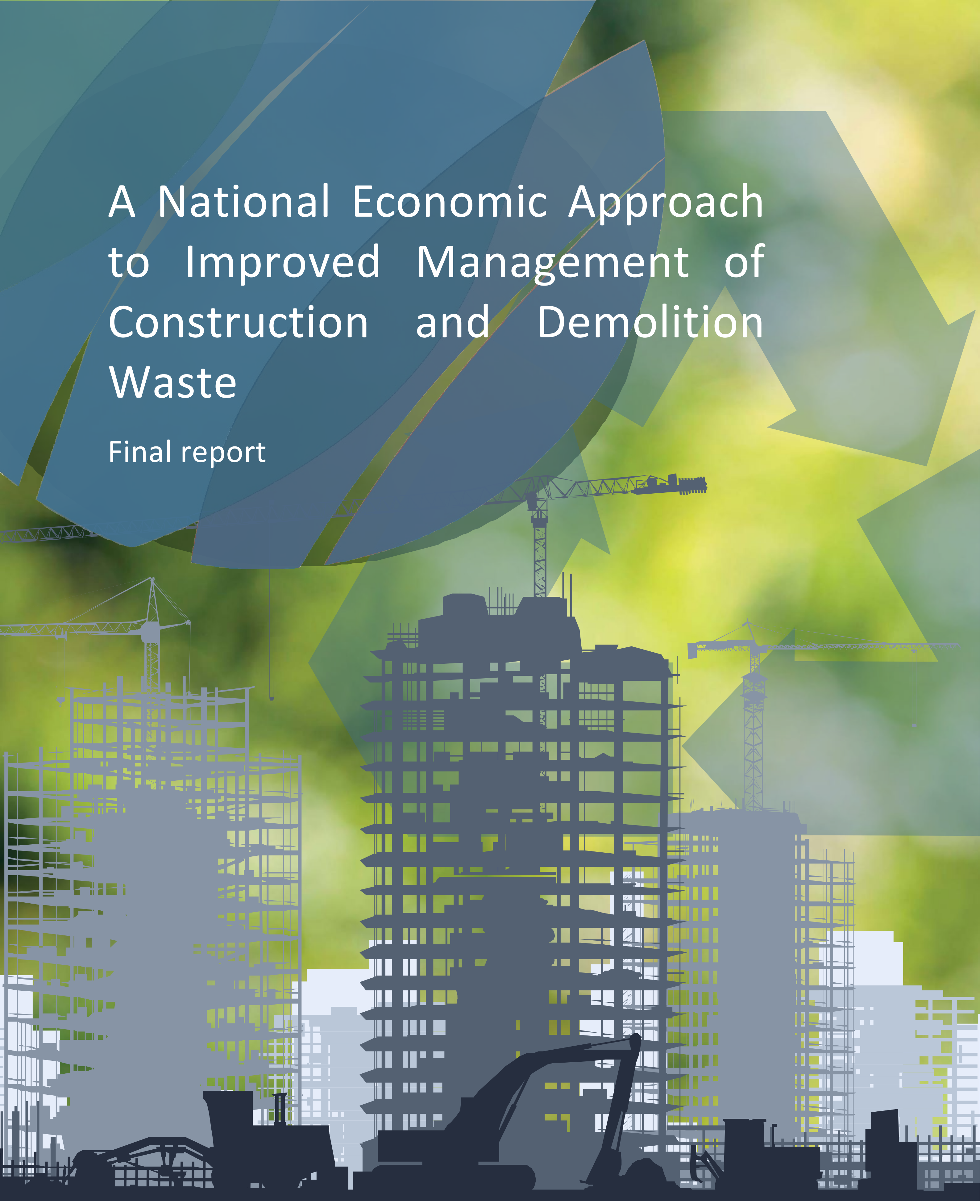
A National Economic Approach to Improved Management of Construction and Demolition Waste

Final report



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Sustainable Built Environment National Research Centre AUSTRALIA

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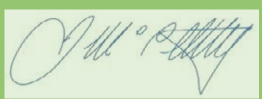
This research would not have been possible without the ongoing support of our core industry, government, and research partners.

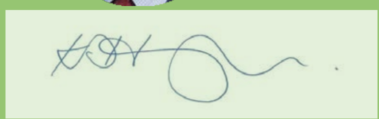
Message from the Chair

The project focused on the management of construction and demolition waste nationally and the capacity and opportunity to address economic barriers and drivers to national harmonisation. In my opinion, the real strength of this project was the ability to bring together industry, government, and academia to look at how we solve issues and challenges with construction development. It was also a great opportunity to help the waste management and resource recovery industry by highlighting what is the largest waste stream in Australia and the ways to deal with this not at the end of the pipeline but at the outset, in how we can design differently to reduce waste materials or make them re-usable.

Preface

The Sustainable Built Environment National Research Centre (SBEnrc), the successor to Australia's Cooperative Research Centre for Construction Innovation, is committed to making a leading contribution to innovation across the Australian built environment industry. We are dedicated to working collaboratively with industry and government to develop and apply practical research outcomes that improve industry practice and enhance our nation's competitiveness. We encourage you to draw on the results of this applied research to deliver tangible outcomes for your organisation. By working together, we can transform our industry through enhanced and sustainable business processes, environmental performance, and productivity.





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Executive Summary

A holistic national approach is required to handle the growing issue of construction and demolition (C&D) waste management in Australia. Through this project, the discrepancies and inconsistencies related to C&D waste management regulations in each jurisdiction were identified and recommendations for harmonising reforms were made. The project also developed a case for creating a marketplace to trade waste across sectors and jurisdictions. The project delivered an innovative integrated supply chain model based on a cradle-to-cradle (lifecycle) approach that will streamline C&D waste management processes, while effectively reducing/reusing/recycling C&D waste. A key deliverable were recommendations to aid national harmonisation of the economic factors and drivers/barriers that govern C&D waste management in a market-driven economy. The specific objectives were:

1. *Review regulations and their application in practice in different jurisdictions governing C&D waste management, identifying discrepancies and making recommendations for reforms.*
2. *Develop a consistent approach to define and measure C&D waste across different jurisdictions.*
3. *Identify economic factors that govern the disposal and reduce/reuse/recycling of C&D waste.*
4. *Conduct a feasibility study on creating a marketplace to connect organisations and industries across jurisdictions for trading waste.*
5. *Identify opportunities to integrate supply chains and develop an integrated supply chain lifecycle model espousing a cradle-to-cradle approach.*

The results presented in this report are based on a comprehensive analysis of literature, regulations, policies and best management practice guidelines. Notably, desktop research focused on the regulatory framework in eight jurisdictions of Australia to understand similarities and differences (Sections 1 and 2). According to this review, several recommendations were made that are both national and state-specific. Next, economic barriers and enablers to the establishment of a domestic C&D waste market were explored, and a set of recommendations were proposed accordingly (Section 3). Next, a comprehensive review was performed to provide information on the Australian and worldwide experience obtained in the establishment and performance of C&D waste market (Section 4).

Furthermore, an economic evaluation based on the mathematical modelling of various C&D waste management techniques (landfilling in regional and metropolitan areas vs. recycling) was conducted. In this evaluation, the economic performance of various waste management methods were analysed and compared, considering associated cost elements of each method (Section 5). A case study approach was adopted to analyse and identify opportunities for reducing C&D waste throughout the supply chain of five typical C&D waste materials brick (Section 6), concrete (Section 7), steel (Section 88), glass (Section 9), timber (Section 10) and steel (Section 8). For each case study, a conceptual model, called LoWMoR (Low of Waste More of Resources) was developed to outline the application of cradle-to-cradle approach to C&D waste in the light of circular economy principles. Then, the opportunities to reduce waste were explored from design through to manufacturing, recycling, reusing and to illegal dumping. Lastly, a survey was conducted to capture the perception of main C&D waste stakeholders about the relevant issues and reforms. The survey captured the responses from 132 participants from across Australia in the construction industry, waste management and recovery industry, waste collectors, designers, and the construction material manufacturing industry (Section 11). An important finding from the survey was the development of a domestic marketplace for trading C&D waste in Australia. Overall, the project findings contribute to Australian understanding of effective management of C&D waste by providing a clear picture of C&D waste state of play. The findings can be further analysed and used by policymakers and whoever has an interest in C&D waste to better plan for innovative and efficient C&D waste resulting in the further diversion of C&D waste from landfills.

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1. Discrepancies in Reglations Governing C&D Waste Stream

1.1 Introduction

The construction industry in Australia has grown significantly in the past two decades in the wake of population growth, migration and expansion in the tertiary education sector. The growing population has necessitated extensive property development, better public transport and improved infrastructure. The range of construction activities initiated in response include the businesses that are involved in creating residential and non-residential buildings (including renovations and additions), engineering structures, and associated trades and services (Australian Bureau of Statistics, ABS, 2006). The industry is identified as the fourth largest contributor to gross domestic product (GDP) (Trading Economics, 2018); more than one million people work in the industry. Unsurprisingly, this volume of construction brings about a huge volume of waste, known in the industry as C&D waste. In 2016-17, approximately 20.4 Mt of C&D waste was produced in the Australian construction industry, which accounts for 38 per cent of the total core waste[1] generated in Australia (Pickin et al., 2018).

Due to its substantial impact on the economy, society and environment, generation of C&D waste has been a source of concern for Australians for many years (Udawatta et al., 2015, London et al., 2013). This has resulted in state governments paying more attention to this growing issue. For instance, in the late 1990s, citizens of Canberra demanded the state government consider a 'no waste policy' to manage C&D waste. In 1996, this demand resulted in the implementation of the first zero-waste strategy of its kind for a city (Zero Waste, 2007). Due to improvements in public awareness about the environment, Australian state governments have become increasingly pressured to tackle this issue. The community also expects construction companies to manage the waste they generate (Environment Protection Authority, EPA Victoria, 2004). Consequently, more state governments have shown interest in launching several construction waste reduction projects and in facilitating multiple strategies to avoid, reduce, recycle and re-use C&D waste (Park and Tucker, 2017).

A number of studies in Australia have highlighted that, among the main factors dictating the effective management of C&D waste, regulations play a decisive role (Park and Tucker, 2017, Udawatta et al., 2015, Udawatta et al., 2018, Teo and Loosemore, 2001). Governance of C&D waste issues occurs within the three tiers of government: federal, state or territory and local. However, the federal government is not directly involved in regulating C&D waste unless the regulations set by the other two tiers are in conflict with international treaties (for example, Agenda 21, Basel Conventions and Stockholm Conventions) or impose threats to the environment that are of national concern. In other words, there is no constitutional authority to regulate waste nationally (Wainberg, 2012). The majority of legislation occurs at the state and territorial government level. Therefore, C&D waste management in each state/territory builds on the specific regulatory framework that prevails in that state. As such, the method typically implemented by the Australian Government is one of multi-stakeholder engagement and the introduction of multi-party agreements. These may be supported by legislative measures in instances where all parties support the need for such fallback legislation at a jurisdictional level (Laviano et al., 2017). Experts argue that inconsistencies at the jurisdictional level can hinder effective management of C&D waste and inflict multiple issues (Hyder Consulting, 2011).

[1] Solid non-hazardous waste and hazardous waste including liquids, and generated in the municipal, C&D and Commercial and Industrial (C&I) sectors, generally excluding primary production.

1.2 Methodology

1.2.1 Data collection, processing and analysis

This review study is based on the secondary data that are publicly available. The document analysis technique was conducted to identify differences in jurisdictional regulatory frameworks and practices in Australia. The sources reviewed include Acts, policies, regulations and strategies that are mostly administrated by the Environment Protection Authority (EPA) and other state-specific authorities (for example, Sustainability Victoria, in Victoria (Vic)), plus reports and initiatives prepared for C&D waste management in Australia. In total, 62 documents that provided information about C&D waste legislation in Australia were analysed. It is worth bearing in mind that amendments to C&D waste regulations and Acts occur periodically; therefore, the information provided in this paper is considered valid at the time of writing. On this basis, the regulations that are not in force and/or have been repealed are excluded from the review. Descriptive analysis is used to analyse and present the data collected. Quantitative results are mostly presented using analytical measures such as frequency and arithmetic average. Microsoft Excel V. 2016 is used to analyse the data and visualise results. All currency reported is in Australian dollars.

1.2.2 Context of study

Australia is a large country with a low population and density. The majority of the population of 25 million is settled in capital cities. Significant growth in migration and population in Australia has generated demands for more construction activities. As a result, more infrastructure and new housing are needed to meet the requirements of this ever-increasing population (IBISWorld, 2019a). A more detailed overview of the construction industry is provided in the results section. The statistics have shown that construction activities generate a large quantity of C&D waste (Pickin et al., 2018). Despite having no physical shortage of landfill sites, there is a high level of community environmental awareness. This means that it is difficult to open new landfill sites and incineration is not tolerated (Wainberg, 2012). As such, the state governments attempt to regulate C&D waste management through enforcing relevant legislation.

1.3 Results of Review

1.3.1 Overview of the Australian construction Industry

Construction in Australia comprises several activities; from general construction to the construction of pipelines, railroads and river works, it also involves irrigation projects and the construction of water, gas, electricity and sewage infrastructure. According to the Australian and New Zealand Standard Industrial Classification (ANZSIC) 2006 (Revision 2), the construction industry (Division E) involves three subdivisions: building construction, heavy and civil engineering construction, and construction services (ABS, 2006). Each of these subdivisions is further divided into various 'groups' and 'classes' with certain activity definitions. Although there has been a slight negative annual growth in this industry from 2014 to 2019 in general, it is projected that the construction industry will enjoy a 2.4 per cent annual growth between 2019 and 2024 (IBISWorld, 2019a).

Analysis of different construction subdivisions reveals a constant annual growth rate. For instance, the historic data from the Australian Bureau of Statistics (ABS) indicate that the value of work done in building construction activities has progressively increased by 33 per cent from 2012 (22,099,416) to 2018 (29,428,494). During this period, the Australian population has grown by 11 per cent (ABS, 2018b). These two trends clearly demonstrate the industry's attempt to keep up with the growing population. In the residential sector, approximately 18,000 dwelling units were approved for construction monthly in 2017 (Martek et al., 2019). In the heavy and civil engineering construction subdivision, the annual revenue was estimated to be $394.3 billion, which provided more than one million jobs in Australia. Road and bridge construction was recorded to benefit a 5.3 per cent annual growth and $28.9 billion revenue (IBISWorld, 2019a). In the construction engineering sector, the annual value of work commenced (all subdivisions) had an average annual growth rate of

19.9 per cent from 2015 to 2018 (June) (ABS, 2018a). This increase is reported to be significantly larger in some states such as Vic (up to 80 per cent) and Western Australia (WA) (39 per cent).

1.3.2 C&D waste generation and management in Australia

The existing pace in construction activities in Australia is also indicative of the generation of more C&D waste. According to the *National Waste Report 2018*, prepared for the Department of the Environment and Energy (DEE) (now the Department of Agriculture, Water and the Environment), in 2016-17 Australia generated 831 Kg of C&D waste per capita (Pickin et al., 2018), which has increased by 2 per cent per capita over a 11-year period (2007–2017). The total waste generated has steadily increased by 1.9 per cent from 2007 to 2017 (Table 1) and reached 20.4 Mt, which represents the largest source stream (43 per cent) of all waste types. C&D waste is mostly recycled and then disposed of in landfills. Hence, C&D waste management is important from economic and environment perspectives. C&D waste accounts for a significant proportion (26.9 per cent) of the solid waste collection and recycling services industry in Australia, an industry that produces $5.2 billion in revenue and enjoys three per cent annual growth. This industry is influenced by two major factors: construction/demolition activities and population growth, both of which are projected to increase in the coming years (IBISWorld, 2019b). Another source, The Waste Management Association of Australia (WMAA) reported that the industry employs 50,000 individuals and contributes $50 billion per annum to the Australian economy (Senate Environment and Communications References Committee, 2018). Modelling by the Centre for International Economics (2017)[2] indicates that a five per cent rise in the recycling rate could add $1 billion to Australia's GDP. Other external factors that alter the industry's performance are number of households, level of urbanisation and public concerns over environmental issues. In Australian jurisdictions, C&D has recently attracted attention due to its economic potential and, as a result, more demand has created social and environmental benefits that the authorities and wider community can enjoy through proper management.

In terms of waste fate, statistics showed that, between 2016 and 2017, more than 6.7 Mt of C&D waste was transferred into landfills (Pickin et al., 2018). Despite the growth in C&D waste generation, the annual average of waste disposal during the period 2007–2017 remains largely unchanged. However, the waste disposal per capita rate shows a different trend, with a 1.6 per cent annual drop (Table 1). Conversely, the quantity of waste recycled has significantly improved during this 11-year period. Recycling of C&D waste has increased by 3.4 Mt, or 34 per cent.

Table 1. Waste generation, recycling and disposal rates in Australia between 2007 and 2017.

C&D waste	2007	2009	2010	2011	2014	2015	2016	2017	Average annual growth rate (%)
Generated – total (Mt)	16.9	18.5	18.4	18.4	17.9	19.4	20.1	20.4	1.9
Generated– per capita (t)	0.82	0.86	0.84	0.83	0.77	0.82	0.84	0.84	0.2
Disposed of (Mt) –total	6.6	7.3	7.0	6.2	6.2	6.7	6.4	6.7	0
Disposed of (Mt) – per capita	0.32	0.34	0.32	0.28	0.27	0.28	0.27	0.27	-1.6
Recycled (Mt)	10.1	11.1	11.3	12.1	11.5	12.4	13.5	13.6	3
Recycled– per capita (t)	0.49	0.52	0.51	0.54	0.49	0.53	0.56	0.56	1.3
Recovery rate (%)	60	60	62	66%	65	65	68	67	1.1

Source: National Waste Report. 2018. This report acquired data from different EPAs across Australia.

Analysis of C&D waste data in different jurisdictions demonstrates unequal proportions of waste disposal in landfills (Table 2). In 2017, the largest quantity of waste disposed was registered in Qld

[2] Centre for International Economics. 2017. Headline economic value for waste and materials efficiency in Australia. https://bit.ly/3gmh9CS

(2,312 Mt) followed by NSW (1,969 Mt) and Vic (1,549 Mt). It seems that the quantity of waste disposed in each state does not correspond to population, and some other factors such as levy rate and availability of proper recycling facilities are potentially involved. From Table 2 it can be noted that recovery rate within different jurisdictions differs significantly. The greatest recycling rate is in South Australia (SA) (91.1 per cent), followed by in Vic (82 per cent) and NSW (69 per cent). Each of these three states has a better recycling performance than the national average (67 per cent).

