	$82/ tonne

3.7 Opportunities associated with use of waste materials in production of steel

3.7.1 Replacing imported scrap metal with local scrap metal



Overview

Discussions with stakeholders from the steel industry in NSW indicates that, at present, greater than 300,000 tonnes of scrap steel are currently exported from NSW. Exporting of unprocessed scrap appears to be used to bypass the landfill levy applied to waste 'floc' generated from the processing of scrap steel. The steel industry in NSW has indicated that it would utilise all or nearly all of the exported scrap if it was available. Indeed, there is substantial cost to the industry involved in importing the scrap shortfall, principally from Queensland. This involves additional cost to the industry (most of which are transport costs), as well as generating Scope 3 (transport) emissions. Scrap imported from overseas (principally from New Zealand), also involves significant cost to industry, but emissions associated with shipping scrap from New Zealand are comparable to local sourcing of scrap via road transport. Being able to source additional scrap from NSW would substantially reduce interstate emissions and transport costs.

Key Issues

The industry sees this as largely a regulatory issue – not so much as a problem with the NSW landfill levy, but with a lack of regulation on unprocessed scrap metal exports.

Assumptions

Variable	Value
Annual transport of scrap from interstate	250,000 tonnes
Emission intensity of transported scrap	0.03 kg CO_{2-e}/tonne/km
Average distance when transported from interstate	990 kms
Average distance when transported from local sources	92 kms
Total transport emissions associated with imported scrap	7,057 tonnes
Avoided transport emissions if imported scrap is replaced with domestic scrap	6,401 tonnes
Avoided transport costs	$6.7 million

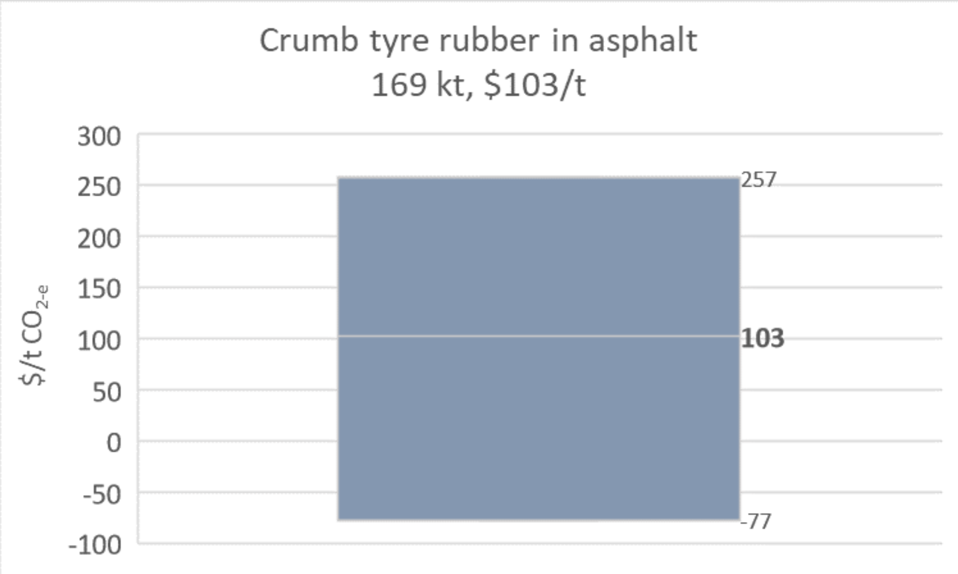
Noting the relatively small emission reduction potential from this opportunity, other opportunities for reducing emissions from steel production were examined for this assessment and explored with stakeholders. One of these is discussed in the following section. Other opportunities explored include:

- the use of biochar as a like-for-like replacement for coke in the blast-furnace;
- the wholesale move to steelmaking base on recycled steel; and
- steel making based on green hydrogen.

These opportunities were not assessed in depth, however either because they posed other potential environmental problems, were not technically or practically feasible or were outside of the scope of this assessment.

3.8 Opportunities associated with waste tyre recovery

3.8.1 Used of crumb rubber in the production of asphalt



Overview

Tyre Stewardship Australia (TSA) has examined opportunities for reducing emissions through recovery of waste tyres (Edge 2022). One of the most promising opportunities from an emissions reduction perspective is the potential for using crumb rubber from waste tyres as a binder in the asphalt production process, replacing some of the bitumen that would otherwise be used.

The TSA study examined a mix involving crumb rubber used as 15% of the binder in the wet process where poly modified binders (PMB) are used. The proposed mix is consistent with a mix trialled for the *National Specification for Crumb Rubber Binders in Asphalt and Seals* developed for Austroads (Urquhart et al. 2021). The TSA study has concluded that this mix has the potential to reduce greenhouse gas emissions by 10% compared to the PMB in the production of the asphalt and a further 30% improvement when the improved service life (from an average of 6 years to 9 years) of the asphalt is factored into the analysis.