Table 2. C&D waste disposal and management in different Australian jurisdictions in 2016-17.

C&D waste	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	AUS
Waste disposal (kt)-total	180	132	1,969	2,312	151	39	1,549	374	6.71
Current recycling rate (%)*	na	69 (2013)	1(2011)	51	91.1	1	82	64	67
Population (thousands:' 000)	406	7,798	245	4,884	1,717	519	6,244	2,568	

Source: National Waste Repor. 2018. This report acquired data from different EPAs across Australia.
***Source:** data is extracted from various reports produced by jurisdictional authorities.

In 2016-17, the quantity of C&D waste recycled was 13.6 Mt, accounting for 43 per cent of the total core waste recycled. This represents the largest source of core waste in Australia. In the same period, C&D waste was reported to hold an energy recovery rate of 0 per cent, a recycling rate of 67 per cent and a total recovery rate of 67 per cent (Table 2). The average annual growth rate of recovery of C&D waste is estimated to be 3 per cent and 1.3 per cent, respectively, for the period 2007–2017 (Pickin et al., 2018). The *National Waste Report Pickin et al. (2018)*reported that the proportion of recycling of masonry materials (for example, asphalt, brick, concrete, rubble, plasterboard and cement sheeting) progressively increased, with a 3.2 per cent average annual growth rate, while landfilling has decreased (Figure 1).

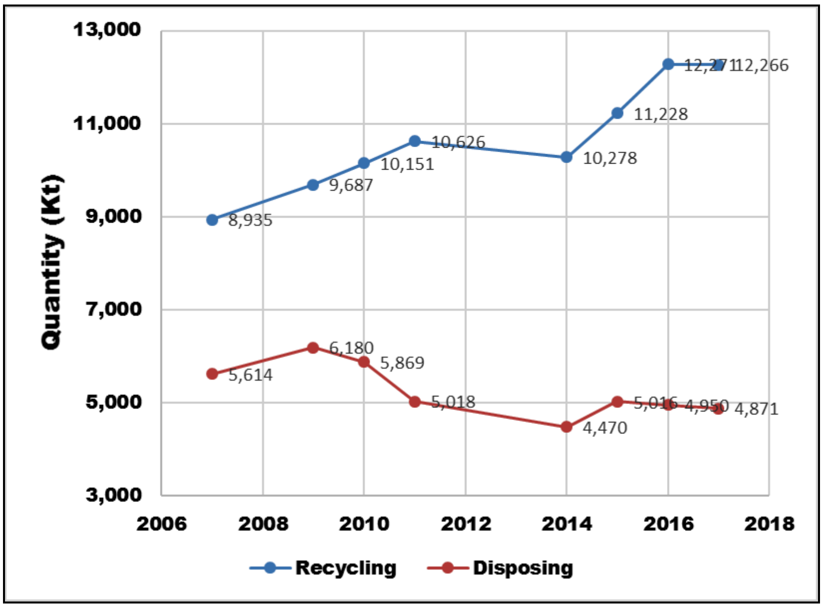

Figure 1. The trend of recycling and dumping masonry materials in Australia.
Source: National Waste Report (2018).

By way of comparison, the rate of recovery of C&D waste was 89.9 per cent in the United Kingdom (UK),[3] 49 per cent in the United States (US) in 2014[4] and 94 per cent in Denmark in 2015 (Statistics Denmark, 2015). In 2014 and 2015, the recovery rate in Australia was about 64 per cent. A European

[3] Department for Environment Food and Rural Affairs, 2018. UK Statistics on Waste. In: AFFAIRS, D. F. E. F. A. R. (ed.). London.
[4] United States Environmental Protection Agency, 2018. Advancing Sustainable Materials Management: 2015 Fact Sheet.

Landfill Directive (Ref 1) promulgated by the European Commission (EC) in 1999 caused significant changes in the treatment of residual waste in Europe. The directive is mainly concerned with ensuring that landfill and waste acceptance standards are uniform across the European Union (EU), to avoid dumping hazardous waste into low-standard sites. In Hong Kong, a three-year levy scheme (2006-08) demonstrated that C&D-specific waste levy taxes can influence construction behaviours regarding C&D waste, resulting in a significant reduction in solid waste disposal.[5] The recycling rate of C&D waste differs significantly among countries, owing to different levels of economic development and technology. In another study in the Australian context, it was found that an increase in the landfill levy causes: waste service providers to invest in resource recovery facilities; governments to initiate infrastructure funding and education programs; and businesses to prioritise recycling over landfill.[6]

1.3.3 The main decision-makers in C&D waste management and regulation

The first difference in C&D waste management among jurisdictions is the variation in the number and type of agencies involved in making policy and authorising waste management practices. Historically, the main authority to regulate C&D waste in jurisdictions is the EPA (Figure 2). In 2009, however, Qld's EPA ceased to regulate C&D waste independently and became a part of the Department of Environment and Resource Management (now the Department of Environment and Heritage Protection). Gradually, EPAs have engaged other specialised agencies in the process of decision-making, policies and strategies development. The focus of these agencies is on the effective management of C&D waste, maximising waste recovery and raising awareness in the public and the construction industry to reduce waste generation. For instance, in WA the Waste Authority, previously known as the Waste Management Board, has become the main authority that provides policy on waste avoidance and recovery. In Vic, Sustainability Victoria, previously known as EcoRecycle Victoria, has worked closely with EPA Victoria and other partners to develop an industry standard on waste management. In SA, Green Industries SA, previously known as Zero Waste, has a statuary requirement (*Zero Waste SA Act 2004*) to develop a waste strategy in SA. These agencies operate in close collaboration with local governments in developing C&D waste policies.

Technically, local governments provide waste collection and recycling services, manage and operate landfill sites, deliver education and awareness programs, and provide and maintain recycling infrastructure.[7] From a more holistic perspective, as outlined by the Department of Agriculture, Water and the Environment website, waste management and resource recovery are not only the responsibilities of governments, but also a range of industries and businesses, as well as communities, and individuals that are involved. Figure 2 displays the various authorities that govern C&D waste in different jurisdictions.

At the national level, there is a greater variety of influencers. Fourteen authorities and associations are involved in the development of C&D waste management strategies and policy by submitting to the Department of Agriculture, Water and the Environment Inquiry. The majority of these influencers have contributed to the development of the *2018 National Waste Policy: less waste, more resources* (*2018 NWP*). Among these, the Australian Local Government Association (ALGA) has a key role in developing national waste policy (NWP) through facilitating assemblies in which state and territory environment ministers/officials, along with business and industry associations and non-government organisations, provide input on priority issues.

[5] Yu, A. T. W., Poon, C. S., Wong, A., Yip, R. & Jaillion, L. 2013. Impact of construction waste disposal charging scheme on work practices at construction sites in Hong Kong. *Waste Management*, 33, pp. 138-146

[6] MRA Consulting Pty Ltd. State of Origin of Waste – NSW v Qld. North Sydney, NSW: Alex Sergo, 2015.

[7] Commonwealth of Australia, *2018 NWP*.

Figure 2. Agencies and associations contribute to management of C&D waste in Australia

Furthermore, the number of contributors to making decisions on C&D waste varies between the jurisdictions. Among the jurisdictions, with five actors, Vic has the largest number of entities guiding C&D waste management practices. In most jurisdictions, a state department that governs environment is engaged in overseeing C&D waste management.

1.3.4 Overview of jurisdictional waste legislation and, policies and guidelines

State and territory legislative frameworks governing waste and recycling are complex and involve multiple pieces of legislation and policy instruments. The primary pieces of legislation for C&D waste management in each jurisdiction are the Acts that are produced and administrated by EPAs, with the exception of Qld, where the overarching Act is produced under the Department of Environment and Science (Table 3).

Most of these Acts are updated regularly to meet current and changing industry and public demands and issues. Among the jurisdictions, Vic and WA have the largest number of Acts in place, followed by the Australian Capital Territory (ACT), NSW and SA with three, and Tas and Northern Territory (NT) with only one Act. In some jurisdictions, other authorities and departments have also produced Acts that contribute to the regulation of C&D waste or amend the primary EPA acts. In the ACT, in addition to EPA-produced Acts, the Transport Canberra and City Services Directorate enforced an Act (*Waste Management and Resource Recovery Act 2016*) which informs C&D waste management. In SA, Green Industries SA has enacted the *Green Industries SA Act 2004*, which promotes innovation and business activity in the waste management, resource recovery and green industry sector in the state. In Vic, Sustainability Victoria developed an Act (*Sustainability Victoria Act 2005*) to promote waste avoidance, waste reduction and recovery, re-use, recycling of resources and best practices in waste management. In WA, the Department of Water and Environmental Regulation developed two Acts (*Waste Avoidance and Resource Recovery Act 2007*; *Waste Avoidance and Resource Recovery Levy Act 2007*) to regulate waste.

These Acts and subordinate regulations primarily contain critical information about waste levy, licensing requirements for waste facilities and activities, and penalties for illegal dumping-related offences. They also regulate activities, products, substances and services that may cause environmental harm from pollution or production of waste. Some of the Acts in use are set to promote waste minimisation through avoidance, reduction, recycling and re-use. Among the jurisdictions, six (ACT, NT, NSW, Qld, Tas, WA) have released Acts that are specifically intended for waste management (Table 3).

In each of the jurisdiction's subordinate regulations, policies and codes have been established to clarify and/or extend the scope and objectives of the overarching Acts. WA has three subordinate regulations, followed by ACT, NSW, Qld, Tas and Vic, which enforce two regulations. Another layer of waste management is waste strategy documents that are also published in jurisdictions to specify targets, strategies and priorities in the management of waste. Victoria is yet to develop a holistic waste strategy that facilitates implementation of C&D waste-related regulations. Among Australia's jurisdictions, only NSW has provided specific documents (Standards for Managing Construction Waste in NSW) that further clarify the requirements of state regulations to manage C&D waste.

At the national level, there are three pieces of legislation that can inspire and inform C&D waste management regulatory frameworks in the studied jurisdictions. These include the *National Environment Protection Council Act 1994*, the *Hazardous Waste (Regulation of Exports and Imports) Act 1989* and the *Product Stewardship Act 2011*. The *National Environment Protection Council Act 1994* indicates the responsibility of polluters (that is, waste producer) and the users of goods and services in relation to the cost associated with waste generation. Similarly, the *Product Stewardship Act 2011* is a strategy with an environmental management focus that declares whoever is involved in production and consumption of a good should take responsibility for reducing its environmental impact. The *2018 NWP* is probably the most relevant document. It leads C&D waste management activities across Australia by setting 14 strategies that provide a framework for waste management improvements. This document is a benchmark against which jurisdictions can upgrade and align their regulations. It also assists in the development of jurisdictional waste strategies, which are consistently developed documents to achieve uniform goals. The *Guide to Pavement Technology* Part 4E: Recycled Material is a national guideline presenting the acceptance requirements of recycled materials, including C&D waste, to be used in road pavement projects across Australia.

Table 3. Jurisdictional waste legislative and management framework

	Key legislation documents	Strategies/guidelines
ACT	Environment Protection Act 1997 Waste Management and Resource Recovery Act 2016 Environment Protection Regulation 2005 Waste Management and Resource Recovery Regulation 2017	ACT Waste Management Strategy: Towards a Sustainable Canberra 2011–2025 Waste and Recycle Management Code for the Act Sustainable Procurement Policy 2015
NSW	Protection of the Environment Operations Act 1997 No 156 Protection of the Environment Administration Act 1991 No 60 Waste Avoidance and Resource Recovery Act No 58 2001 Protection of the Environment Operations (Waste) Regulation 2014 Environmental Planning and Assessment Regulation 2000	Waste Levy Guideline Waste Avoidance and Resource Recovery Strategy 2014–2021 Reducing Waste: Implementation Strategy 2011–2015 Extended Producer Responsibility (EPR) Environmental Guidelines Solid Waste Landfills Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage 2010 NSW Illegal Dumping Strategy 2017–2021 Management of Wastes on Roads and Maritime Services Land Management of Road Construction and Maintenance Wastes: Technical Guide 2016 Standards for Managing C&D waste in NSW Waste and Resource Recovery Infrastructure Strategy 2017–2021 –draft Sustainable Procurement Guide: for local government in NSW
NT	Waste Management and Pollution Control (WMPC) Act 1998 WMPC (Administration) Regulations	Territory 2030 Strategic Plan 2009 Guidelines for the Siting, Design and Management of Solid Waste Disposal Sites in the Northern Territory 2003 Waste Management Strategy for the Northern Territory 2015–2022
Qld	Environmental Protection Act 1994 Waste Reduction and Recycling Act 2011 Environmental Protection Regulation 2008 Environmental Protection (Waste ERA Framework) Amendment Regulation 2018	Queensland's Waste Reduction and Recycling Strategy 2010–2020 Waste Management and Resource Recovery Strategy 2019 Queensland Waste Avoidance and Resource Productivity Strategy (2014–2024) Transforming Queensland's Recycling and Waste Industry – *Directions paper* Queensland's Waste Strategy 2010–2020 Recycling and Waste in Queensland 2017 The proposed Queensland Regulated Waste Framework Landfill siting, design, operation and rehabilitation Transport and Main Roads Specifications MRS35 Recycled Material Blends for Pavements
SA	Environment Protection Act 1993 Development Act 1993 Green Industries SA Act 2004 Environmental Protection Regulations 2009 Environment Protection (Waste to Resources) Policy 2010	South Australia's Waste Strategy 2015–2020 Waste-derived materials—Guiding Principles for Determining Approval Processes and Product Standards Standard for the Production and Use of Waste Derived Fill-2013 Recycled Fill Materials for Transport Infrastructure - Operational Instruction 21.6 Specification: Part 215 Supply of Pavement Materials Ecologically Sustainable Development Guide Note Planning, Design and Delivery of New and

	Key legislation documents	Strategies/guidelines
		Refurbished Buildings SA Sustainable Procurement Guideline Standard for the Production and Use of Refuse Derived Fuel South Australia's Waste and Resource Recovery Infrastructure Plan 2018
Tas	Environmental Management and Pollution Control Act 1994 Litter ACT 2007 Litter (Infringement Offences) Regulations 2011 Environmental Management and Pollution Control (Waste Management Regulations) 2010 Environmental Management and Pollution Control (Controlled Waste Tracking) Regulations 2010.	The Tasmanian Waste and Resource Management Strategy 2009 Waste and Resource Management Strategy
Vic	Environment Protection Act 1970 Environment Protection (Resource Efficiency) Act 2002 Environment Protection (Amendment) Act 2006 Sustainability Victoria Act 2005 Environment Protection (Distribution of Landfill Levy) Regulations Environment Protection (Industrial Waste Resource) Regulations 2009 Waste Management Policy (Movement of Controlled Waste Between States and Territories) Waste Management Policy (Siting, Design and Management of Landfills) 2004	Siting, design, operation and rehabilitation of landfills VicRoads Standard Specifications for Roadworks and Bridgeworks State-wide Waste and Resource Recovery Infrastructure Plan (2016-2046)
WA	Environmental Protection Act 1986 Environmental Protection (Landfill) Levy Act 1998 Waste Avoidance and Resource Recovery Act 2007 Waste Avoidance and Resource Recovery Levy Act 2007 Environmental Protection Regulations 1987 Environmental Protection (Controlled Waste) Regulations 2004 Waste Avoidance and Resource Recovery Regulation 2008 Waste Avoidance and Resource Levy Regulation Administration Policy 2009	Extended Producer Responsibility Policy Statement Waste Strategy Avoidance and Resource Recovery Strategy 2030: Western Australia's Waste Strategy: Western Australia's Waste Strategy Western Australian Waste Strategy: Creating the Right Environment Waste Strategy 2030 Main Roads Western Australia Specification 501 – Pavements Guide to Sustainable Procurement 2017
National	National Environment Protection Council Act 1994 Hazardous Waste (Regulation of Exports and Imports) Act 1989 Product Stewardship Act 2011	2018 NWP Environmental Sustainability Policy National Environment Protection (Movement of Controlled Waste Between States and Territories) Measure Sustainable Procurement Guide 2013 Guide to Pavement Technology Part 4E: Recycled Material

*These pieces of legislation are subject to change; an updated copy of some of this legislation can be found on the legislation website of each state/territory (for example, www.legislation.qld.gov.au)

1.3.5 Health and safety regulations and policies related to C&D waste management

Health and safety requirements during dealing with various C&D waste materials is another source of disparity among the Australian jurisdiction regulatory frameworks. The jurisdictional regulations propose different waste classification systems, including maximum permissible hazardous contaminants such as asbestos. These different requirements can have a negative impact on creating an efficient C&D waste management system in Australia. Table 4 shows the health and safety-related regulations and policies that are implemented across Australia.