Key Issues

Avoided emissions in NSW

Most production emission reductions achieved through using a 15% crumb mix in the binder will result from reducing emissions by replacing bitumen in the binder. Bitumen is a very emissions intensive material. However, it is no longer produced in NSW but imported from overseas or Victoria. This follows the progressive closure of oil refineries in NSW and elsewhere in Australia over the past decade, with the result that only the Viva petroleum refinery in Victoria still produces bitumen. This means that any emissions savings for NSW associated with the use of crumb rubber will stem from the improved service life of roads and avoided emissions over time from delaying the need to resurface roads and the associated construction emissions and emissions embodied in other (non-bituminous) materials. It is possible that there may also be emission savings from avoiding tyres being disposed to landfill but for this analysis we have assumed that most of the waste tyres used for crumb rubber will be diverted from exported waste tyres.

There is likely to be an insufficient quantity of waste tyres to include crumb rubber in all asphalt. For this analysis we have assumed that approximately 48% of resurfaced asphalt could include a 15% crumb rubber mix.

Costs

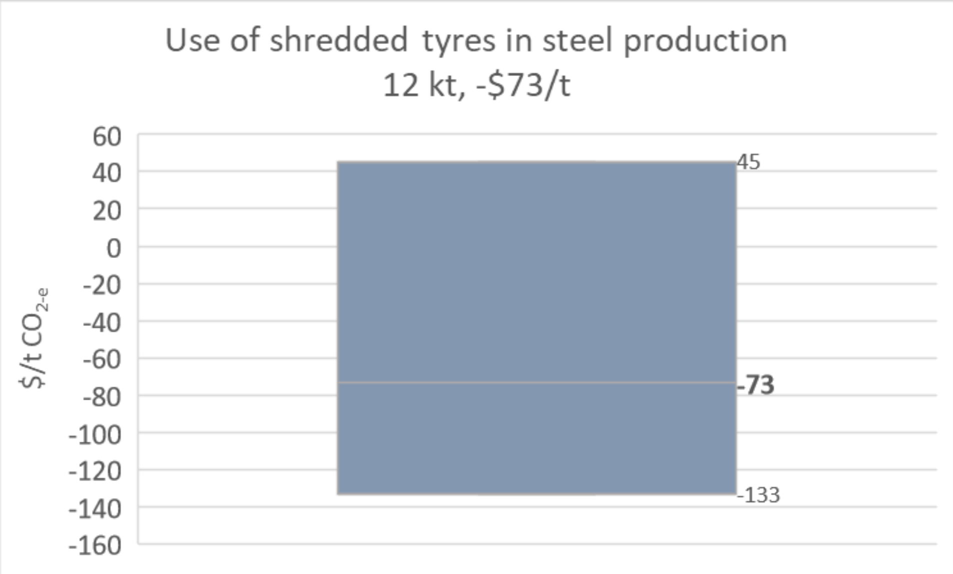
Additional costs of asphalt produced with crumb rubber are uncertain, with stakeholders and reports (e.g., Urquhart et al. 2021) indicating cost increases of between 10% and 40%, excluding long term cost savings associated with the service life of roads. We have assumed a 25% increase in the cost of producing asphalt.

Analysis of the avoided emissions of approximately 169,000 tonnes per year and a levelised cost of $103/ tonne have been assessed over 15 years to ensure consistency with other opportunities. If the analysis is undertaken over a much longer period (e.g., 40 years) avoided emissions are likely to average greater than 250,000 tonnes per year, at a substantially lower levelised cost.

Assumptions

Variable	Value
Emissions associated with the production of asphalt and construction of a 1 km length of asphalt road (9m wide)	128 t CO_{2-e}/km
Emissions associated with the production of asphalt and construction of a 1 km length of asphalt road (9m wide), excluding bitumen	46 t CO_{2-e}/km
Estimated length of road resurfaced each year in NSW	33,032 kms
Length of road resurfaced each year using crumb rubber binder	15,855 kms
Tyres required each year @15% binder and 5% binder in asphalt	137,416 tonnes
Additional cost of producing a 1 km length of asphalt road with conventional PMB binder	$105,000/ km
Cost of producing a 1 km length asphalt road with crumb rubber in binder	$131,250/ km

3.8.2 Use of shredded tyres in EAF steel production



Overview

Electric Arc Furnace (EAF) steel production typically has an emissions intensity of about 0.5 tonnes/$CO_{2\text{-}e}$/ tonne steel. About 20% of these emissions are associated with carbon inputs provided by the addition of coke in order to maintain correct furnace chemistry (Echterhof 2021, Fan & Friedman 2021). Molycop Australasia is part of the Molycop Group. In NSW, Molycop's EAF steel production works, located at Waratah, has adopted a process known as Polymer Injection Technology and developed by the Centre for Sustainable Materials Research and Technology (SMART) at UNSW, to replace the coke with crumbed rubber (Zaharia et al. 2012). This has resulted in:

- reduction in electricity consumption;
- reduced energy consumption from reduced furnace power-on-time; and
- reduction in carbon inputs.

The overall impact is estimated to reduce emissions intensity by about 5%. The process could feasibly be extended to other EAF steel producers in NSW.