Table 4. Health and safety regulations and policies

	Key legislative documents
National	• Guidelines for managing asbestos at construction and demolition waste recycling facilities- 2012 (Department of Environment and Conversation) • Asbestos Waste in Australia 2016 (Australian Government) • How to safely remove asbestos code of practice (Safe Work Australia) • Demolition Work Code of Practice 2016 (Safe Work Australia)
ACT	• Dangerous Substances Act 2004 (ACT Government) • Dangerous Substances (General) Regulation 2004 (ACT Government) • Loose-fill Asbestos Legislation Amendment Bill 2020 • Work Health and Safety Act 2011 • Work Health and Safety Amendment Act 2019
NT	• Demolition notifications 2018 (NT Safe Work) • The Work Health and Safety (National Uniform Legislation) Act 2011 (NT Department of the Attorney-General and Justice) • Work Health and Safety (National Uniform Legislation) Regulations (Department of the Attorney-General and Justice)
NSW	• Waste classification guidelines Part 2: Immobilisation of waste 2019 (NSW EPA) • Code of Practice Demolition Work 2019 (NSW Government)
Qld	• The proposed Queensland Regulated Waste Framework 2015 (Department of Environment and Heritage Protection)
SA	• Wastes containing asbestos – removal, transport and disposal- 2017(SA EPA) • Work Health and Safety Act 2012 (SA Government) • Work Health and Safety Regulations 2012 (SA Government)
Tas	• How to manage and control asbestos in the workplace 2018 (Safe Work Australia)
Vic	• Occupational Health and Safety Act 2004 (Victorian Government) • Occupational Health and Safety Regulations 2007 (Victorian Government) • Guide to Best Practice at Resource Recovery Centres (Sustainability Victoria) • Code of Practice for Manual Handling 2000 (Work Safe Victoria). • The Occupational Health and Safety (Asbestos) Regulations 2003 (EPA Victoria). • Industrial Waste Resource Guidelines Asbestos Transport and Disposal • Recycling Construction and Demolition Material: Guidance On Complying with the Occupational Health and Safety (Asbestos) Regulations 2003 (WorkSafe Victoria) • Compliance Code: Managing asbestos in workplaces (WorkSafe Victoria).
WA	• The Environmental Protection Amendment Regulations 2018 • Waste Avoidance and Resource Recovery Levy Act 2007 • Environmental Protection (Controlled Waste) Regulations 2004 • Summary of the Guidelines for the Assessment, Remediation and Management of Asbestos – Contaminated Sites in Western Australia 2009 (WA Department of Health) • Environmental Protection (Unauthorised Discharges) Regulations 2004

1.3.6 Waste strategy policy in Australia

Most jurisdictions have a strategy document that guides government organisations and industries in improving waste management over the strategy period. In many cases, strategies set targets for resource recovery or other waste performance indicators. Table 4 specifies the current strategy documents and any targets within them.

Waste strategy documents are an important part of waste management governance in Australia (Figure 4). Despite not having statutory power, they guide efforts to improve waste management in different jurisdictions. On the one hand, they are required to be developed under relevant jurisdictional Acts. On the other hand, they also have a significant impact on the jurisdictional legislative framework, through objectives, targets and reforms proposed for implementation in primary and secondary waste-related legislations. For instance, in WA, the *Waste Avoidance and Resource Recovery Act 2007* under Division 1, Waste Strategy (Part 4, Management Documents) commissioned the Waste Authority to prepare a draft waste strategy containing a long-term strategy for continuous improvement of waste services, waste avoidance and resource recovery.

Figure 3. Australian waste management strategy documents

The primary framework underpinning waste strategies followed by Australian jurisdictions is the waste hierarchy. The waste hierarchy is a nationally and internationally accepted concept used to prioritise and guide efforts to manage waste. This framework, as shown in Figure 4, contains six levels of waste management. The least preferable option is waste disposal and the most desirable is to collectively avoid and reduce waste. The waste hierarchy also plays an important role in waste-related Acts and regulations by contributing to setting regulations' objectives that aim to achieve waste management goals. Some examples of the hierarchy's application include regulations and Acts enforced in the ACT,[8] NSW,[9] WA,[10] Qld,[11] SA[12] and Vic.[13] However, its application (for example, the modification in the levels of hierarchy) differs greatly.

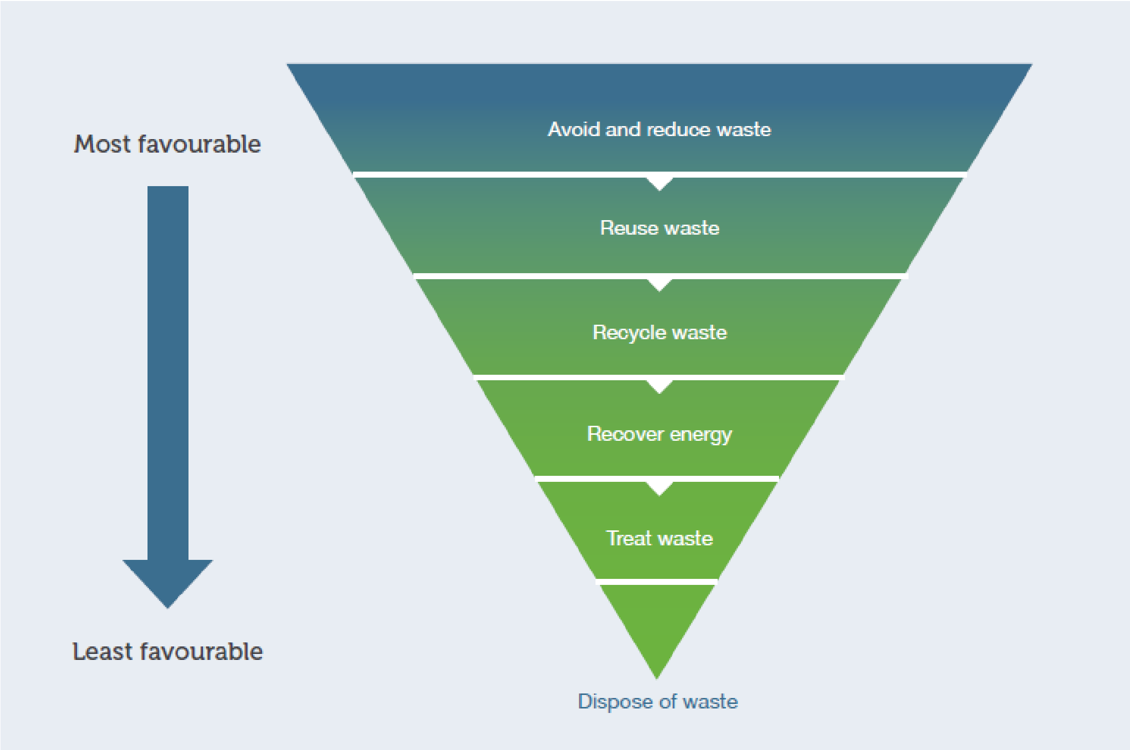

Figure 4. Waste hierarchy adopted by waste strategy documents across Australia

In addition to this framework, each strategy provides principles and objectives that determine actions to manage waste within each jurisdiction. Table 4 summarises the main principles enshrined in the waste strategy document for each jurisdiction. Comparisons among these strategies can reveal the inconsistencies that exist between the strategies taken in different jurisdictions. They also provide the opportunity to improve the actions and strategies being advised, according to successful outcomes in jurisdictions that have led by example. In order to keep the review relevant to the context of C&D waste, only strategies that have directly or indirectly impacted on C&D waste management activities are described.

[8] Waste Management and Resource Recovery Act 2016 – ACT.
[9] Waste Avoidance and Resource Recovery Act No. 58 2001 (NSW).
[10] Waste Avoidance and Resources Recovery Act 2007 – WA.
[11] *Waste Reduction and Recycling Act 2011* – Qld.
[12] Environment Protection Act 1993 / Green Industries SA Act 2004 – SA.
[13] Environment Protection Act 1970 – VIC.

Table 5. Summary of waste strategy documents in different jurisdictions

	Objectives and Strategies	Document
ACT	**(1) Less waste generated– target: reuse of goods expands in the ACT** -Awareness, education and action -Promote reuse through ACT business and charities -Encourage on-site reuse for C&D waste **(2) Full resource recovery– target increase resource recovery rate to more than 85 per cent by 2025** -Promote education and active recycling -Government procurement -Develop markets for recyclable materials and strengthen regional connections -Disincentives to landfill including appropriate pricing and regulation **(3) A clean environment– target: ACT leads Australia in low illegal dumping and protection of ACT environment** -Reduce litter and dumping through laws and raising awareness -Develop the Hume Resource Recovery Estate -Maintain a safe and environmentally responsible landfill to meet the ACT's future needs. -Manage hazardous waste -Increase soil reuse and rehabilitation **(4) A carbon neutral waste sector– target: ACT waste sector is carbon neutral by 2020, energy produced from waste doubles by 2020** -Expand bioenergy generation and investigate new energy-from-waste technologies to generate energy -Increase recycling to avoid greenhouse gas emissions (GHGs) -Ensure energy efficient waste collection and transport solutions	**-ACT Waste Management Strategy 2011–2025**
NSW	**(1) Avoid and reduce waste generation– target: reduce the rate of waste generation per capita** -Economic incentives -Behaviour change -Product stewardship (PS) -Industrial ecology **(2) Increase recycling– target: increase recycling rate for C&D waste to 80 per cent by 2021–2022** -Develop markets and encourage innovation -Build capacity for developing regional recycling plans **(3) Divert more waste from landfill– target: increase the waste diverted from landfill to 75 per cent by 2021-2022** -Co-fund large-scale infrastructure for viable resource recovery energy-from-waste projects -Manage problem wastes better -Reduce litter -Reduce illegal dumping- target: 30 per cent reduction -Establish partnership with key stakeholders to increase opportunities for people to care about their own environment -Build capacity at local level for key stakeholders to increase their knowledge and expertise to implement practical regional solutions	**-NSW Waste Avoidance and Resource Recovery Strategy 2014–21** **-NSW Illegal Dumping Strategy 2017–21**

	Objectives and Strategies	Document
	-Strengthen compliance and enforcement activities to detect, investigate and prosecute illegal dumping consequences -Organise education campaign to raise community awareness about illegal dumping repercussions -Build a robust evidence based through data collection and analysis on illegal dumping incidents, attitudes and behaviour to help key stakeholders identify, prioritise and target local needs as well as monitor and evaluate the effectiveness of their actions	
NT	**(1) Engagement and education** -Promote community awareness and understanding of resource efficiency, waste avoidance and resource recovery; -Provide best-practice guidance materials for handling and disposing of commercially generated wastes including contaminated soils and concrete -Facilitate and promote PS programs for recycling and treating nationally significant waste streams -Collaborate with the Waste and Recycling Industry of the NT (WRINT) to identify emerging trends and issues requiring multi-faceted solutions; -Facilitate coordination of localised waste arrangements in regional development projects -Work with local government and the NT Government to coordinate local efforts to prevent litter and illegal dumping -Work directly with local and regional councils and local service authorities to monitor, detect and reduce community exposure to the risks of poor waste management **(2) Improve waste management** - Develop and guide waste avoidance and reduction programs - Support proposals by regional councils to consolidate recycling infrastructure at central locations - Facilitate opportunities to connect waste recovery and reuse markets with key waste producers (for example, organics, green waste, C&D waste and C&I waste); -Work with industry and government agencies to demonstrate the economic incentives available through improved waste management and resource recovery, including options for reducing GHGs from landfill -Assess the status of landfill sites in the Territory to: prioritise high environmental risk sites requiring operational improvement; impact monitoring or rehabilitation, including in a remote context; regulate landfills in accordance with the objectives of the WMPC Act 1998; -Develop guidance to demonstrate best practice expectations: identify and develop guidelines to assist landfill operators in better managing their waste and resources -Develop a waste infrastructure mapping database to identify locations of accessible facilities and to assist strategic planning for the future requirements of the Territory; - Collaborate with local waste operators and industry bodies to identify and address the limitations to their delivery of waste management services. -Recommend waste reduction and waste management plans are developed and implemented on significant developments - Advise on specific infrastructure required to deal with liquid wastes generated locally - Highlight the need for early consideration of asbestos disposal locations across the NT, including in remote housing and infrastructure projects; -Assist local and regional councils and industry to identify key infrastructure needs and to identify appropriate land for future waste management sites;	**-Waste Management Strategy for The Northern Territory 2015–2022**

	Objectives and Strategies	Document
	-Recommend that industry and government agencies seek innovative technologies as preferred waste solutions, to stimulate waste research and investment **(3) Improve waste data collection, monitoring and analysis** -Identify waste facilities that are not reporting waste data and develop an approach for capturing essential data from these sites; - Develop an improved system for recording and interpreting waste data required to be collected by the Nortern Territory EPA (NT EPA); - Continue to participate and assist in the development of nationally consistent waste classification systems; - Prioritise targeted waste streams for an audit and compliance program, to ensure a complete tracking pathway from source to destination; -Assist industry to identify business opportunities where demand for waste treatment facilities is not being met; - Ensure relevant government and council agencies have access to waste data as required to inform strategic planning; and undertake an analysis of NT waste streams based on available data. **(4) Improve the regulatory framework** - Assess the waste-related components of current legislation administered by the NT EPA to determine their relevance and effectiveness as tools to improve waste management practices in the Territory. **(5) Reporting and public reviews** - Provide an update on progress in implementing each of this Strategy's management actions in its annual report - Review the Strategy, and as appropriate, renew its content, within five years	
Qld	**(1) Reducing the impact of waste on the environment** - Recycle better, avoid waste, reduce waste, choose to reuse, find better ways to dispose of waste, and not litter or dump - Audit landfills to test the quality of Queensland landfill infrastructure and identify non-compliance - Provide assistance for alternative arrangements where landfill facilities are to be progressively closed - Develop an education strategy to integrate waste and recycling behaviours into the education system. - Avoid and minimise the long distance transport of waste where practicable - Continue to educate industry members about the appropriate management actions to take for particular wastes **(2) Transitioning to a circular economy for waste** -Assess the opportunities of the circular economy model for Queensland. -Collect and amalgamate data to understand material flows across the economy and address knowledge gaps. -Explore options to expand reporting of waste to build baseline datasets and inform decision making. -Develop material-specific action plans for problem wastes. -Deliver community campaigns and education programs that support waste avoidance, re-purposing, reuse and recycling. -Explore scope for industry leadership in developing a voluntary specification code for minimum recycled content in packaging and products. -Support and develop extended producer responsibility and product stewardship initiatives. -Develop an energy from waste policy. -Work with other governments to develop quality standards for product packaging -Inform and educate business clients about options to reduce waste and increase recycling. -Offer service options that provide clients with choice about the level of recycling they want to adopt.	**- Waste Management and Resource Recovery Strategy 2019**

	Objectives and Strategies	Document
	(3) Building economic opportunity -Develop and implement the Advance Queensland Resource Recovery Industries 10 Year Roadmap and Action Plan. -Continuously improve and reform waste-related legislative frameworks. -Develop proposals for landfill disposal bans. -Work with the Commonwealth Government to standardise waste policy, legislation, regulation and messaging. -Review the land-use planning system to ensure pathways for industry development are supported. -Promote the development of waste precincts. -Develop a coherent state-wide waste infrastructure planning framework and regional infrastructure plans. -Support the commercialisation of successful recycling and remanufacturing technologies. -Create market development plans for key waste types and waste sectors. -Investigate alternative end-uses and markets for recycled materials. -Consider how procurement can stimulate demand for recycled material manufactured in Queensland. -Develop programs to stimulate the growth of markets for recycled materials. -Strengthen collaborative partnerships with key organisations in the sector.	
SA	**(1) Developing a resource efficient economy** -Promote green innovation (such as the development and uptake of new, cleaner technology). -Recognise the lifecycle of products and account for the resources used. -Develop and adopt innovative products and services that help reduce our ecological footprint to create comparative economic advantage. -Increase and maintain capacity of recycling systems and reprocessing infrastructure. -Identify new opportunities through developing and promoting innovative policy, reforms and solutions. -Avoid and reduce wasteful use of resources in production processes and products, such as leaner production, design for the environment and EPR. -Encourage the greater use of products made from recycled materials. **(2) Building a stable and efficient market for investors** -Increase and maintain capacity of recycling systems and reprocessing infrastructure. -Implement policy settings and regulation that drives progress, and encourages long-term investment decisions. -Promote safe and equitable resource recovery and build upon the strong resource recovery reputation of SA. -Monitor and evaluate the effectiveness of appropriate price signals and legislative instruments. -Increase procurement by all levels of government of re-manufactured products. **(3) Forming a culture enabling the SA community** -Develop and adopt innovative products and services that help reduce our ecological footprint to create comparative economic advantage. -Learn the importance of, and foster, attitudes and lifestyle choices that encourage us to live within nature's limits. -Embed this new learning within our education systems. -Support consumers to make informed purchasing choices. -Implement regulation and other reforms that drive progress and long-term investment decisions.	**-South Australia's Waste Strategy 2015-2020**

	Objectives and Strategies	Document
	-Identify new opportunities through developing and promoting innovative solutions. -Generate new business opportunities through improving cross-industry resource efficiency (industrial symbiosis). -Support appropriate R&D.	
Tas	**-No current waste strategy**	**-No current waste strategy**
Vic	**-No current waste strategy**	**-No current waste strategy**
WA	**(1) Avoid (WA generates less waste): -target: 2025: 10 per cent reduction in waste generation per capita** -Coordinate consistent state-wide engagement and education on waste avoidance behaviours with an emphasis on focus materials. -Investigate, develop and publish, in collaboration with stakeholders, locally relevant actions for reducing waste generation with an emphasis on focus materials. -Lead collaboration between state government agencies on actions that reduce the waste generation with an emphasis on focus materials. -Collaborate with decision-makers and opinion leaders to explore opportunities arising from circular economy approaches and communicate them publicly. -Develop mechanisms and platforms that enable the community to adopt avoidance behaviours, and explore reuse and low-waste alternatives -Provide support to community, government and industry initiatives that lead to waste avoidance and contribute to waste strategy targets with an emphasis on focus materials Introduce regulations to prevent unnecessary waste generation **(2) Recover (WA recovers more value and resources from waste) -target: 2025 increase material recovery to 70 per cent** -Investigate options to recover and promote related local markets through State Government procurement actions with an emphasis on focus materials. -Develop better practice guidance and standards for waste derived products to build confidence in recycled products and ensure protection of the environment. -Develop education and engagement resources to communicate the benefits of resource recovery and the use of recycled products, and to minimise contamination in collection systems. -Develop and publish better practice guidance to support increases in recovery with an emphasis on focus materials -Identify and implement options for collaboration between industry and the State Government to support market development and recovery -Investigate and improve reporting on material that is reused to better monitor the state's move toward becoming a circular economy. -Establish mechanisms, including funding approaches to support investments in local infrastructure for recovery with an emphasis on focus materials. -Provide funding to promote the use of priority recycled products and support the establishment of local markets with an emphasis on focus materials. -Support community, government and industry initiatives that promote resource recovery through grant programs. -Develop a legislative framework to encourage the use of waste derived materials, including product specifications, to build confidence in	**-Western Australia's Waste Strategy: Waste Strategy 2030**

	Objectives and Strategies	Document
	recycled products, increase their demand and develop relevant markets while protecting the environment -Implement measures and policies that support sustainable government procurement practices and outcomes that encourage greater use of recycled products and support local market development. **(3) Protect (WA protects the environment by managing waste responsibly)- target: 2030- no more than 15 per cent of waste produced in Perth and Peel** -Detect, investigate and prosecute illegal dumping -Review and update the regulatory framework for waste to ensure it is appropriate and reduces the environmental impacts and risks from waste management -Revise waste classifications and definitions to reflect current knowledge to ensure waste materials are managed according to their risk and are treated and/or disposed of appropriately -Develop and revise legislative frameworks to encourage the use of waste derived materials and build confidence in recycled products	

Furthermore, it is worth understanding how C&D waste is prioritised in different jurisdictions. Some jurisdictions have acknowledged how precious C&D waste materials are and have considered them as priority materials due to their financial advantage. In WA, C&D waste is among the 'focus materials'; in Tas it is in the 'priority material' category; and in SA it is one of the three subcategories of 'waste derived fill'.

1.3.7 Strategies supporting the revision of the existing C&D waste regulatory framework

Development of jurisdictional waste strategy documents and relevant regulations go hand in hand. Ideally, objectives outlined in waste strategies inspire amendments to regulatory frameworks; some of these objectives recommend reforms according to the practical outcome of waste management regulations. However, evaluation of alignments between legislation and these strategies sometimes demonstrates fundamental differences in the study jurisdictions. These differences imply that, while the issues are identified, and solutions are outlined in waste strategy documents, there is little legislative support to achieve the solutions. Therefore, it is worth examining how these strategy documents propose reforms to the existing regulatory framework in each jurisdiction. Notably, most of these strategies were written a few years ago and, therefore, care must be taken to exclude the strategies, actions, and objectives that are already achieved and reflected in the jurisdictional regulatory frameworks. Table 6 summarises the strategies that support modifications in existing waste regulations.

Table 6. Strategies supporting improvements in the regulatory framework

State	Objectives and Strategies
ACT	**ACT Waste Management Strategy 2011-2025** **Challenges and opportunities:** -The safety and health risks arising from landfill gas emissions are managed across all landfills through appropriate regulation and licence requirements. **Strategies and actions:** -Disincentives to landfill including appropriate pricing and regulation
NSW	-**NSW Waste Avoidance and Resource Recovery Strategy 2014–21** **-NSW Illegal Dumping Strategy 2017–21** **Challenges and opportunities:** -Regulation and enforcement help to change behaviour, protect the environment and reduce health risks -Local councils usually regulate small-scale dumping, while the EPA regulates larger incidences **Strategies and actions:** -EPA provides clear and consistent regulations for waste disposal, recovery and recycling -Building the regulatory capacity of councils and public land managers
NT	**-Waste Management Strategy for The Northern Territory 2015–2022** **Challenges and opportunities**: -Existing regulation is not sufficient to provide incentives for innovative waste solutions or to deter inappropriate waste practices Further review and implementation of the available environmental legislation will improve the NT EPA's capacity to measure and reduce the impacts of waste handling activities and to steer practice towards achieving the preferred hierarchy of waste management options **Strategies and actions:** -EPA will assess the waste-related components of other legislation administered by the NT EPA to determine their relevance and effectiveness as tools to improve waste management practices in the Territory -EPA is conducting a review of the WMPC Act 1998 and the Litter Act 1972. This will provide the public, industry, government and local government with a discussion paper examining the deficiencies and strengths of the Acts in providing soundly managed waste issues
Qld	**-Waste Management and Resource Recovery Strategy 2019** **Strategies and actions:** -Continuously improve and reform waste-related legislative frameworks. -Develop proposals for landfill disposal bans.

State	Objectives and Strategies
	-Work with the Commonwealth Government to standardise waste policy, legislation, regulation and messaging -The Qld's Government should consider how best to ensure appropriately classified wastes from one process can be used as a resource and feedstock for downstream value-adding processing
SA	**South Australia's Waste Strategy 2015-2020** **Strategies and actions:** -Identify new opportunities through developing and promoting innovative policy, reforms and solutions. -Implement policy settings and regulation that drives progress, and encourages long-term investment decisions -Monitor and evaluate the effectiveness of appropriate price signals and legislative instruments
Tas	**Draft Waste Action Plan 2019** **Challenges and opportunities:** -The growing amount and diversity of waste has created challenges that can only be solved by considering the entire 'lifecycle" of a product -The absence of a landfill levy, along with the transport challenges from being an island state **Strategies and actions:** -Work with local government to introduce a statewide waste levy by 2021 to fund waste management and resource recovery activities. -Work with the Australian Government to ensure that reviews of relevant legislation, such as the Product Stewardship Act 2011, result in effective programs that enhance resource recovery. -Investigate and discuss models for waste management governance with local government - Develop a Tasmanian Waste and Resource Recovery Infrastructure Plan by 2021 - Help to support the establishment of standardised data management systems to capture waste data, to monitor progress against targets and facilitate businesses investment in resource recovery
Vic	**No current waste strategy**
WA	***Waste Avoidance and Resource Recovery Strategy 2030: Western Australia's Waste Strategy*** **Challenges and opportunities** -The state government can provide waste management leadership and influence waste behaviours through legislation, regulation, policies and programs that align with a national approach -Regulation and policy – to provide a level playing field and deliver efficient and effective waste management outcomes **Strategies and actions:** -Contribute to NWP and programs aimed at waste avoidance, resource recovery and environmental protection. -Review the scope and application of the waste levy to ensure it meets the objectives of its waste strategy. -Review and revise regulations and policies to achieve a level playing field for industry, which ensures entities that are compliant and apply best practice are not disadvantaged. -Introduce regulations to prevent unnecessary waste generation. -Review and update the regulatory framework for waste to ensure it is appropriate and reduces the environmental impacts and risks from waste management. -Revise waste classifications and definitions to reflect current knowledge to ensure waste materials are managed according to their risk and are treated and/or disposed of appropriately.

Among the jurisdictions, Vic is the only one that has not published a waste strategy as of the time of writing. Tasmania's (Tas) waste strategy is outdated but not excluded from this comparison. It seems that the most frequently indicated strategy across jurisdictions is the review of waste regulations for their effectiveness, including checking their consistency, relevance and strength. The second-ranked demand is to revise existing levy arrangements to ensure they are a disincentive to landfilling. The ACT, SA, Tas and WA are the jurisdictions which proposed this revision. Other revisions include providing legislative power to other agencies (NSW), community engagement (NT), development of a new Act and regulations (Qld), building capacity in regulations to inform long-term investment decisions and to provide a level playing field for industry (SA and WA), contribution to the development of a NWP (WA) and revising waste classifications and definitions to reflect current knowledge about waste management activities (WA).

1.3.8 Waste recycling

Waste recycling is the third-most favourable option in the hierarchy of waste management. Waste recycling has numerous benefits, including a reduction in waste being sent to landfill, positive environmental results, creation of jobs, and potentially saving energy, waste and other resources that would have otherwise been used to extract or produce new products. However, the benefits of recycling activities need to be tangible to motivate those who are involved in the process of generating waste to provide its re-use or disposal. The factors that are most influential in determining the extent of effective recycling are found to be the value of materials to be recycled,[14] technical capabilities,[15] level of stakeholder commitment, and government policies and regulations.[16] Several pieces of research have indicated that government plays a considerable role in paving the way for waste recycling activities through setting sound policies and regulations that provide opportunities for re-use of recycled materials. For instance, since 2002, a regulation (Aggregates Levy[17]) has been imposed in the UK to make recycled C&D waste more competitive relative to the virgin aggregates. The levy is a tax (£2 per tonne) on the commercial exploitation of rock, sand and gravel, and it aims to adjust the price of virgin aggregates to better reflect their intrinsic environmental costs. The tax is further expanded to target imported materials. A similar tax has also been implemented in some EU countries including France, Denmark and Sweden.[18]

In Australia, re-use of recycled materials is strongly encouraged under Ecologically Sustainable Development and sustainable procurement (SP) programs. At the national level, the *2018 NWP* sets a target to reduce waste generation through prevention, reduction, recycling and re-use. This policy has also emphasised the application of the principles of a circular economy to support better and repeated use of our resources. Two strategies to promote SP in Australia are at the forefront of the policy: Strategy 8 (Sustainable Procurement by Governments) and Strategy 9 (Sustainable Procurement by Business and Individuals). These two strategies urge the public and private sectors to promote demand for recycled materials and products containing recycled content.

The National Waste Policy, Action Plan 2019[19], listed seven national targets for improvement in the waste management system, among which a significant increase in the use of recycled content by governments and industry is suggested. The Action Plan indicated that this target would stimulate demand for recycled materials relative to virgin materials, encourage innovation and investment in recycling to meet demand from new markets, support domestic jobs and industries by retaining the value of recycled materials, and encourage economy-wide behaviour change. However, despite these suggestions and strategies, there is no reported tangible actions towards a circular economy in the waste management and resource recovery sector.

1.3.9 Current and target rate of C&D waste recycling

Statistics indicate that the recycling rate has increased at a slow pace in Australia, with an annual growth rate of three per cent during the last decade. Table 7 represents the changes in recycling of

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[14] Lu, W., Yuan, H., Li, J., Hao, J.J., Mi, X. and Ding, Z., 2011. An empirical investigation of construction and demolition waste generation rates in Shenzhen city, South China. Waste management, 31(4), pp. 680-687.

[15] Tran, V. 2017. Evaluating the Economics of Construction and Demolition Minimisation and Zero Waste in the New Zealand Construction Industry. PhD thesis. Faculty of Design and Creative Technologies. Auckland University of Technology.

[16] Au, L.S., Ahn, S. and Kim, T.W., 2018. System Dynamic analysis of impacts of government charges on disposal of construction and demolition waste: A Hong Kong case study. Sustainability, 10(4), p. 1077.

[17] Aggregate Levy Manual.2014. https://www.gov.uk/hmrc-internal-manuals/aggregates-levy

[18] Hyder Consulting. 2012. Construction and demolition waste status report. p. 43.

[19]National Waste Policy, Action Plan 2019. https://bit.ly/3xbOVAz

C&D waste in Australia. According to submissions to the Australian Senate Environment and Communications References Committee and other previous reports, the four main factors that influence C&D recycling activities are: 1) price signal (that is, landfill levy and illegal dumping penalty); 2) enforcement; 3) availability of required infrastructure in the proximity of the waste generation location; and 4) the development of a domestic market for recycled materials.

Table 7. C&D waste recycling rates in Australia

C&D waste	2007	2009	2010	2011	2014	2015	2016	2017	Average annual growth rate (%)
Recycled (Mt)	10.1	11.1	11.3	12.1	11.5	12.4	13.5	13.6	3
Recycled– per capita (t)	0.49	0.52	0.51	0.54	0.49	0.53	0.56	0.56	1.3
Recovery rate (%)	60	60	62	66	65	65	68	67	1.1

Source: National Waste Report. 2018. This report acquired data from different EPAs across Australia

As a result of support from different entities in Australia, a race has begun between waste management authorities in different jurisdictions to increase the recycling rate. The first step in this race was to set a target rate for recycling. However, among the jurisdictions, NT, Tas and Vic have not specified a target for C&D waste recycling. The remaining jurisdictions have set a target, although in some cases (for example, Qld and WA) it seems to be too ambitious. Currently, only SA has achieved the target rate (90 per cent) that is set for 2020; this state has the highest C&D waste recycling rate (91.1 per cent), followed by Vic (82 per cent). The lowest recycling rate for C&D was registered in NT and Tas. Table 1.7 shows the current and target rate for recycling C&D waste. It is worth keeping in mind that these varied rates are the product of various factors, including an increase in the waste generation rate (NSW), interstate waste transfer (Qld), lack of obligatory disposal levy (Tas) and the lack of an effective waste data management system (NT).

Table 8. Future target proposed for the recovery of C&D waste in different jurisdictions

	Date	Target Rate (%)	Current rate (%)	Document
ACT	2020 2025	85% 90%	na	ACT Waste Management Strategy: Towards a sustainable Canberra 2011–2025
NSW	2021-2022	75-80%	69% (2013)	NSW Waste Avoidance and Resource Recovery Strategy 2014–21
NT	×	×	1%(2011)	Waste Management Strategy for the Northern Territory 2015–2022
Qld	2050	75%	45-51%	Queensland Waste Avoidance and Resource Productivity Strategy 2014–2024 Recycling and Waste in Queensland 2017 Queensland's Waste Reduction and Recycling Strategy 2010–2020
SA	2020	90%	91.1%	South Australia's Recycling Activity Survey 2016–17 Financial Year Report
Tas	×	×	1%	The Tasmanian Waste and Resource Management Strategy 2009 Rethink Waste Tasmania Fact Sheet
Vic	×	×	82%	State-wide Waste and Resource Recovery nfrastructure Plan A 30 year roadmap for Victoria (SWRRIP) 2018
WA	2020	75%	64%	Western Australian Waste Strategy: Creating the Right Environment (2012)
National	×	×	67%	

1.3.10 Legislative support for use of recycled C&D waste materials

At the jurisdictional level, different local governments have initiated projects to re-use and recycle C&D waste materials. For instance, the Australian Capital Territory Government (ACT Government) promotes re-use of C&D waste onsite through the ACT Smart Business Recycling program, which allows business owners to efficiently recycle their waste. In WA, the Waste Authority provides members of the Master Builders Association Western Australia with information and tools to reduce waste and increase re-use and recycling. The Australian Building Codes Board enforces the Building Code to implement sustainable building practices.

As mentioned above, the *2018 NWP* encourages the use of recycled C&D waste through SP. The other strong motivation for using recycled materials is the adoption of SP principles by government agencies, business and individuals (Strategies 8 and 9 – *2018 NWP*). The definition of SP accepted by the United Nations (UN), the UK Government and the Australasian Procurement and Construction Council (APCC) is:

> *A process whereby organisations meet their needs for goods, services, works and utilities in a way that achieves value for money on a whole life basis in terms of generating benefits not only to the organisation, but also to society and the economy, whilst minimising damage to the environment*[20].

The APCC *Australian and New Zealand Government Framework for Sustainable Procurement* is implemented by the federal government to pursue three aims when procuring goods, services, works and utilities. These aims involve reduction of environmental impacts, social impacts and economic impacts through the procurement process. This framework also shares some principles with the circular economy in considering alternatives to the 'take, make and dispose' approach. According to this framework, government has a decisive role in providing a market driver for increased use of recycled materials in the goods and works that it procures. Therefore, the federal government and some local governments developed SP guidelines to coordinate their decisions and actions towards SP and the purchasing of recycled materials. In 2012, SA's local government was the first authority to release a *Sustainable Procurement Guide*.[21] One year later, in 2013, the federal government also released the first Australian guideline on SP.[1] This work was further complemented by state-specific guidelines to tailor SP requirements in the ACT[22] (2015), NSW[23] (2017) and WA[24] (2017). In the context of waste management, the national guideline uses a procurement hierarchy to benchmark it against the waste hierarchy (Figure 5).

[20] Commonwealth of Australia. 2013. *Sustainable Procurement Guide*, p. 8.
[21] SA Government. 2012. Sustainable Procurement Guideline.
[22] Australian Capital Territory Government (ACT Government). Sustainable Procurement Policy 2015.
[23] NSW Government. 2017. Sustainable Procurement Guide for Local Government in NSW.
[24] WA Government. 2017 WALGA Guide to Sustainable Procurement.

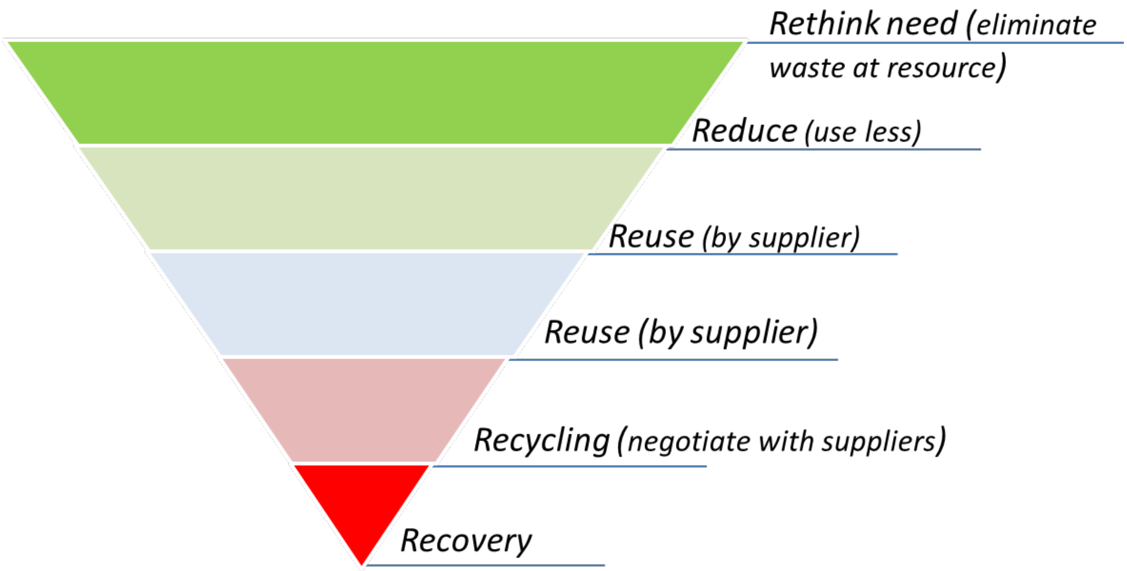

Figure 5. Waste procurement hierarchy
Source: Adapted from the Commonwealth of Australia. 2013. Sustainable Procurement Guide

The levels in the procurement hierarchy represent opportunities to minimise waste generation and are outlined as follows:

A. avoid or reduce consumption
B. identify whether there is a more sustainable alternative readily available
C. rethink and revise specifications in order to improve sustainability outcomes.

The jurisdictional SP guidelines, however, do not provide specific information about C&D waste materials. In the ACT, the SP policy has suggested directorates to incorporate the practice of sustainability into the procurement of goods, services and construction. In WA, the Western Australian Local Government Association (WALGA) procurement toolkit has been prepared for different categories, including the 'Provision of Construction Works', to identify the materials impact and detail how sustainability objectives are integrated into the procurement process. The next version of the SP guidelines can improve by following the procurement hierarchy, with the aim of explaining how the recycled C&D materials should be used in projects running in each state and territory. This may include a range of examples, from the use of raw material in one project to the re-use of recycled waste in another project.