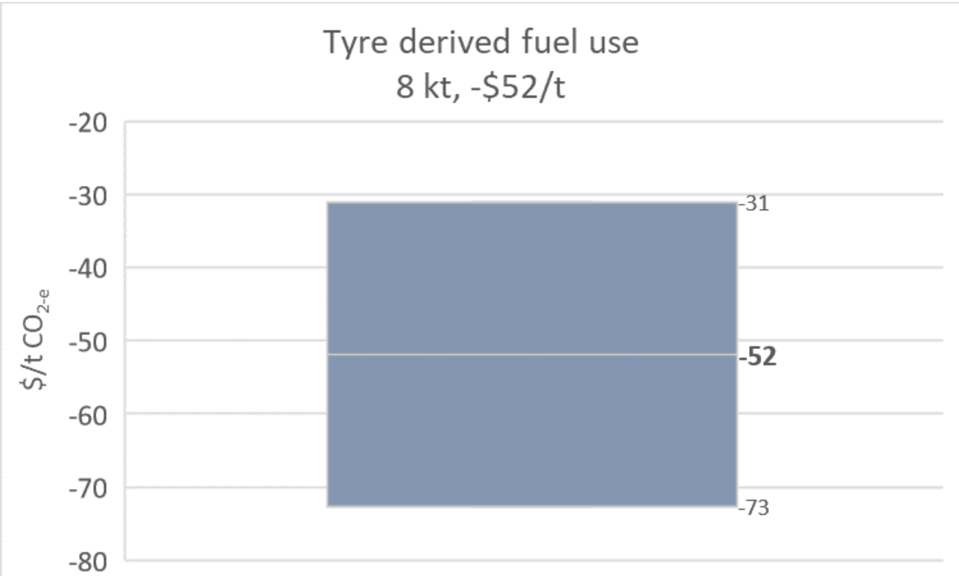
Key Issues

The process is estimated to reduce the cost of steel production by about 5-6%. However, this will vary depending the costs of coke, electricity and other inputs.

Assumptions

Variable	Value
Approximate annual production of EAF steel in NSW (other than Molycop)	0.5 million tonnes
Emissions intensity of steel production using coke inputs	0.5 t CO_{2-e}/ t steel
Total emissions from steel production using coke inputs	250,000 tonnes
Emissions intensity of steel production using crumbed rubber inputs	0.476 t CO_{2-e}/ t steel
Total emissions from steel production using crumbed rubber inputs	237,910 tonnes
Reduced cost of steel production (per tonne)	5.8%

3.8.3 Tyre derived fuel use



Overview

Analysis for TSA of reducing emissions through waste tyre recovery has also considered the potential for tyre derived fuel (TDF) from waste tyres to be used in a number of applications (Edge 2022, TSA 2021). Analysis of this opportunity for the TSA has estimated that where end-of life tyres are substituted for coal in fuel combustion, the greenhouse gas emissions will be reduced by around 30-35% on a substituted energy basis (OLM 2021). The most likely feasible application of TDF in NSW is to replace coal in kilns for the cement clinker production process.

Key Issues

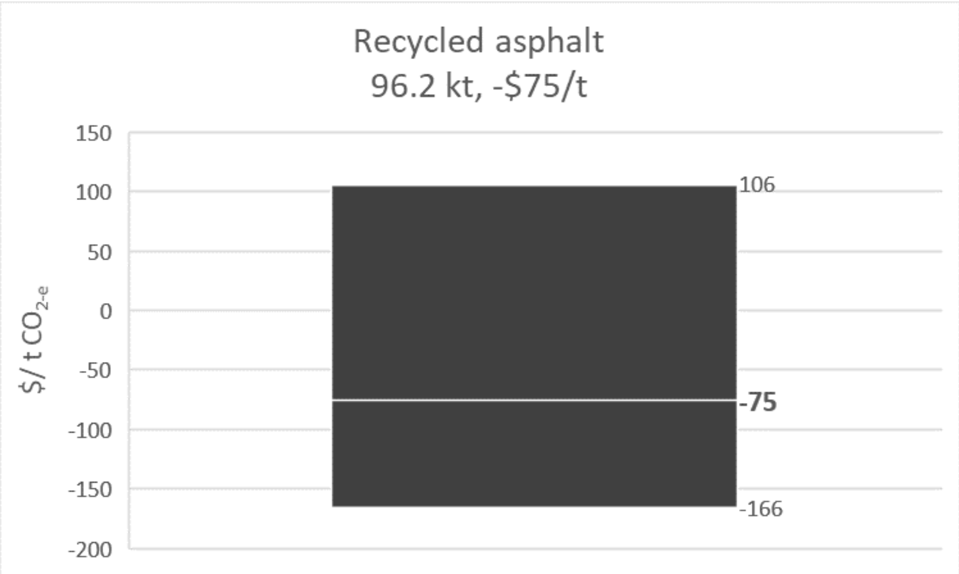
The Boral clinker facility in Berrima already uses Solid Waste Fuel (SWR) as a substitute for some of the coal used in its kilns and current EPA license conditions are likely to restrict a significant increase in the use of SWF. Thus, there is only limited potential for increasing SWF through the use of TDF. In any case, use of waste tyres in other opportunities discussed earlier in this report is likely to restrict availability of suitable waste tyres for this application. For this analysis we have assumed that 20,000 tyres are available each year for use as a TDF in cement production. This would substitute for only about 7.5% of the coal used in the kiln. This substitution would reduce costs of production overall by about 0.5% over 15 years, after allowing for additional capital and operating costs.