In this section, the waste strategy documents of different jurisdictions were reviewed to provide an understanding of how states and territories have designed their plans for recycled waste materials. The following are the results of this review, as presented for each jurisdiction.

In the ACT,[25] Strategy 1.7 (Encourage Onsite Re-use of C&D Waste) proposes that there is an opportunity for temporary onsite facilities in new suburban developments in the ACT where several homes are being built concurrently. These facilities will encourage local recycling of waste into products that can be used, through the development and exchange of surplus C&D waste materials within the development site. This strategy also aligns with Strategy 2.6 (Government Procurement), which encourages government purchasing and use of recycled products where possible. The

[25] ACT Waste Management Strategy 2011-2025 – ACT.

government, as part of this strategy, should also review the specifications used for government tendering to identify where recyclable alternatives can replace non-recyclable materials.

In NSW,[26] the Waste less, Recycle More initiative (2017–2021) financially supports the establishment of a network between C&D companies to adopt industrial ecology. This network promotes buying products that are recycled, recyclable, repairable, refillable, re-usable or biodegradable. The initiative also provides a fund for the establishment of new markets for recycled waste materials and innovation in recycling technology. The waste strategy outlines the duties that different stakeholders can fulfil, including specifying and purchasing recycled materials (local government), separating recycling states at source to ensure that waste and recycling is handled by legitimate operators (industry and businesses) and improving the efficiency of recycling activities to expand their recycling facilities to cover more waste materials (waste recycle industry).

The main recommendations made in the NT's[27] waste strategy include to: '*facilitate opportunities to explore technologies for the beneficial re-use of wastes*"; '*collaborate with the Waste and Recycling Industry of the NT … to identify emerging trends and issues requiring multi-faceted solutions*"; '*facilitate opportunities to connect waste recovery and re-use markets with key waste producers*"; '*work with industry and government agencies to demonstrate the economic incentives available through improved waste management and resource recovery*"; and '*support proposals by regional councils to consolidate recycling infrastructure at central locations*".

In Qld,[28] the waste strategy emphasises investment in regional recycling infrastructure and developing markets for recycled products. It encourages local government to engage with the C&D sector to support research and improved best management practices, and to identify opportunities for recycling and incentivise the purchase of recycled-content products. A significant strategy for encouragement of further recycling in Qld is to revise policies about price signal through a landfill levy. Development of new markets for recycled material is also proposed as an effective enabler towards more waste recycling. The strategy states that businesses should modify consumer behaviour by marketing recyclable and recycled-content products.

In Tas,[29] stimulating the right market conditions for recycled waste materials and implementing an obligatory and consistent landfill levy across the state are the two main strategies to promote an increase in recycling activities. In WA[30], six strategies are documented in WA's waste strategy that can improve recycling activities. Its strategies include 'implementing sustainable procurement practices', 'development of standards for waste derived products', 'provide funding to promote use of recycled material and development of new markets', 'develop legislative support to increase use of recycled materials' and 'implement supportive measures and policies for local market development and government SP'.

1.3.11 Opportunities for the use of recycled C&D waste

The majority of C&D waste is recyclable if properly separated at source with minimum contamination. The scientific literature has indicated the potential use of recycled C&D waste for many purposes such as concrete,[31] asphalt mixture[32] and insulation[33]. Table 9 shows other potential uses for different C&D waste recycled materials.

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[26] NSW Waste Avoidance and Resource Recovery Strategy 2014–21 – NSW.
[27] Waste Management Strategy for The Northern Territory 2015–2022 – NT.
[28] Queensland's Waste Reduction and Recycling Strategy 2010–2020 – Qld.
[29] LGAT Waste and Resource Management Strategy 2017- A submission to LGAT – Tas.
[30] Western Australia's Waste Strategy: Waste Strategy 2030 – WA.
[31] Behera, M., Bhattacharyya, S.K., Minocha, A.K., Deoliya, R. and Maiti, S., 2014. Recycled aggregate from C&D waste & its use in concrete–A breakthrough towards sustainability in construction sector: A review. *Construction and Building Materials*, 68, pp. 501-516.

Table 9. Recycled and non-recycled C&D waste materials potential uses

Waste material	Reuse and Recycling
Brick	Clean and/or render over for reuse; crushed fill, levelling materials, drainage layers
Concrete	Crushed fill, levelling materials, drainage layers, road pavement subbase, and irrigation and landscape applications.
Ferrous and non-ferrous metals	Recycled back into metal products
Glass	Road pavement, landscape application, reusing as a building facade
Hardwood **Other timber (not CCA treated pine)**	Reuse as floors, roof framing, fencing or furniture Reuse as formwork, bridging, propping, blocking, chip (mulch) for use in landscaping
Crushed rock and stone	Road pavement subbase, drainage, irrigation and landscaping applications
Cardboard	Cardboard timber
Plasterboard	Crush and use in compost or soil conditioner or as a gypsum replacement
Roof tiles	Reuse off-site; crushed for the landscape of drainage use
Reclaimed asphalt pavement	New asphalt mixture
Soil	Soil conditioners or mixed with organic material to improve soil structure

Source: Hyder Consulting (2012)[34], Richardson (2013)[35] and Vicroads (2019)[36]

1.3.11.1 Application of C&D waste in road pavement projects:

In Australia, one widespread use of recycled C&D waste materials is in road pavement projects. This application is supported both at the national and jurisdictional level. In 2009, Austroads, which is the Association of Australian and New Zealand Road Transport and Traffic Authorities, published the first national road pavement guidance (Guide to Pavement Technology Part 4E: Recycled Materials). This guideline provides the specification of recycled materials accepted for road pavement. In addition to this guideline, different jurisdictions also prepared specific guidelines. In NSW ‘the Roads & Transport Directorate’[37]; in Qld ‘the Department of Transport and Main Roads’[38]; in SA ‘Department of Planning, Transport and Infrastructure’[39]; in Vic ‘Vicroads’[36,40]; and in WA ‘Main Roads’[41] have established the guidelines to specify the requirements for using recycled C&D waste for road pavement projects and other construction activities. In NSW, an Environment Fact Sheet EFS-709[42] was developed by the Department of Transport and Main Roads to guide potential off-site reuse of excavated, recovered and C&D waste materials. Furthermore, in 2010, the Office of Environment and Heritage (then known as the Department of Environment, Climate Change and Water NSW) contracted the Institute of Public Works Engineering Australia (NSW Division) to improve the specification for the use of recycled materials in a range of public works (for example, pavements, earthworks and drainage)[43]. In Vic, a partnership program[44] between Sustainability Victoria, the

[32] Akbulut, H. and Gürer, C., 2007. Use of aggregates produced from marble quarry waste in asphalt pavements. Building and Environment, 42(5), pp. 1921-1930.
[33] Leiva, C., Solís-Guzmán, J., Marrero, M. and Arenas, C.G., 2013. Recycled blocks with improved sound and fire insulation containing construction and demolition waste. *Waste Management*, 33(3), pp. 663-671.
[34] Hyder Consulting Pty Ltd. 2012. Construction and demolition waste status report. management of construction and demolition waste in Australia
[35] Richardson, A. ed., 2013. Reuse of materials and by-products in construction: waste minimization and recycling. Springer Science & Business Media.
[36] VicRoads. 2019. Use of recycled materials in Roads Pavements. Technical Note: TN 1077.
[37] Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage 2010.
[38] Transport and Main Roads Specifications MRS35 Recycled Material Blends for Pavements- 2018.
[39] Specification: Part 215 Supply of Pavement Materials- 2017.
[40] VicRoads Standard Specifications for Roadworks and Bridgeworks.
[41] Main Roads Western Australia Specification 501 – Pavements -2012.
[42] Re-use of waste off-site, Transport Roads and Maritime Services.
[43] Environment, Climate Change & Water. Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage 2010.
[44] About the Recycled Roads to Zero Waste Project. 2009. https://bit.ly/3dyFxQ3

Municipal Association of Victoria, the Australian Road Research Board and VicRoads was initiated in 2009. This program aimed to use recycled products in road construction projects in partnership with local government. This program seeks the following objectives:

(a) reduction in stockpiles of crushed concrete, brick and glass
(b) changing the procurement practices of local government concerning road construction, and delivering major CO_2 emission reductions
(c) achieving more sustainable uses of current quarry reserves and reducing the number of new quarries opened

Sustainability Victoria researched[45] on the application of C&D recycled waste materials in a road construction project and found that it can reduce the total quantity of material required and lead to a reduction in reflective and fatigue cracking, an increase in longevity of the roads and a decrease in traffic noise. There is no comprehensive report on the uptake rate of recycled materials in road and pavement building projects in Australia. Below are just examples of the application of C&D recycled waste materials in road construction projects in Australia:

Table 10. Example projects of recycled C&D waste materials in road pavement applications

	Project(s)
NSW	❖ Waverley Council substituted 15 t of glass cullet into the road projects, 7.5 t into the asphalt and 7.5 t into the concrete. ❖ Fairfield City Council engaged a contractor to replace 175m² of the failed pavement material with 150 m² of crushed concrete in 2002 in Delgarno Road, Bonnyrigg Heights. Inspection after seven years shows that the pavement is still in excellent condition, with no defects being observed
SA	❖ On the Northern Expressway project, 12,000 t of RAP plus 5,000 t of waste asphalt were reused in the asphalt laid on site. ❖ Projects that have used recycled C&D waste in structural pavement layers include the Port River Expressway where approximately 90 per cent of 620,000 t of fill used in Stage 1 was recycled material.
Tas	❖ Rosny Park Tennis Club car park was constructed using– base/ pipe embedment material, kerbing and asphalt. It also used 53 tonnes of crushed glass.
WA	❖The City of Canning has been using recycled road base for the past 10 years and currently buys around 9,300 t of the material each year and builds 100 per cent of its roads out of recycled product.

It seems that complicated specifications set by policy makers in different jurisdictions is a major barrier to the use of recycled materials in road projects. Transport logistics and associated distances may prove to be the main barrier to recovering of the recycled materials. It would be greatly beneficial to have National specifications for recycled content materials in road building, consistent in approach and including alternative recyclables[46].

1.3.12 Waste disposal

Waste disposal at landfill sites is the least favourable level on the hierarchy of waste management (Figure 4). According to the *2018 NWP*'s Principle 4: Better Manage Material Flows to Benefit Human Health, the Environment and the Economy, the new way of thinking about waste aims to keep materials cycling in productive use rather than being lost to landfill or escaping to the environment and oceans through irresponsible disposal. However, waste disposal has historically been a key element of waste management in Australia. The primary task of landfill is to accept waste that cannot be avoided, reduced, re-used, recycled or recovered. A global trend has, however, commenced that aims to reduce the number of landfills, due to social, economic and environmental

[45]Sustainability Victoria. 2016. The business case for using recycled materials in roads. https://bit.ly/3v4ugN1
[46]MRA Consulting Group. 2019. Public Procurement of Road Building Materials – Research into Recycled Content. https://bit.ly/3gofahg

issues.[47] For instance, the EC has initiated a Circular Economy Package, which includes a set of measures to shift to a circular economy, including promoting economic instruments to discourage disposal[48].

In Australia, the main issue with landfill, according to submissions to the Senate Inquiry into the Waste and Recycling Industry In Australia, is related to the inability of this method to recover resources from the waste efficiently[49]. At the time of writing, none of the jurisdictions has provided a plan detailing a waste management system wherein the need for landfill is removed. Indeed, due to financial (the need for receiving levy fees) and technological (systematic lack of modern technologies to recover waste) reasons, this target seems to be ambitious. There is limited access to valid and current national data about the number of landfill sites (licensed and un-licensed) in different regions of Australia. According to the latest statistics, there are 1,168 landfill sites operating across eight jurisdictions. Table 11 provides estimated statistics on waste management facilities by jurisdictions in Australia, in 2013.

Table 11. Number of waste management facilities in different jurisdictions (2013)

	Landfill site	Resource recovery facility
ACT	1	6
NSW	369	121
NT	118	10
Qld	265	88
SA	117	247*
Tas	19	14
Vic	92	233
WA	187	86
Total	1,168	806

* Includes 153 container deposit recycling depots in SA
Source: Compiled by Rawtec/WCS based on jurisdiction's input-August 2013

According to a more updated but speculative estimate[50] drawing on national databases (for example, the National Pollution Inventory or the National Greenhouse and Energy Reporting Scheme), Qld has the greatest number of sites, followed by NSW and WA. In terms of size of these facilities, Vic and Tas have a high percentage of large-to-medium sites, while NSW has the largest sites, representing its relatively large population. Queensland, WA and SA hold comparatively high numbers of small sites, matching their widely dispersed populations. Landfill sites differ in size and range from small, trench-based facilities with a capacity of 1,000 t of waste per year, to large, engineered facilities receiving more than 100 kt per year. Most of the waste produced in Australia goes to a small number of large sites. However, the majority of Australia's landfills are small, accepting annually less than 20,000 t of waste[51]. Figure 6 shows the distribution of waste management facilities across Australia.

[47] Paul Klymenko. 2018. Landfill is not a long-term solution for waste management in Australia. Planet Ark.
[48] EU Action Plan for the Circular Economy. 2018. Circular Economy Package: https://bit.ly/3sx9DHB
[49] The Senate Environment and Communications References Committee. 2018. Never waste a crisis: the waste and recycling industry in Australia.
[50] McCabe B., and W. Clarke, 2017. Explainer: How much landfill does Australia have? *The Conversation*: https://bit.ly/3n1T0mi
[51] Ibid.

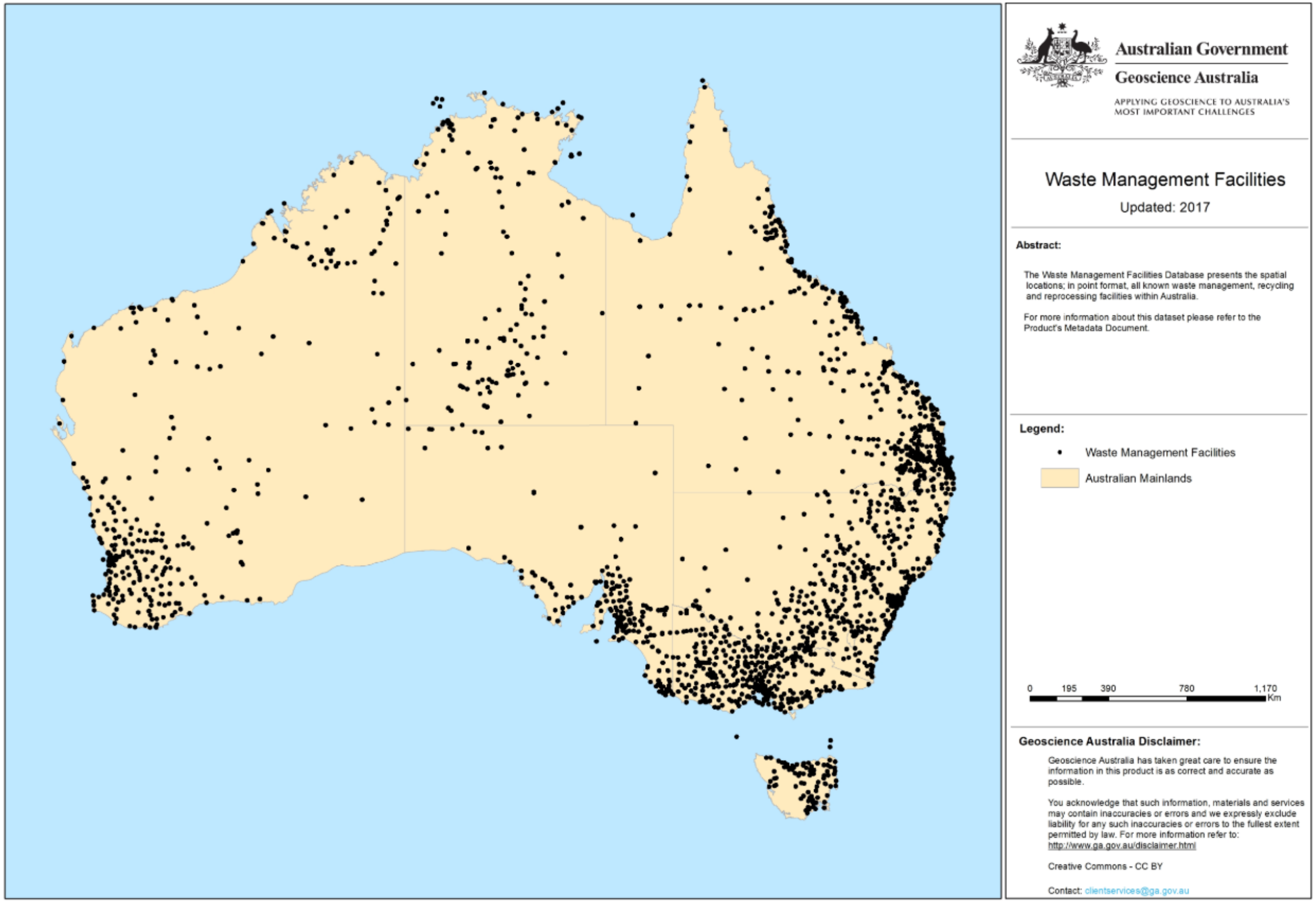

Figure 6. National map of waste management facilities (landfill sites, transfer stations, composting facility, solid waste store facility and resource recovery facility) distribution in Australia
Source: Geoscience Australia (2017)

1.3.12.1 Who is responsible for the management and regulation of landfill sites?

In Australia, local councils, together with private companies, are responsible for landfilling activities in their areas; however, state governments and EPAs regulate these sites within each jurisdiction. In Tas and NT, companies do not operate landfills due to these jurisdictions' small populations and lack of economic advantage. There are fundamental discrepancies in the approach taken by the jurisdictions: some jurisdictions adopt a forethoughtful approach and set complicated regulations for landfills to ensure restricted and environmentally friendly waste management arrangements are implemented, whereas other jurisdictions take a more relaxed approach. Queensland and NT are the two jurisdictions with the least amount of regulation and restrictions over their landfills. Victoria, on the other hand, has heavily regulated landfills compared with other jurisdictions in Australia[52].

1.3.12.2 Disposal levy fees

Authorities in Australia have encouraged the construction industry to further recycle C&D waste by imposing landfill disposal levies. The aim of these levies is to set a price on waste disposal that is higher than the cost of recycling, such that recycling becomes a more attractive endpoint. Except for NT, all of Australia's other jurisdictions have introduced landfill levies; however, levies are imposed differently (Senate Environment and Communications References Committee, 2018). The differences originate in the distinction between metropolitan areas versus regional areas, levy rate, obligatory versus voluntary levies, and having or not having levy zones. As displayed in Figure 7, some jurisdictions (ACT, Qld, Tas and WA) differentiate the levy rate between metropolitan and regional areas, offering a lower rate in regional areas. The voluntary levy in Tas is between $0 and $7.5 per tonne. In the ACT, there is no C&D waste-specific levy and the same fee that applies to C&I is followed, which ranges from $146.2 to $199.2 (waste with less than 50 per cent of recyclable materials). New South Wales, Vic and WA have levy zones that are limited to specific areas of the state, while SA considers the entire state as the levy zone[53].

Another interesting pattern that arose previously is the link between the proportion of levy fee and the quantity of waste disposed of in Qld. Furthermore, in a report that investigated the transport of waste to Qld, it was found that lower levies in this state have facilitated interstate transport of waste to Qld's landfills (Queensland Government, 2017). On average, 60,000 t of predominantly C&D waste is being transported from metropolitan Sydney to South East Qld each month[49]. In the wake of issues faced in Qld, Qld's EPA plans to introduce new levy rates in July 2020.

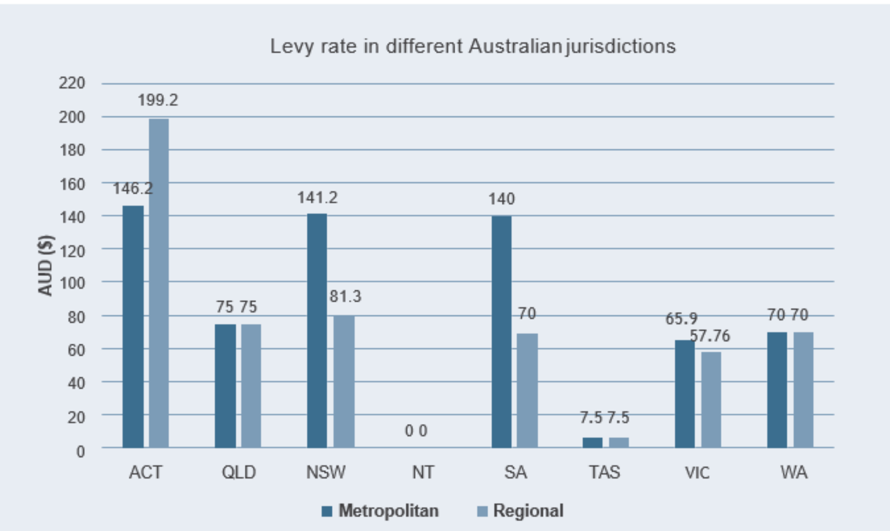

Figure 7. Levy fees for C&D waste disposal in different jurisdictions
Source: EPA in each of Australia's jurisdictions

[52] Lavino, H. J Barlow, M Ton, N. Dawood. 2018. An Inquiry into the Waste and Recycling Industry In Australia. Submission to the Senate Inquiry (Environment and Communications References Committee). p. 13.

[53] Waste Reduction and Recycling (Waste Levy) and Other Legislation Amendment Bill 2018, Explanatory note, p. 9

South Australia, Vic and WA impose the levy only at waste facilities that include a landfill, whereas NSW charges at any waste management facility and the levy is rebated if it is then transferred to another facility. In WA, the levy is not charged until the waste is actually disposed to landfill at the site, whereas the levy is charged on delivery to the site in other jurisdictions[54]. While it is a fact that the levy rate for C&D waste disposal is a product of many factors such as the time and cost, size of the construction industry, available lands, financial situations, regulatory environment and shortage in recycling facilities,[55] it is worthwhile to compare these rates across the world. Table 12 presents landfill tax rates imposed on C&D waste in a few exemplary countries.

Table 12. Rate of tax imposed on C&D waste at landfills

Country	Levy rate in the given currency per tonne	Levy rate in A$ * per tonne
Canada	CA$ 90	$ 95
China	¥ 25	$ 5.11
UK	Two rates apply: GBP 88.95 GBP standard rate £ 2.8 GBP *applies to C&D waste with less polluting waste	 $ 159.3 $ 5
EU	€ 3-100	$ 4.8 – 160.8
Hong Kong	HKD 446	$ 80
New Zealand	NZD 10	$ 10

*the exchange rate is driven from a trusted currency authority: www.xe.com viewed on 10.01.2019

1.3.12.3 How are landfill levy revenues distributed?

Landfill levies not only discourage waste generators from disposing of their waste, but also contribute to effective management of C&D waste through funding state environmental initiatives. Technically, a part of revenue earned from waste disposal is used to improve enforcement and compliance, development of sound policies and to fund actions and strategies that contribute to waste minimisation. In Australia, there is no nationally prescribed method for distribution of levies for such purposes and each local government does so according to its priorities and the objectives outlined in its waste strategy document. This section compares how levies are budgeted for distribution in the search for better waste management in different Australian jurisdictions.

In NSW, local government has launched an initiative, Waste Less, Recycle More to re-invest levy revenue, with the aim of increasing the effectiveness of resource recovery and reduction in litter and illegal dumping activities during the five years from 2017 to 2021.[56] This initiative provides $337 million in grants for nine programs: 1) Local Government Waste and Resource Recovery Program; 2) Illegal Dumping Prevention and Waste Enforcement Fund; 3) Household Problem Waste; 4) Waste and Recycling Infrastructure Fund; 5) Organics Infrastructure Fund and Program; 6) Litter Prevention and Enforcement Fund; 7) Business Recycling Program; 8) Recycling Innovation Fund; and 9) Heads of Asbestos Coordination Authorities programs. A small part of this grant ($5 million), under the Business Recycling Program, is dedicated to industrial ecology networks in C&I and C&D sectors throughout NSW.

In Vic, in 2010, EPA Victoria enacted regulations[57] to determine the share of levy revenue to be received by each state's agencies In this state, during the 2015 financial year, the levy revenue was

[54] N Above. P. 9

[55] Menegaki, M. & Damiagos, D. 2018. A review on current situation and challenges of construction and demolition waste management. *Current Opinion in Green and Sustainable Chemistry*. 13 (2018): 8-15.

[56] NSW Government. 2017. Waste Less, Recycle More.

[57] Environment Protection (Distribution of Landfill Levy) Regulations 2010.

distributed to the following agencies: EPA Victoria received 18 per cent, Sustainability Victoria received 12 per cent and Waste and Resource Recovery Groups (councils) received five per cent. Similar to Vic, WA has a piece of primary legislation[58] that specifies the arrangement of levies imposed and directs that the money collected through levies are used by the environment minister to[59] (a) fund certain programs relating to the management, reduction, re-use, recycling, monitoring or measurement of waste and (b) fund a person or body to conduct the activities mentioned in (a).

Other local governments, however, have not revealed a firm plan that determines how the levies charged at landfill sites should be distributed; in this situation, funding has been granted on a case-by-case basis and according to waste jurisdictional strategy objectives. For instance, the NT's waste strategy document indicates that government will fund and support campaigns to encourage the community to generate less waste, and also to maximise use of current waste collection systems so that waste going to landfill is minimised where possible and practical.[60] In SA, the waste strategy (2015–2020) declared that more than $80 million sourced from levy revenue had been invested into industry during the past decade; the fund allegedly was used by Zero Waste SA to build capacity and improve industry competitiveness.[61] This strategy also indicates that 50 per cent of the levy be transferred to the Waste to Resources Fund. In Qld, in 2018, the Waste Reduction and Recycling (Waste Levy) and Other Legislation Amendment Bill 2018 was presented to discuss how the state's levy revenue should be spent. The regulations indicte that the revenue *'will be used to fund implementation of a statewide waste and resource recovery strategy and complementary sustainability and environment initiatives. Surplus funds from the levy may benefit the entire Queensland community*'.[62]

1.3.12.4 Harmony in jurisdictional landfilling regulations

Inconsistencies in management of landfills in Australia are evident in the varying levy rates, designs of landfill sites, the complexity of waste disposal requirements, classification methods of waste and standard waste treatment performed in each jurisdiction. These inconsistencies for regulating landfilling activities have impeded the productive and environmentally sensitive management of waste in Australia. In reality, waste generators from jurisdictions that have more restricted waste regulations in place are exploiting landfill sites located in jurisdictions with relaxed regulations. To ensure regulatory measures are successful and unavoidable, legislation must be consistent across all jurisdictions. A relatively consistent regulatory framework in all jurisdictions will contribute to achieving sustainable waste management activities in Australia. In addition, and given the Australian waste management status quo, the Australian Government should take a more active role and introduce initiatives that target landfills, encouraging them to operate in a beneficial manner through recovering useful resources, instead of disposing all the waste collectively. This would assist them to reduce waste and increase the availability of resources.

1.3.12.5 Illegal dumping

Different types of people commit the offence of illegal dumping across Australia. However, due to data unavailability and poor data management practices, it is difficult to realise the overall extent of illegal dumping activities (Senate Environment and Communications References Committee, 2018). This issue creates numerous ecological problems and can pose several direct and indirect risks for human health and wellbeing. Research has shown that illegal waste disposal and stockpiling accounts for a higher liver and lung cancer mortality rate in the long term and congenital malformation in the short term (Triassi et al., 2015); in severe cases, it can lead to leptospirosis outbreaks (Hayati et al., 2018). The unsegregated nature of waste being illegally disposed of can also pose the risk of exposure to toxic materials such as asbestos to Australian residents.

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[58] Environmental Protection (Landfill) Levy Act 1998 – WA.

[59] Environmental Protection Act 1986 – WA.

[60] ACT Waste Management Strategy (2011–2025). Towards a sustainable Canberra. ACT.

[61] South Australia's Waste Strategy, 2015–2020, p. 10.

[62] Waste Reduction and Recycling (Waste Levy) and Other Legislation Amendment Bill 2018, Explanatory note, p. 4.

Illegal dumping presents a significant management issue for Australian governments through economic, social and environmental risks. Illegal dumping can occur in various forms including illegal landfilling where waste is used as a fill with/without the consent of the landowner, or when disposal activities do not observe the necessary planning or licencing approvals and stockpiling. The Australian Sustainable Business Group (ASBG) identified three types of illegal dumping in Australia based on the location of incident and accessibility thereof:

1. On publicly accessible lands (for example, parks and roads).
2. On private/public lands with limited access (for example, industrial lands, residential lands government-owned/managed lands).
3. On waste landfill sites or recycling facilities (for example, sites that dispose waste that is not meeting the acceptance criteria imposed by relevant regulations or policies).

The ASBG indicated that figures on illegal dumping only focus on the costs accrued by local councils in managing clean-up and supporting law enforcement associated with illegal dumping. Therefore, in addition to the environmental risk, illegal dumping is regarded as a financial burden on taxpayers. In NSW, conservative estimations made in 2015 suggested that the annual illegal dumping management expenditure would be between \$20 million and \$30 million (EPA New South Wales, 2015). In Qld, it was reported that, during 2016-17, managing 8.5 t of illegally disposed waste cost local government \$18 million, 20 per cent of which was C&D waste. In Qld, 14.5 t of litter and illegally disposed waste cost local councils \$11 million to manage. In the NT, the City of Darwin and Crown Lands together spend \$100,000 a year to clean up illegally dumped material (EPA Northern Territory, 2015) and this cost is on an upward trend. In Vic, it is reported that the cleaning up of 27.4 kt of dumped and littered waste cost \$12.5 million in 2016-17. Using an approximate estimate, it is safe to assume that, in the same period, Australia spent about \$70 million to manage and control illegal dumping. Another report revealed that the approximate cost of illegal disposal of waste is \$670 per tonne (Laviano et al., 2017), which is about six times costlier than legal landfill management costs.

The EPA Northern Territory (2015) listed four reasons that contribute to illegal dumping activities in Australia, which include 1) convenience; 2) using organised networks that systematically operate for businesses; 3) an unwillingness to pay landfill tax; and 4) an uncaring attitude. However, there is evidence that proves that inconsistent jurisdictional waste regulations play a role in creating this issue. The inconsistencies involve varying definitions of illegal dumping, inconsistent waste data management procedures, different perceptions of activities regarded as illegal dumping, varied penalty rates, plus different strategies and targets to address illegal dumping and key responsible stakeholders.

The unavailability of valid and comparable data is partially rooted in different measuring criteria and understandings of waste illegally disposed in different jurisdictions. Although there are some isolated statistics about illegal dumping, these are not consistently collected and presented. For many states, statistics on the frequency of incidents, the volume and the composition of waste being dumped do not exist. In SA, during 2016-17, there were 346 illegal dumping reports. In Tas, it is noted that illegal dumping comprises up to 10 per cent of reports to the Pollution Hotline (EPA Tasmania, 2017). In the ACT, several stakeholders have highlighted the high incidence of illegal dumping of C&D waste on privately owned lands (Hyder Consulting, 2011). Despite such evidence, according to the submissions made to the Senate Environment and Communications References Committee (2018), these governments have indicated that illegal dumping is not a major concern in their jurisdictions. For instance, the SA Government submission[63] indicated that 'there may be less

[63] Senate Standing Committees on Environment and Communications – submission 10: waste and recycling industry in Australia- Submission from the South Australian Government, 2017 p. 10.

concerning levels of inappropriate landfilling than is alleged in some other states', and the government attributed this to landfilling requirements for licensing within SA.

This contradictory issue is partially caused by different understandings of activities that are considered as illegal waste disposal in Australian jurisdictions. It is thus useful to compare the definitions of illegal dumping across jurisdictions to understand how illegal dumping is being perceived and managed. Table 13 summarises the definitions of illegal dumping in jurisdictional legislation.

Table 13. Illegal dumping definition and relevant regulations

	Illegal dumping definition	Relevant legislations
ACT	A person commits an offence if – (a) the person intentionally dumps litter at a public place; and (b) either – (i) the volume or weight of litter is more than the amount prescribed by regulation; or (ii) the litter is larger than the size prescribed by regulation	*Litter Act 2004* *Dangerous Substances Act 2004*
NSW	Deals with the unlawful transporting, acceptance and depositing of waste that the owner, transporter and person receiving the waste or allowing their waste to be received are committing a crime	*Protection of the Environment Operations Act 1997, under sections 143 and 144*
NT	The unlawful disposal of any waste that is larger than litter to land or waters. Illegal dumping is where waste materials are dumped, tipped or otherwise deposited on private or public land	*WMPC Act 1998* *WMPC (Administration) Regulations*
Qld	The unlawful deposit of any type of waste material that is 200 litres or more in volume	*Waste Reduction and Recycling Act 2011, sections 103, 104 and 251*
SA	Disposal of waste on public or private land or into water without a licence, permit or approval from the relevant authority such as the EPA or local council	*Environment Protection Act 1993, Section 36* *Environment Protection (Waste to resources) Policy 2010, under Clause 10*
Tas	(a) Drop or throw litter in, on or into a place; and (b) leave litter in or on a place; and (c) put litter in such a location that it falls, descends, blows, is washed, percolates or otherwise escapes or is likely to fall, descend, blow, be washed, percolate or otherwise escape into or from a place; and (d) cause, permit or allow litter to fall, descend, blow, be washed, percolate or otherwise escape into or from a place	*Litter Act 2007 Litter (Infringement Offences) Regulations 2011*
Vic	Leaving waste on private or public land that is not licensed to accept such waste	*Environment Protection Act 1970*
WA	Unauthorised discharging or abandonment of waste, and is an offence	*Environmental Protection Act 1986, under Section 49A*

In Tas and the ACT, there is no specific definition for illegal dumping and relevant regulations only describe littering as an offence under the *Litter Act*[64,65]. This can create confusion, as there is a distinction between illegal dumping and littering activities, generally with different motivations, barriers, participants and locations. In Qld, it is the volume of waste that determines whether unauthorised waste disposal is an offence. Unlike other jurisdictions, in NSW the definition of illegal dumping is expanded to hold responsible those who are involved in transporting, disposing and receiving waste, and landowners who allow waste to be dumped on their land. Similarly, there is a major difference in the extent of the punishment of illegal dumping across Australian states and territories. Legislators in Australia's jurisdictions have set different penalty fees for illegal waste

[64] Litter Act 2007 – Tas.
[65] Litter Act 2004 – ACT.

dumping activities. The jurisdictions share a commonality in the fact that penalty arrangements separate individual and corporation offences and each has a different penalty rate.

New South Wales administers the most detailed penalty system among the jurisdictions, with penalties applied at four thresholds: an on-the-spot penalty, maximum penalty, penalty for frequent offence and penalty for activities that have potential harm to the environment. This model, however, is barely established in other jurisdictions. New South Wales also imposes the most severe penalty fees, with offenders facing up to $1 million and $5 million and/or seven years' imprisonment for individual or corporation offences, respectively. The next highest penalty fees are being charged in Vic and the NT. The lowest penalty fees are charged in the ACT and Tas. Table 14 shows the differences in penalties enforced in eight Australian jurisdictions.

Table 14. Penalties enforced by the EPA (except in Qld) for illegal dumping in different jurisdictions

	Individual				Corporation			
	On-the-spot (basic) ($)	Maximum penalty ($)	Frequent offence ($)	Potential harm to environment (maximum) ($)	On-the-spot (Basic) ($)	Maximum penalty ($)	Frequent offence ($)	Potential harm to environment (maximum) ($)
ACT	Basic littering 1k Dangerous substances 200k			5,000	Basic littering 5,000 Dangerous substances 1m			5,000 and/or 25,000 and/or six months' imprisonment
NSW	7,500	250,000	250,000 + 60,000 daily	1 million and/or seven-years' imprisonment (wilful) – 500,000 and/or four-years' imprisonment (negligent)	15,000	1 million	1 million + 120,000 daily	5 million and/or seven-years' imprisonment (wilful) 2 million (negligent)
NT	119			574,000 and/or five-years' imprisonment	656			2.9 million
Qld	2,088 to 2,611	53,000 to 130,000	n/a	n/a	6,600 to 9,800	53,000 to 130,000	n/a	n/a
SA	120,000 + up to two-years' imprisonment				250,000			
Tas	157	7,850	n/a	n/a	2,512	n/a	n/a	n/a
Vic	611,000/ seven-years' imprisonment				> 1.2 million			
WA	62,500				125,000			

Note: for ease of reading figures are rounded up.