Assumptions

Variable	Value
Approximate annual production of cement in NSW	1.4 million tonnes
Emissions intensity of cement production with current fuels	0.97 t CO_{2-e}/ t cement
Emissions intensity of geopolymer cement	0.23 (t CO_{2-e}/ t cement)
Replacement of coal with TDF	7.5%
Total emissions from cement production without TDF	1.35 million tonnes
Total emissions from cement production with TDF	1.34 million tonnes
Cost impact on production of cement	-0.5%

3.9 Opportunities associated with reuse of asphalt

3.9.1 Increased use of recycled asphalt in road paving



Overview

Recycled asphalt is now regularly used when roads are being resurfaced, with as much as 20-30% of the material inputs being reclaimed asphalt pavement (RAP). Even so, an estimated 1-1.5 million tonnes of waste asphalt are still being disposed to landfill in NSW each year[18]. A recent study and modelling for Lake Macquarie City Council has examined options for use of recycled materials in roads, one of which entails increasing RAP in roads from 30% to 50% (Edge 2021). This was found to decrease the carbon footprint of road construction by 5% compared to the baseline. This result is broadly consistent with results from trials of asphalts that combine alternative recycled materials, such as glass, rubber, plastic, slag and toner, with RAP (Boral 2021b). Use of RAP is also expected to reduce the cost of road construction as RAP is cheaper than new asphalt and other virgin material inputs, such as aggregates and sand used in the wearing course.

Although the percentage reduction in emissions associated with this option is relatively small, when extended across road resurfacing in NSW more broadly the emission reduction potential is quite significant.

Key Issues

The Edge analysis suggests that the cost of increasing the RAP content of roads is substantially negative (-$185/ tonne CO_{2-e}). The cost estimate appears not to have understated collection and transport costs of RAP. When these costs are adjusted however, the cost still appears to be significantly negative.

Assumptions

Variable	Value
Quantity of RAP needed in roads assuming 20% RAP content	120 tonnes / 1 km 2 lane road
Estimated annual length of road resurfaced each year in NSW (urban areas)	6,989 kms
Total quantity of RAP needed with 20% (or increase by 20%) of RAP used in resurfacing	908,540 tonnes
Emissions factor with 30% RAP	274 tonnes/km
Emissions factor with 50% RAP	260 tonnes/km
Reduction in road cost with 20% RAP increase	1.4%

—

18 Marsden Jacob analysis drawing on NSW EPA waste projections model and other NSW and national waste databases

4. Emerging markets

4.1 Immediate priorities

Of the potential priority waste materials and opportunities assessed for inclusion in the carbon abatement cost curve, three materials emerge as immediate priorities. These materials are currently problematic waste in NSW and the development of a large recycling or reuse market in NSW in the short term would generate significant benefits, both in terms of carbon abatement and in improving the recovery of materials and thereby reducing waste and advancing NSW towards a circular economy.

4.1.1 Coal Ash

Burning coal in coal fired power stations results in the production of coal ash, or coal combustion products (CCPs). There are two types of coal ash, fly ash and furnace bottom ash. Coal ash is stored by power stations in ash dams or taken for reuse.

Dams are estimated to contain 400 million tonnes of fly ash across Australia (NSW Government, 2021). In its submission to the Inquiry into costs for remediation for sites containing coal ash repositories, the NSW Government acknowledged there may be contamination risks to human health, the environment and future land use and development (NSW Government, 2020).

An increasing amount of 'run of station' fly ash is being diverted from ash dams for reuse (for example, in geopolymer cement and supplementary cementitious material, as aggregate in concrete products, in road base, mining backfill and in waste stabilisation (ADAA, 2020)).

As discussed in more detail in section 3.1, high value uses of fly ash, for example in geopolymer cement and in supplementary cementitious materials, have the potential to contribute a substantial amount of carbon abatement in NSW, estimated at about 615,000 tonnes per year. In the future, other potential uses of fly ash, for example in asphalt, may also have potential for carbon abatement, however further research and data is required to assess the suitability of products and the carbon abatement they could achieve. The demand for products that re-use fly ash is expected to grow (ADAA, 2020).

Run of station fly ash produced is expected to decline year by year as coal is phased out. Estimated quantities of run of station fly ash produced per year for NSW based power stations are provided in Table 4, which also provides estimates of the quantities of fly ash that could be reused after taking account of fly ash already being used for other purposes and the future phase out of power stations.

Table 4: Estimated future availability of run of power station fly ash (Mt)

Facility	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Bayswater	1.5	1.5	1.5	1.5	1.5	1.13	1.13	0.99	0.99	0.99	0
Eraring	1.2	1.2	0	0	0	0	0	0	0	0	0
Liddell	0.8	0	0	0	0	0	0	0	0	0	0
Mt Piper	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Vales Point B	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0	0	0	0
Total	**4.8**	**4 .0**	**2.8**	**2.8**	**2.8**	**2.43**	**2.43**	**1.59**	**1.59**	**1.59**	**0.6**
Less fly ash already in use	**2.95**	**2.49**	**1.79**	**1.79**	**1.79**	**1.57**	**1.57**	**1.09**	**1.09**	**1.09**	**0.52**

As the quantity of run of station fly ash reduces and the emerging market for fly ash sees an increase in demand, the harvesting of fly ash from dams will become more desirable. As discussed in section 3.1.1, harvesting of ash is likely to involve significant additional cost. Early planning and investment decisions to enable the transition from run of station fly ash to the extraction of fly ash from dams in infrastructure will ensure the potential NSW carbon abatement is achieved. Ensuring the right policy settings and market conditions exist for the sector to respond efficiently to increasing demand for products that re-use fly ash and lead to carbon abatement (for example, geopolymer cement and supplementary cementitious materials) will be important in ensuring there is sufficient supply to meet demand.

4.1.2 Tyres

End-of-life tyres (EOLT) represent a problematic waste in NSW. Tyre Stewardship Australia estimate that the landfilling of tyres produces between 671 and 1,008 kg of $CO_{2\text{-}e}$ emissions per tonne of EOLT. With current estimates of over 60,000 tonnes of used tyres estimated to be disposed of in stockpiles and landfill, or in onsite disposal and dispersed dumping, and another 57,500 tonnes exported, EOLT represent a significant waste source available for reuse in NSW. There are a number of uses of EOLT, including crumbed rubber in asphalt, tyre derived fuel in kilns, use in pyrolysis, and tyre re-treading. Facilitating these emerging markets will help to meet the 80% recovery rate under the 2022 export ban, and in many cases, has potential to abate carbon.

Section 3.8 discusses the significant carbon abatement potential of waste tyre recovery applications in the form of crumbed rubber in asphalt binder and to a lesser extent, shredded tyres in Electric Arc Furnace (EAF) steel production and tyre derived fuel in cement production.

New truck and bus tyres result in higher $CO_{2\text{-}e}$ emissions than the re-treading of truck and bus tyres and has potential to achieve significant carbon abatement globally. However, this opportunity was not included in the carbon abatement cost curve for NSW since emissions relating to new tyres occur overseas, and it is not clear whether or how many of the tyres that could be re-tread in NSW would be diverted from landfill (thereby reducing landfill emissions in NSW). It is thought most of the tyres that could be re-tread would be diverted from those currently exported. It is estimated that 34,600 Off-the-Road tyres (OTR) from mining and agriculture are disposed of onsite. Re-treading of these

OTR tyres could potentially lead to carbon abatement in NSW however, not enough is known about the management of OTR tyres at present to confidently assess emission abatement potential and costs. Uncertainties include:

- feasibility of re-treading OTR tyres that are currently being disposed onsite;
- current OTR disposal practices and associated emissions;
- emissions and costs associated with collecting and transporting tyres to re-tread facilities from mining and agriculture sites; and
- emissions intensity of re-treading tyres.

Information addressing these uncertainties could see this opportunity included in future versions of the carbon abatement cost curve.

Emerging markets for EOL tyres could be further enabled to deliver carbon abatement through a focus on research to investigate and demonstrate the performance of products incorporating waste tyres and associated environmental impacts, in addition to supporting investment in infrastructure, and where appropriate the prompt assessment and removal of unnecessary barriers that may prevent these emerging markets for used tyres, such as specifications and standards.

4.1.3 Asphalt

Section 3.9 outlines the carbon abatement potential and cost for increasing the use of reclaimed asphalt pavement (RAP) in road paving. While this already occurs, since an estimated 1 – 1.5 million tonnes of waste asphalt continue to be disposed to NSW landfill each year, there is potential to increase the use of reclaimed asphalt to reduce both carbon emissions and road costs.

Many different asphalt products present the opportunity to reuse waste products (for example, crumbed tyres as discussed above, glass fines, soft plastic) and often also to reduce emissions.

Carbon abatement can occur in different ways, for example it can occur through:

- the replacement of bitumen (which has high emissions)
- extending the life of asphalt
- requiring less asphalt for the same road surface
- reducing transport and other emissions associated with the use of virgin materials the waste products replace.

While the current carbon abatement cost curve includes only the opportunities to use RAP and crumbed tyres in asphalt, many other products and opportunities were not included due, in part at least, to a lack of data. Further research to understand these products and their impacts including the collection of data, is likely to generate further opportunities for carbon abatement and waste diversion.