In Australia, local government areas are the frontline for combating waste dumping; however, the regulatory arrangements, reporting and coordination of the efforts to tackle illegal dumping commonly occur in EPAs. Furthermore, some jurisdictions have dedicated specialised teams to monitor, enforce and battle illegal waste disposal activities.

In the ACT, the City Rangers investigate illegal dumping. Furthermore, illegal dumping incidents are reported to Canberra Connect. In NSW, the New South Wales EPA (NSW EPA) enforces relevant regulations and investigates illegal dumping under the *Protection of the Environment Operations Act 1997 No. 156* (under sections 143 and 144). In addition, there are regional illegal dumping squads (for example, Hunter and Central Coast Regional Illegal Dumping Squad) specialising in fighting and preventing illegal dumping activities. New South Wales also established the RIDonline database/reporting tool in 2015 through which people can report illegal dumping incidents.

In the NT, the EPA regularly receives reports of illegal dumping (through the Pollution Hotline) from the community and actively investigates these to identify the offenders so that they can bear the cost of any clean-up, as well as be prosecuted in court. In Qld, the Department of Environment and Heritage Protection, with the authorised local governments, are responsible for combatting illegal dumping. The Litter and Illegal Dumping Unit was established to provide oversight on the implementation of litter and *Queensland's Litter and Illegal Dumping Action Plan*.

In SA, the EPA has a dedicated team, the Illegal Dumping Unit, which targets, investigates and stops illegal waste activities using intelligence, covert surveillance and other investigative techniques to identify all parties that are involved in an illegal waste activity. In Tas, management of illegal dumping is spread between several agencies and stakeholders. The Litter Officer, EPA Division, is mainly responsible, but its capacity is limited with respect to being able to adequately undertake compliance and enforcement activities along with the roles, responsibilities and resources available for land managers (that is, local government and other state agencies). Citizens can report illegal dumping through an online form or the Litter Hotline.

In Vic, EPA Victoria's illegal dumping Strikeforce program was established to reduce the risks to the environment from illegal waste management and to create a more level playing field. The program established a partnership with the Victorian Building Authority, WorkSafe, Consumer Affairs Victoria and Energy Safe Victoria to support stopping illegal dumping and appropriate management of C&D waste. In WA, the Department of Water and Environmental Regulation (DWER) is responsible for investigating and prosecuting illegal dumping under the *Environmental Protection Act 1986* (under Section 49A) through the DWER's illegal dumping (pollution watch) program. In addition to parent environmental protection Acts and subordinate waste-related regulations, various waste management strategies and targets have been proposed in different jurisdictions to navigate efforts towards illegal dumping reduction. These strategies are typically released under the title of Waste Strategy and cover a certain period. Table 15 presents the relevant strategies to reduce activities known as illegal dumping.

Table 15. Strategies proposed to reduce illegal dumping

	Illegal dumping minimisation direct strategies/targets	Strategy document
ACT	Reduce litter and dumping through laws and awareness-raising (Strategy 3.1) Participate in national approaches to litter management (Strategy 3.2) The ACT leads Australia in low litter and incidents of illegal dumping (Target 3) No quantitative target is introduced	*ACT Waste Management Strategy 2011–2025*
NSW	Reduce illegal dumping by 30% by 2020 compared with 2011 Seven approaches are proposed: 1) evaluation and monitoring; 2) education and awareness; 3) stakeholder engagement and capacity-building; 4) regulation and enforcement; 5) building an evidence base; 6) prevention, infrastructure and clean-up; and (7) evaluation and monitoring	*NSW Waste Avoidance and Resource Recovery Strategy 2014–21* *NSW Illegal Dumping Strategy 2017–21*
NT	Work with local government and the NT Government to coordinate local efforts to prevent litter and illegal dumping (Action 7) No quantitative target is set	*Waste Management Strategy for The Northern Territory 2015–2022*
Qld	Reduce the total amount of, and the environmental impacts from, litter and illegal dumping (Target 5) Reactive compliance and enforcement (Program 1) Education, engagement and awareness-raising (Program 2) Hotspots – proactive compliance (Program 3)	*Queensland's Waste Reduction and Recycling Strategy 2010–2020* *Queensland's Litter and*

	Illegal dumping minimisation direct strategies/targets	Strategy document
	Data, research and evaluation (Program 4) Capacity-building and networking (Program 5) No quantitative target is set	*Illegal Dumping Action Plan*
SA	Decreased incidences and tonnages of illegal dumping No quantitative target is introduced	*South Australia's Waste Strategy 2015–2020*
Tas	No current waste strategy	No current waste strategy
Vic	No current waste strategy	No current waste strategy
WA	Move towards zero illegal dumping by 2030 (Objective 3: protect) Identify and collect required data to monitor illegal dumping and allow better targeted monitoring and enforcement (Strategy 23) Deliver a community engagement and education campaign to raise awareness of illegal dumping and its impacts (Strategy 24) Work with landowners and managers to build their capacity to tackle illegal dumping (Strategy 28) Provide relevant funding and guidance to prevent the illegal dumping of waste at charitable recycler waste collection sites (Strategy 31) Detect, investigate and prosecute illegal dumping (Strategy 33) No quantitative target is set	*Waste Avoidance and Resource Recovery Strategy 2030: Western Australia's Waste Strategy*

Although the documents listed in Table 15 may have provided different strategies that can have indirect impacts on illegal dumping, only those strategies that exclusively target illegal dumping are presented. Furthermore, two of the eight jurisdictions (Vic and Tas) do not have current waste strategies and therefore their outdated waste strategy documents are excluded from consideration. Two states, NSW and Qld, have developed a specific strategy and action plan for illegal dumping management. Aside from NSW (target: 30 per cent reduction by 2020), none of the jurisdictions were able to define a quantitative target to reduce illegal dumping.

According to the waste strategies[66,67,68,69,70,71] and submissions by different organisations and agencies to Australia's Senate Environment and Communications References Committee, the main reforms proposed for better illegal dumping management are funding for education programs and enforcement through local government imposing waste levies. In terms of law enforcement, introducing a uniform levy across Australia, in particular, can reduce the motive for illegal dumping (Laviano et al., 2017).

Education has a decisive role in tackling illegal dumping in Australia. Most jurisdictions have formed teams dedicated to educating industry people as well as the wider community (DEE(Pickin et al., 2018). Several non-governmental and industry organisations, such as Clean Up Australia, Keep Australia Beautiful and Rethink Waste, collaborate to minimise litter and illegal dumping through education. Furthermore, jurisdictional waste strategies have introduced initiatives to fund education programs aiming to reduce waste and illegal dumping. For instance, in WA, the *Waste Avoidance and Resource Recovery Strategy 2030*, under Objective 3: Protect, has introduced Strategy 24 to 'deliver a community engagement and education campaign to raise awareness of illegal dumping and its impact' (Waste Authority, 2018, p. 35). In Qld, *Queensland's Litter and Illegal Dumping*

[66] ACT Waste Management Strategy 2011–2025.
[67] NSW Illegal Dumping Strategy 2017–21.
[68] Waste Management Strategy for The Northern Territory 2015–2022.
[69] Queensland's Litter and Illegal Dumping Action Plan 2013.
[70] South Australia's Waste Strategy 2015–2020.
[71] Waste Avoidance and Resource Recovery Strategy 2030: Western Australia's Waste Strategy.

Action Plan has proposed five programs to tackle illegal dumping. The second program's (Education, Engagement and Awareness Raising) aim is to *'initiate and drive behavioural change by removing excuses through awareness raising, sharing information and communicating to a wide audience about littering and illegal dumping'*.

In practice, detection of activities related to illegal dumping significantly contributes to lessening illegal activities. Using technologies such as remote sensing, Geographical Information Systems (GIS) and drones that provide aerial images of vast areas with illegal dumping activities potential can be helpful. Lega et al. (2012) conducted a comparative study between different aerial tools (for example, aeroplane, drone, helicopter and satellite) in the field of environmental research and law enforcement in Italy. In Australia, a research project on mapping potential illegal dumping activities found that GIS can be successfully used to map and predict the likelihood of illegal dumping on the Qld's Sunshine Coast (Glanville and Chang, 2015). In particular, drones are providing a cost-effective tool for monitoring, data collection and analysis in the field of waste management and their usage is on the rise (Smith, 2015, Capolupo et al., 2014, Kiss Leizer, 2018). Until today, none of the study jurisdictions have systematically considered taking advantage of these technologies; hence, a fortiori relevant regulations have not been developed.

1.3.13 Infrastructure plan

Another discrepancy found among jurisdictions relates to having a statewide infrastructure plan. According to Principle 2 of the *2018 NWP*[72] (Improve Resource Recovery), for improvements in recycling and resource recovery, among other factors, Australia depends on having the right infrastructure, facilities and rules in place and making sure that they are economically sustainable. An infrastructure plan is quite helpful to achieve these goals. However, among the jurisdictions (at the time of writing), only two states have developed such a plan: SA and Vic. The other jurisdictions are either in the process of developing such a plan or simply do not have one. Victoria is the first jurisdiction in Australia to release a statewide infrastructure plan[73] that provides a roadmap for a waste and resource recovery system for a 30-year period in the state. This plan, together with regional implementation plans that describe how the plan will be implemented at a local and regional level, aims to achieve the following:

(a) effectively manage the expected mix and volumes of wastes and materials
(b) support a viable resource recovery industry
(c) reduce the amount of available materials going to landfill
(d) reflect environmental justice principles.

South Australia's statewide infrastructure plan[74] also provides for the waste and resource recovery industry for the next 30 years. The objectives of this plan are as follows:

(a) provide an evidence base that enables common understanding by all stakeholders of waste and resource recovery infrastructure types and needs across the state and the associated economic benefits, job creation and investment opportunities
(b) provide a clear policy framework and a platform conducive to attracting investment, which allows for a well-coordinated and balanced approach towards waste and resource recovery infrastructure and capability-building that promotes innovation and economies of scale
(c) inform the state's land-use planning system, enabling land use planning to provide for appropriate and essential waste and resource recovery infrastructure investment, including adequate provision of suitable sites and buffers
(d) support a viable resource recovery and re-manufacturing industry and foster industry capabilities in SA that can be exported.

[72] National Waste Policy 2010: less waste, more resources, p. 14.
[73] Statewide Waste and Resource Recovery Infrastructure Plan – Vic.
[74] Green Industries SA. 2018 South Australia's Waste and Resource Recovery Infrastructure Plan.

In 2017, the NSW EPA prepared a consultation draft for a statewide infrastructure plan[75] that seeks to analyse the needs throughout the state and finalise a robust strategy that will help achieve NSW's waste strategy objectives. In WA, the Waste Authority has committed to developing an infrastructure plan. As a result, a Strategic Waste Infrastructure Planning Working Group has been established to support the development of the plan. The aim is to determine the waste management infrastructure needs and contribute to achieving waste strategy targets. In Qld, the Department of Environment and Science has commenced a process to develop a statewide infrastructure plan.

1.3.14 Application of C&D waste regulations in practice

In this section, the application of C&D regulations in Australia in practice is assessed using a literature review technique. The literature used in this review includes relevant reports and submissions to the inquiries managed by authorities in different jurisdictions and Australian organisations. At the conclusion of the survey, more insights from different stakeholders will be added to the pool. The two main issues in the C&D regulations that are discussed in this section are landfill levy and the proximity principle.

1.3.15 Perceptions of the imposition of landfill levy in Australia

In 2011, a C&D supply chain guide[76] prepared for the Australian Government reported that many stakeholders had indicated that landfill costs (landfill operation and levies) are a significant driver for the use of salvaged and recycled C&D waste. In 2018, various respondents to the call for submissions to the Senate Environment and Communications References Committee expressed support for the continuous imposing of landfill levies (Senate Environment and Communications References Committee, 2018). The submissions highlighted that levy schemes can act as a disincentive for waste disposal. Further, they concluded that the ensuing revenue is an important source of funding for investment in waste and recycling management initiatives.The following table (Table 16) shows examples of support from different submitters.

Table 16. The evidence of the effectiveness of landfill levies in Australia

Respondents	Indicative language
WA Government	There has been a notable diversion from landfill for two waste streams (i.e. C&D and C&I) since 2011 when levy rates were considerably increased
Re.Group (http://www.re-group.com/)	NSW's relatively high recovery rate for two waste streams (C&D and household waste) has been driven by the landfill levy
SA Government	Progressive increase of waste recovery (reduction in waste disposal) has been concurrent to continuous increase in levy fee; the increase was more than 20% in 2015-16 (81.6%) compared to 2003–2014 (60%)
WALGA	There is evidence that the landfill levy has been responsible for diverting inert material from landfill; however, it is not known where this waste is being diverted
Envorinex (https://envorinex.com/)	Landfill levies should be priced high enough to encourage major business to send their waste to recyclers and not to landfill sites

Source: Senate Senate Environment and Communications References Committee (2018).

In addition to support from the submissions to this Committee[49], there are some concerns about the unintended consequences that emerge from the improper design of levy schemes. These concerns express that the jurisdictional legislation levy should not give rise to unintended outcomes such as interstate waste transfer because of cost disparity, discouraging private investors from investing in recycling infrastructure, high administrative costs corresponding to the application of complex schemes, and stockpiling and illegal dumping.

[75] EPA. NSW Waste and Resource Recovery Infrastructure Strategy. 2017-2021 – Draft for consultation.

[76] Edge Environment Pty Ltd. 2011. Construction and Demolition Waste Guide – Recycling And Re-Use Across The Supply Chain. The Commonwealth Government of Australia.

In addition, some respondents provided evidence which shows that imposing a landfill levy did not achieve the intended goals (for example, reduction in waste disposal or increase in waste recovery activities).[77] Indeed, this evidence demonstrates there are limits to what can be achieved through the imposition of a landfill levy. Table 17 summarises these challenges associated with landfill levies.

Table 17. Unexpected results from the implementation of landfill levies in Australia

Submitter	Indicative language
The Law Council of Australia (LCA)	Landfill levies can encourage stockpiling and illegal dumping.
GCS Consulting	During the period when the amount of the metropolitan NSW levy doubled, the NSW C&D industry was found to have reduced its recycling rate, which is contrary to expected market behaviour and the efficacy of the levy as a pricing mechanism that was achieved when the levy was at much lower levels.
Unspecified submitters	Little effect on waste generation, as ratepayers have no direct financial incentive to reduce waste destined to landfill.
Adelaide Hills Region Waste Management Authority	Waste disposal levies do 'not act as a direct driver for the community to reduce waste generation or increase recycling habits' because any increase in waste levies is 'covered by general rate revenue'.
ASBG	Highlighted that there is evidence that an increase in the landfill levy results in incurring additional costs for the recycling industry.
National Waste and Recycling Industry Council	A levy on the disposal of recycling residuals reduces the competitiveness of materials sold into the international market.
Centre of International Economics	In NSW, the waste levy of $120 reduced the profit margin of metal recyclers in 2011
The Australian Council of Recycling	When recyclers are liable to pay the levy for the disposal of contaminants that have entered the recycling stream, they see it as a disincentive towards being involved in the recycling industry and instead it encourages shipping unprocessed waste overseas
Re Group	The disposal of residuals generally represents a significant cost for recycling facilities, which can obviously create commercial incentives to seek lower disposal cost options; it also justifies transport waste to interstate locations with a lower disposal rate
Visy, Owens-Illinois and SKM Recycling	Landfill levies penalise the recycling industry for the disposal of residual rubbish that enters the recycling stream

Source: Senate Environment and Communications References Committee (2018)

Aside from the views tabulated above and beyond the scope of this report, several respondents indicated that levies have little impact on domestic waste generation patterns in Australian cities.[78] The findings indicate that, because councils charge households at a flat fee to recover the levy fees, which they pay on behalf of ratepayers, they have no motivation to reduce the amount of waste disposed. In other words, basically, the price signal is not passed on through the rates directly. There is a lesson in this causality that can be transferred to the context of C&D waste management: the levy should be accompanied by other financial incentives to effectively target waste generation at origin – for example, during the design and construction stages.

Several trends emerged in response to the call made by WA's DWER for submission to a discussion paper on landfill levy. Some of the submissions presented different issues that were not considered in the relevant regulations and policies. The following is a selection of their responses to the latest levy regime in WA:

[77] Ibid pp. 47-58.
[78] Ibid p. 51.

‘*A levy, by its nature, is a penalty/cost impost. In what way is the payment of a levy an incentive? Those paying the levy have less funds available to put into their own research and subsequent implementation of their own waste reform policies and systems*.’[79]

‘In addition, we are concerned that this appears to be a revenue-raising activity rather than a legitimate pursuit of better environmental outcomes for Western Australian.’[80]

Therefore, the future design and implementation of regulations and policies should ensure that:

1. Any levy imposed should be articulated as the ‘key environmental lever’ not an ‘economic policy lever’.
2. A rebate system is put in place for those who are involved in landfill diversion.
3. Alternative methods for calculating waste volumes, rather than just utilisation of weigh stations, are allowed.

Another barrier to effective enforcement of landfill levies discussed previously is to nationally harmonise gate fees. The support for harmonisation is abundant (Senate Environment and Communications References Committee, 2018) and it is thought it can substantially minimise inter-jurisdictional waste transfer. However, it should be remembered that such an arrangement might not produce the best results. Simple harmonisation may overlook the existing contextual conditions in each jurisdiction. It may also interfere with the specific waste management system implemented in different states and territories. Hence, it is better to set up the levy fees in a way that ensures the negative impact on the effective management of C&D waste across Australia is minimised. For instance, a rate disparity should be calculated to the extent that it does not prompt unnecessary long-distance waste transfer.