In some cases, the potential for carbon abatement is dependent on local supply chains and current waste disposal pathways. For example, Southern Sydney Regional Organisation of Councils' (SSROC's)

'Paving the way' initiative has created a local market for glass fines in asphalt. Investigations revealed that 14% of glass recovered was being transported by the local MRF to Victoria and finding a local use for these glass fines in asphalt resulted in carbon abatement through avoided interstate transport and avoided transport of the virgin sand that the glass replaces. Since this initiative is in train (contracts have been signed and production has commenced) it was not included as a future opportunity. However, it is likely that glass, and other waste that could be used in asphalt, is also being transported significant distances in other areas of NSW and that diverting this waste to local uses in asphalt to replace virgin material provides an opportunity for carbon abatement. Further work with councils and MRFs to identify where waste is being exported but could be used locally may identify opportunities that could be included in future versions of the carbon abatement cost curve.

4.2 Potential priorities subject to further data

The consultation and research undertaken for this study revealed many circular economy opportunities with the potential for carbon abatement in NSW. Further research and analysis to identify and understand data pertaining to the potential for NSW emissions abatement, the associated costs, and product impacts (including quality, longevity, environmental impacts) could reveal these opportunities as priority materials in the future.

Opportunities for which the collection of data should be prioritised include:

- The use of biochar, for example from forest products as a coke replacement in steel manufacturing, and from wastewater/water treatment systems.
- The use of plastic waste as a bitumen replacement in asphalt, and in manufacturing construction products.
- The use of local glass and other waste as a replacement for sand/aggregates in asphalt and/or concrete where its disposal pathway is currently leading to high transport emissions (i.e. where local MRFs are currently transporting it interstate).
- Increasing composting of organics, including from street sweeping or separation from contaminated waste materials such as plastics, paper.
- Using mycelium to produce compostable food packaging or insulation products. Mycelium is effectively the root part of a fungus. It grows around agricultural waste and can be dried and used to replace polystyrene packaging and insulation. It can be disposed of in the garden where it biodegrades in weeks.
- Producing feed stock from household food waste.
- Recycling textiles.

Additionally, further research may be warranted to better understand barriers to increasing the recycling of waste cardboard and paper. These include a lack of demand for recycled paper products, in part because producers are avoiding using recycled cardboard in packaging due to concerns about quality. As a priority therefore, research may be needed to indicate the extent to which these concerns are unnecessary limiting the take up of recycled paper and to identify priority actions needed to address them.

4.3 Longer term priorities

The priority materials (coal ash, tyres and asphalt) discussed above have demonstrated clear potential to produce carbon abatement in the short to medium term. Some planning and investment may be required to ensure they also produce carbon abatement into the longer term. For example, the extraction and use of fly ash currently stored in ash dams to reduce emissions from cement in concrete will become a priority in the longer term as the supply of run of station fly ash ceases with the transition away from coal fired power stations.

In addition, there are opportunities to design buildings, other infrastructure and products to reduce waste and deliver carbon abatement in NSW in the longer term through improving:

- Longevity. For example, many asphalt products are emerging that are expected to last longer than traditional asphalt and so will result in carbon abatement through time. Replacing 'fast fashion' trends with clothing that lasts longer will reduce textile waste and associated emissions.
- Repairability. Designing clothing, products and infrastructure for repairability contributes to their longevity and will reduce waste and emissions associated with whole product replacement. Modular building components can enable the isolation of damage (for example, of a building) and allow it to be replaced without requiring the whole building to be demolished and replaced.
- Re-usability and recyclability. There are many opportunities to ensure materials used in construction and manufacturing can easily be re-used or recycled which present an opportunity for carbon abatement. Textiles can also be designed to be recycled, for example, so that synthetic and organic materials are easily separated. Designers can specify the use of materials that are easily re-used or recycled rather than composite materials that are more costly or difficult to recycle and reuse.

Opportunities to improve longevity, repairability, re-usability and recyclability can be facilitated through the development of cost-effective technologies and processes. The development and adoption of these technologies and processes can be driven by regulatory approaches, such as those that have been developed in line with Europe's Circular Economy Action Plan. Grants and other incentives can also be used.

The carbon abatement cost curve produced by this study is based on the potential carbon abatement in NSW that circular economy opportunities in the waste, manufacturing and construction sectors can provide in the short to medium term. These design-focussed opportunities haven't been included in the carbon abatement cost curve primarily because the carbon abatement they could deliver will occur in the longer term. Others haven't been included because further data is required.

To realise the significant potential for NSW carbon abatement that these opportunities present in the long term, it is critical to focus on and invest in design-based research and development now.

5. Opportunities not assessed

Numerous opportunities for adoption of circular economy opportunities were identified during the course of discussions with stakeholders or review of the literature. Many of those opportunities were not subsequently assessed and incorporated into the CACC. Reasons for this include:

- insufficient data to assess abatement potential or abatement costs;
- uncertainty as to whether the opportunity will materially abate emissions;
- the likelihood that the abatement opportunity will only achieve emissions abatement outside of NSW, that is, will not reduce NSW Scope 1 emissions;
- the likelihood that significant emission reductions are unlikely to be realised in the next 15-20 years;
- resource constraints or significant potential environmental risks associated with the opportunity; and/or;
- the opportunity is essentially outside the scope of the analysis.

This latter group includes many of the opportunities associated with changes to energy inputs in production processes.

Examples of the opportunities not assessed due to a lack of emissions or cost data include the innovative use of waste plastics, glass, textiles and other materials in the production of ceramics and other products, which are currently being explored by the Centre for Sustainable Materials Research and Technology (SMART) at UNSW.

Examples of opportunities that are likely to achieve emissions abatement outside of NSW include many of the opportunities associated with the recycling of aluminium, plastics, textiles and tyres noting that there is no production of tyres currently undertaken in NSW, minimal production of textiles and aluminium production facilities in NSW are not geared up to recycle aluminium, with all recovered aluminium being exported.

Possible resource constraints and environmental risks are related to substitution of materials – for example timber for steel or aluminium – or waste to energy options. Redesign of materials or infrastructure are likely to lead to substantial emission reductions but often only in the longer term.

Table 5 provides a list of the opportunities identified but not assessed for the CACC. As noted earlier in the report, exclusion of these opportunities from the analysis is not necessarily an indication that they are not worthy of further consideration to assess their potential to reduce GHG emissions or to meet other circular economy objectives.

Table 5: Opportunities identified but not assessed, with reasons for not including in the CACC

Material	Opportunity	Lack of data	No/unclear NSW emission reductions	Environmental or resource issues	Unlikely to deliver significant emission reductions in short to medium term	Outside scope of analysis
Aluminium	Increase recycling rates of aluminium in NSW		✓			
	Reduce energy use of smelter/ alternative energy sources					✓
Steel	Reduce energy use of smelter/ alternative energy sources					✓
	Replace coke with biochar from forest products	✓		✓		
	Reduce steel consumption/ replace with other materials			✓	✓	
Asphalt	Recycling plastic and tyres as a bitumen replacement	✓	✓	✓		
	Recycling glass for use as aggregate	✓	✓			
	Using less asphalt (e.g., product design/use that extends life, uses less)	✓			✓	
	Alternatives to chemical additives (such as lime)	✓	✓			
	Co-generation				✓	✓
Cement/ Concrete	Reduce waste through design	✓				✓
	Replace concrete with materials with lower embodied carbon	✓		✓		

Material	Opportunity	Lack of data	No/unclear NSW emission reductions	Environmental or resource issues	Unlikely to deliver significant emission reductions in short to medium term	Outside scope of analysis
	Replace aggregates in concrete with waste (e.g., glass)	✓	✓			
	Replace coal fuel in concrete manufacture with waste to energy		✓	✓		
Organics	Collecting organics from street sweepings and composting	✓				
	Separating organics from heavily contaminated plastics and composting	✓		✓		
	Biochar from biosolids in wastewater/water treatment systems	✓				
	Household waste to feedstock	✓				
	Using mycelium waste from mushroom farmers to produce insulation	✓				
	Anaerobic digestion	✓	✓	✓		
Paper	Composting of paper	✓		✓		
	Anaerobic digestion/ waste to energy	✓	✓	✓		
Plastics	Manufacturing construction products such as sound walls, insulators in rail, speed humps, cable protectors with recycled plastic	✓	✓			

Material	Opportunity	Lack of data	No/unclear NSW emission reductions	Environmental or resource issues	Unlikely to deliver significant emission reductions in short to medium term	Outside scope of analysis
	Increase recycling of HDPE, PET, PVC, PP, EPS, XPS		✓			
Glass	Recycling flat glass offcuts and windscreens to produce fibreglass insulation	✓	✓			
Textiles	Increase recycling rates of textiles	✓				
	Move away from ‘fast fashion’	✓				

References

ACTA (2021) *Thread Count: NSW Textile Data Report*, Report for NSW EPA.

Advancing Net Zero, World Green Building Council and Ramboll (2019) *Bringing embodied carbon upfront: Coordinated action for the building and construction sector to tackle embodied carbon*, World Green Building Council.

Aldred, J. and Day, J. (2012) 'Is geopolymer concrete a suitable alternative to traditional concrete?' In *37th Conference on our world in concrete & structures*, Singapore (pp. 29-31)

Ash Development Association of Australia (ADAA) (2020) *Annual Production and Utilisation Survey Report Jan – Dec 2020*

Berndt, M., Rajeev, P. and Sanjayan, J. (2017) *Guide to Specification and Use of Geopolymer Concrete with Case Studies*, Swinburne University of Technology.

Beyond Zero Emissions (BZE) (2017) *Zero Carbon Industry Plan: Rethinking Cement*, Beyond Zero Emissions Inc, Melbourne.

Boral (2021) *Boral NSW and ACT Pre-mix Concrete EPD, Environmental Production Declaration*, In accordance with ISO 14025 and EN 15804.

Boral (2021b) *Asphalt EPD: Environmental Product Declaration*, In accordance with ISO 14025 and EN 15804

Boston Consulting Group (BCG) (2021) *Net-Zero Challenge: The supply chain opportunity*, World Economic Forum, January 2021.

Carre, A., Crossin, E. and Clune, S. (2015) *LCA of Kerbside Recycling in Victoria*, Prepared for: Sustainability Victoria, RMIT University, Melbourne.

Cement Industry Federation (CIF) (2020) *Australian Cement Industry Report 2020*, CIF.

Crawford, R.H., Stephan, A. and Prideaux, F. (2019) *Environmental Performance in Construction (EPiC) Database*, The University of Melbourne, Melbourne.

Department of Environment, Climate Change and Water (DECCW), NSW (2010) *Environmental Benefits of Recycling*, DECCW NSW.

Department of Industry, Science, Energy and Resources (DISER) (2020). *National Greenhouse Accounts Factors, Australian National Greenhouse Accounts*, August 2021, Commonwealth of Australia.

Department of Planning, Industry and Environment, NSW (DPIE) (2021) *NSW Waste and Sustainable Materials Strategy 2041: Stage 1 2021-2027*, NSW Government, Sydney.

Department of Industry, Science, Energy and Resources (DISER) (2021) *National Greenhouse Gas Industry Report 2021*, Volume 2, April 2021, Commonwealth of Australia.

Edge Environment (2021) *Use of recycled materials in roads: Report for Lake Macquarie City Council*, October 2021.

Edge Environment (2022) Greenhouse Gas Emissions Analysis of Waste Tyre Recovery: Key findings prepared for Tyre Stewardship Australia, 17 June 2022.

Envisage Works, Industry Edge, Randell Environmental Consulting and Sustainable Resource Use, (2021) *Australian Packaging Consumption Recycling Data: 2018-19*, Australian Packaging Covenant Organisation.

Envisage Works (2021) *Australian Plastics Flows and Fates 2020-21: NSW Report*, NSW EPA, June 2021.

Echterhof, T. (2021) "Review on the Use of Alternative Carbon Sources in EAF Steelmaking". *Metals* 2021, 11, 222.

Fan, Z. and Friedman, J. (2021) "Low-Carbon Production of Iron & Steel: Technology Options: Economic Assessment and Policy", *Joule*, Volume 5, Issue 4, 21 April 2021, pp 829-862.

Hamilton, L. and Feit, S. (2019) *Plastic & Climate: The Hidden Costs of a Plastic Planet*, Center for International Law.

Industry Edge (2020) *2020 Pulp & Paper Strategic Review*, Industry Edge, Geelong.

Industry Edge (2021) 2021 *National Pulp, Paper and Packaging Sustainability Report*, Australian Forest Products Association.

OLM (2021) *Australian National Greenhouse Gas Accounts and End-of-Life Tyre Combustion Emission Factor*, prepared for Tyre Stewardship Australia by OLM Technical Service, July 2021.

Public Works Committee, Legislative Council, NSW Government (NSW Government) (2021) *Costs for remediation of sites containing coal ash repositories,* Report 4, March 2021.

Public Works Committee, NSW Government (NSW Government) (2020) *NSW Government submission Public Works Committee Inquiry into Costs for Remediation of Sites Containing Coal Ash Repositories,* Submission 83, received 28 February 2020, p. 11.

Ramboll, Fraunhofer ISI and Ecologic (2020) *The Decarbonisation Benefits of Sectoral Circular Economy Actions*, Final report, EEA/ACC/18/001/LOT 1, European Environment Agency.

Schandl H, King S, Walton A, Kaksonen A, Tapsuwan S and Baynes T (2020) *National circular economy roadmap for plastics, glass, paper and tyres*, CSIRO, Australia.

Sharma, B. and Grant, T. (2015) *Life Cycle Inventory of Cement & Concrete produced in Australia*, Life Cycle Strategies Pty Ltd, Melbourne.

Shayan, S. (2016) *Specification of Geopolymer Concrete: General Guide*, Research Report AP-R531-16, Austroads.

SRU (2019) *Recycling market situation: Summary Review*, Australian Government Department of Environment and Energy.

Tyre Stewardship Australia (TSA) (2021) *Recent activities on the circular reuse of tyres and the increased uptake of lower carbon material substitutes*, TSA, December 2021.

Urquhart, Q, Young, C, Conglin, C. and Patrick, S. (2021) National Specification for Crumb Rubber Binders in Asphalt and Seals, Austroads Technical Report AP-T359-21, Austroads.

VDZ (2020) *Decarbonisation Pathways for the Australian Cement and Concrete Sector*, Cement Industry Foundation.

Venkataraman, M. et al. (2019) *Zero-carbon steel making: The opportunities and role of Australia in nurturing a 'green steel' industry*, Energy Change Institute, Australian National University.

Yin, J., Chaoen Li, S., Xin Xiang, Y. and Paicu, G. (2020), *Retrofitting calcium carbonate looping to an existing cement plant for CO_2 capture: a techno-economic feasibility study*, CSIRO.

Zaharia, M. et al. (2012) "Recycling of Rubber Tyres in Electric Arc Furnace Steelmaking: Carbon/Slag Reactions of Coke/Rubber Blends", High Temp. *Mater. Proc*. 2012, 31(4-5): pp. 593–602.

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