1.3.16 Perceptions of the proximity principle

This principle requires waste generators to send their waste to a facility that is located in a certain perimeter of origin. Several submissions to the Senate Senate Environment and Communications References Committee (2018) argued that the proximity principle (PP) can assist in preventing movement of waste between jurisdictions for the purpose of avoiding and minimising levy liabilities. A criticised example of the implementation of the PP is happening in NSW, where waste generators are only allowed to dispose of their waste within a 150 km perimeter. The Waste Contractors and Recyclers Association of NSW instead suggested that a national PP would be more effective. In this respect, the LCA suggests that implementation of a national PP should align with Section 92 of the Constitution, which stipulates that trade and commerce among the states are to be regarded as absolutely free.

The submission from the Waste Management and Resource Recovery Association of Australia indicates that its members need to stop the practice of long-distance transportation of waste. This association argues as follows:

We do not agree with long-distance transportation; we actually agree there has to be a [PP] in place to stop the excessive and unnecessary movement of waste across distances, particularly if there is the infrastructure in place. You can’t actually invest [in] and develop infrastructure if you haven’t got certainty about what’s coming through the front gate. In Europe you do have a [PP], so we need to solve how we do that. (p. 59).

[79] Activa developments Pty ltd. 2017. Comments on waste reform project.

[80] Alcoa of Australia Limited. 2017. Comments on waste reform project.

The other argument in regard to the PP is that authorities have to be alerted to the consequences of implementation of such a policy. It is argued that there are some environmental benefits that come with waste transport that could be diminished by the imposition of a PP. In the case of development of a domestic market for C&D waste, the trade of recovered/unrecovered waste materials between different locations is necessary to sustain industries and businesses involved in the market. China's National Sword policy is another driver for the wise adoption of a PP in Australia. This policy forces the Australian waste and resource recovery industry to commit to the development of a sustainable domestic market for trading waste materials across Australia. For waste energy recovery, the need for sustainable waste feedstock is found to be the main barrier to development of EfW facilities. It can be concluded that until the full potential for waste management in proximity is fulfilled, a reasonable transportation distance of recovered/unrecovered waste materials should be allowed.

1.4 Recommendations

1.4.1 State_specific reforms

Following the review of the waste-related legislative and non-legislative documents in the eight jurisdictions of Australia, some reforms are hereby suggested to address the inconsistencies among them. While some of the reforms below are specifically recommended for one jurisdiction, there are recommendations that apply to more than one jurisdiction.

These recommendations primarily emerge from the following sources:

1) Review of national and jurisdictional legislations.
2) Review of jurisdictional waste strategy documents.
3) Review of national and jurisdictional reports, consultation and review drafts, submissions to the Senate Environment and Communications References Committee.

It is expected that these recommendations will be modified when the project has completed the administration of a survey on different aspects of C&D waste management, and the resulting responses are gathered and analysed. Almost all of the following recommendations can be incorporated in jurisdictional legislations, and their benefits can be achieved when they are supported in primary legislation and subordinate regulations.

1) Differentiate between littering and illegal dumping, and provide of a specific definition and regulations for illegal dumping in the ACT and Tas.
2) Set a quantitative target for reducing illegal dumping incident frequency in the ACT, NT, Qld, Tas, Vic and WA.
3) Separate levies between metropolitan and regional areas in the ACT, NT and Tas.
4) Increase penalty fees for illegal dumping in the ACT, Qld and Tas.
5) Extend the legal liability of illegal dumping activities to those who transport, accept and allow waste to be illegally disposed of anywhere in the ACT, NT, Qld, SA and Tas.
6) Prepare guidelines on the siting, design, operation and rehabilitation of landfills that can best match the waste hierarchy objectives in the ACT and Tas.
7) Make regulations, similar to Vic's (Environment Protection (Distribution of Landfill Levy) Regulations 2010, that outline how the landfill revenue is to be distributed in the ACT, NSW, NT, Qld, SA and Tas.
8) Set specific regulations for supporting C&D waste and energy from waste where further recycling is not technically and financially practical. The NSW Energy from Waste Policy Statement is a good model to follow in this important step towards the target of sending zero waste to landfill by 2025 in the ACT, NT, Qld, SA, Tas, Vic and WA.

9) Provide regulatory support for both fixed and mobile crushing and screening equipment that encourages equitable management of these two systems, potentially resulting in cost-efficient C&D waste recycling practices in the ACT, NSW, NT, Qld, Tas, Vic and NSW.
10) Develop regulations and strategies to manage emergency C&D waste in natural disaster incidents (that is, earthquake, landslide or flood) in NSW, NT and Qld.
11) Develop or update the outdated waste strategy in Tas.
12) Introduce a policy/guideline that is used to assess proposals for EfW facility design and establishment, according to the EPA-administrated primary legislations and subordinate legislations in Tas.
13) Distinguish between litter and C&D waste in state regulations in NSW.
14) Implement or improve waste data collection, monitoring and analysis in Tas and the NT.
15) Establish a policy that provides direction and guidelines for the development of SP, which will encourage confidence in recycling facility operators to produce products that meet end-use requirements in the NT, Tas and Qld.
16) Develop a procedure to determine levy and penalty fees in the NT.
17) Consider management options against the waste hierarchy in the NT and Tas.
18) Provide a clear process for determining licence requirements or exemptions based on environmental risk in the NT.
19) Encourage PS schemes through the development of relevant regulations, policy and guidelines in Tas and WA.
20) Revisit levy fees to promote recycling and recovery of C&D waste and encourage investment in these areas, leading to the development of a market for recycled materials and curtailing interstate waste transfer from NSW in Qld.
21) Revisit legislation to ensure better consistency with other states and territories to stop waste transfer to Qld state and improve waste management activities performance in Qld.
22) Introduce a landfill levy for material disposed at statewide landfills to encourage investment in resource recovery and recycling, and implement practices that reduce waste generation in Tas.
23) Increase the power of the Litter Officer, EPA Division, to better enforce regulations in Tas.
24) Provide additional resources to bolster the capability of the regulator to provide improved regulation and compliance (for example, via landfill levy) in Tas.
25) Establish a statewide organisation to lead/champion and implement state waste and resource recovery strategies in Tas.
26) Develop a state waste and resource recovery infrastructure plan that provides a roadmap to meet the future waste disposal needs and resource recovery objectives of each state/territory
27) Support industry to use materials efficiently, re-use materials and to understand the business case to improve resource recovery, create jobs and boost the economy in Tas.
28) Create an alignment between state policies and national policies in Tas.
29) Ensure gate fees are consistent between council and privately operated facilities to avoid long distance travelling in WA.
30) Amend the *Environmental Protection (Landfill) Levy Act 1998* to clearly outline in detail how the landfill revenue is to be distributed in WA.

1.4.2 Nationwide reforms

Similar to the reforms provided for each jurisdiction, there are certain suggestions that can result in the improved management of C&D waste nationally. These suggestions are based on previous reports, including submissions to the Senate's Standing Committee on Environment and Communications 2018) and a review of the regulatory framework in Australia. Due to their complex nature, they can only be implemented through a coordinated decision-making process supported by all states and territories. To achieve this, environment ministers at all levels of government should meet regularly to reach an agreement in principle, based on the following:

1) Harmonise specifications of recycled materials to be used in road pavement, and increase use of recycled materials to avoid data gaps and data bias (this provides an opportunity to better aggregate and report waste data).
2) Provide consistency in the scope of waste-related regulations and policies.
3) Give consistent guidance and training for all jurisdictions.
4) Develop a nationwide waste and recycling infrastructure plan that stipulates the minimum design and construction requirements; this will improve development, management and operation of protected sites for landfills, energy recovery sites, composting sites and all forms of recycling activities.
5) Provide consistent guidelines for waste auditing that is applicable throughout Australia.
6) Increase the usefulness of shared information and improve assessment of outcomes of projects, policies, laws and business transactions in different jurisdictions.
7) Establish a robust and consistent national waste data management system that is obliged to improve assessment of outcomes of projects, policies, laws and business transactions in different jurisdictions.
8) Provide uniform reporting of waste data to better aggregate and report waste data. The first step is for the Australian Government to implement the 65 agreed improvements to the *National Waste Report 2018* as established by Blue Environment Pty Ltd's *Improving National Waste Data and Reporting* report.
9) Set a policy to align jurisdictional data management and reporting procedures with international reporting requirements.
10) Approximate waste levies as an impetus for greater recycling, reduction of interstate waste transportation, enforcing companies to invest more in efficient technologies to recover waste, reduction in the amount (cost and volume) of waste land filled, and to prevent unnecessary waste transfer.
11) Set a policy that includes the minimum staff required to monitor and enforce waste regulation; provide for the availability of sufficient staff to minimise illegal dumping across Australia.
12) Show leadership through the urgent implementation of the 16 strategies established under the *2018 NWP*.
13) Support jurisdictional educational programs that result in raised societal environmental awareness about waste management and further recycling.
14) Provide incentives to encourage industry professionals to invest in industrial waste sorting and more waste recycling; in particular, the federal government can encourage jurisdictions to invest in facilities for sorting mixed C&D waste through landfill levy revenue.
15) Restructure the market towards greater domestic recycling and recovery of waste away from export reliance.
16) Revisit Australia's building codes to facilitate the use of recycled materials in buildings.
17) Simplify regulations to provide greater clarity, remove unnecessary regulatory burden and remove clauses that are no longer required.
18) Provide legislative support for the use of technologies such as remote sensing, GIS and drones.
19) Introduce Commonwealth legislative targets for waste and recycling standards to transition towards a more circular economy in which materials are used, collected, recovered and re-used.
20) Adjust PS schemes established under the *Product Stewardship Act 2011* to better represent real-world conditions.
21) Develop a SP policy specifically for recycled C&D waste materials to increase the use of recycled materials.

1.5 Conclusions

This review demonstrates that there are fundamental discrepancies in the legislative framework among Australian states and territories. It is claimed that these discrepancies are hindering effective action. Many businesses operate in national markets and must fulfil different obligations in every jurisdiction. Indeed, national and common approaches can improve the efficiency of Australia's waste and resource recovery processes, and this in turn can contribute to growing markets for recycled waste materials. While some of these discrepancies are the direct product of contextual conditions and may be difficult to address urgently, there are areas of improvement for C&D waste management that can be gained through harmonisation. In an ideal world, harmonisation will bring many benefits as stated above; however, it is worth keeping in mind that any harmonisation needs support from all stakeholders affected. Currently, Australia lacks a level playing field within which industry can operate, and therefore regulatory authorities must ensure that efforts for harmonisation will not adversely impact the key stakeholders in different jurisdictions. On this basis, this review provides specific reforms for each jurisdiction as well as for the whole country to ensure that these reforms provide the best benefits for every party involved in the management of C&D waste.

2. A Consistent Approach to Define and Measure C&D Waste

2.1 Introduction

The effective management of C&D waste largely hinges on the consistency in approaches to defining, measuring and treating this waste stream across Australia. It is widely known and documented that a harmonised approach can remove many barriers to reducing, re-using, recycling and recovering waste across a country like Australia with different regulatory authorities. The assessment of whether certain material is waste is important to the application of the Acts and regulations imposed by these authorities. Therefore, a clear and consistent definition of 'waste' and 'resource' to be used across sectors and jurisdictions needs to be considered.

This report aims to first review the approaches taken in different jurisdictions to highlight the extent of consistencies/inconsistencies in the corresponding management systems. The review of regulations will help establish a clear understanding of the circumstances in which a 'waste' should be considered as a 'resource'. For this purpose, the five main indicators in jurisdictional regulations are explored. These indicators show the characteristics of a waste relative to resource and include a 'definition of waste', 'definition of clean fill', 'waste classification', 'when waste ceases to become a waste' and 'waste data management systems'. Indeed, when the inconsistencies in these indicators are identified and dealt with, Australia can plan for the development of a marketplace wherein different parties can effectively trade their waste across borders and industries. The subsidiary aim of this report is to propose a set of recommendations used to develop a consistent approach to define and measure C&D waste across different jurisdictions.

2.2 Definition and terminologies

2.2.1 Definition of waste

Although the *2010 NWP* set an objective to develop a national definition of waste under Strategy 4 (National Classification System for Waste), to date there is no consistent definition for general waste or C&D waste specifically. Defining waste is not an easy task and there is no single domestic or international definition. This is because of the complicated nature of waste and because the nature (for example, composition) of waste is changing. It is rapidly comprising increasingly diverse materials and products, as well as involving new processing and management technologies and regulations.[81] Defining waste offers an understanding of its characteristics, which has become important with the customisation of modern waste management systems for various types of waste materials.

In Australia, the practice of waste definition is excessively associated with classification of hazardous materials and determination on landfill levy liability. Inconsistent definitions of waste can potentially result in levy avoidance or the inability to achieve the best management practices. An inappropriate definition of hazardous waste can result in material being excluded from appropriate treatment. Despite there being general similarities among the definitions of C&D waste, each jurisdiction uses specific wording and practical applications. The definition of waste can decide when a material is a 'waste', a 'product' or a 'resource'. As such, this can have substantial regulatory, environmental and financial impacts for those who are involved in this industry (for example, waste-makers, recycling and disposal facility owners, and transporters).[82] As presented in Table 18, the definition of general waste is provided in the EPA-administrated legislation in different jurisdictions. The majority of definitions include some common elements, such as waste status (for example, unwanted, discharged, abandoned or emitted), waste substance (for example, gas, solid or liquid) and intended subsequent use (for example, re-use, recycle or recover). The differences include the source of waste (for example, commercial, demolition) and potential harm to the environment (alteration of the environment). In the case of the ACT, three definitions are provided for general waste, varying in terms of wording, length, potential harm to the environment and intended subsequent use; however, the descriptions do not differ in terms of scope. Lastly, it is noteworthy that, in all

[81] The Allen Consulting Group. 2009. National Waste Policy. Regulatory Impact Statement.

[82] Hyder Consulting Pty Ltd.. 2012. Waste Definitions and Classifications: Report on Issues, Opportunities and Information gaps.

jurisdictional definitions, waste is always regarded as waste whether or not it is useful or intended for re-use, recycling, recovery or reprocessing. In this regard, the definition provided by the *2018 NWP* excludes from being classified as waste any materials and products that are to be re-used without processing.

Table 18. Definitions of general waste and C&D waste in different jurisdictions.

	EPA documents	Waste Policy and other documents
ACT	***Environment Protection Act 1997*** **General waste** Any solid, liquid or gas, or any combination of them, that is a surplus product or unwanted by-product of an activity whether the product or by-product is of value or not. ***Waste Management and Resource Recovery Act 2016*** **General waste** Any substance (whether solid, liquid or gaseous) that is discharged, emitted or deposited in the environment in such volume, constituency or manner as to cause an alteration in the environment; (b) any discarded, rejected, unwanted, surplus or abandoned substance, whether or not intended for sale, recycling, reprocessing, recovery or purification by a separate operation from that which produced it; (c) any other substance declared by regulation to be waste **Environment Protection Regulation 2005** **General waste** A thing, whether valuable or not, that is – (a) discarded; or (b) rejected; or (c) unwanted; or (d) surplus; or (e) abandoned; or (f) intended for recycling, reprocessing, recovery, re-use, or purification **C&D waste** No definition is provided for C&D waste	***ACT Waste Management Strategy 2011–2015*** **C&D waste** Generated by the building and construction industry
NSW	***Protection of the Environment Operations Act 1997 No. 156*** **General waste** Any substance (whether solid, liquid or gaseous) that is discharged, emitted or deposited in the environment in such volume, constituency or manner as to cause an alteration in the environment, or (b) any discarded, rejected, unwanted, surplus or abandoned substance, or (c) any otherwise discarded, rejected, unwanted, surplus or abandoned substance intended for sale or for recycling, processing, recovery or purification by a separate operation from that which produced the substance, or (d) any processed, recycled, re-used or recovered substance produced wholly or partly from waste that is applied to land, or used as fuel, but only in the circumstances prescribed by the regulations, or (e) any substance prescribed by the regulations to be waste ***Protection of the Environment Operations Act 1997 No. 156*** **C&D waste** Unsegregated material (other than material containing asbestos waste) that results from: (a) the demolition, erection, construction, refurbishment or alteration of buildings other than chemical works, or mineral processing works, or	**Waste Levy Guidelines 2018** ***NSW Waste Avoidance and Resource Recovery Strategy 2014–21*** **C&D waste** Is generated from construction or demolition works, and includes asphalt waste or excavated natural material

	EPA documents	Waste Policy and other documents
	container reconditioning works, or waste treatment facilities, or (b) the construction, replacement, repair or alteration of infrastructure development such as roads, tunnels, sewage, water, electricity, telecommunications and airports, and includes materials such as bricks, concrete, paper, plastics, glass and metal, and timber, including unsegregated timber, that may contain timber treated with chemicals such as CCA, high temperature creosote, pigmented emulsified creosote (PEC) and light organic solvent preservative (LOSP), but does not include excavated soil (for example, soil excavated to level-off a site prior to construction or to enable foundations to be laid or infrastructure to be constructed)	
NT	***WMPC Act 2016*** **General waste** A solid, a liquid or a gas; or (b) a mixture of such substances that is or are left over, surplus or an unwanted by-product from any activity (whether or not the substance is of value) and includes a prescribed substance or class of substances **C&D waste** No definition is provided for C&D waste	***Waste Management Strategy for the Northern Territory 2015–2022*** **C&D waste** Solid waste sourced from C&D works, including building and demolition waste, asphalt waste and excavated natural material
Qld	***Environmental Protection Act 1994*** **General waste** Includes anything, other than an end-of-waste resource, that is – (a) left over, or an unwanted by-product, from an industrial, commercial, domestic or other activity; or (b) surplus to the industrial, commercial, domestic or other activity generating the waste. Waste can be a gas, liquid, solid or energy, or a combination of any of them. (3) A thing can be waste whether or not it is of value **C&D waste** No definition is provided for C&D waste	***Queensland's Waste Reduction and Recycling Strategy 2010–2020*** **C&D waste** Is generated as a result of building, refurbishing, renovating or demolishing structures, buildings and infrastructure such as roads, bridges and docks, and includes material such as timber, clean soil, concrete, asphalt, plasterboard, steel, bricks, ceramic and clay tiles, and aluminium
SA	***Environment Protection Act 1993*** **General waste** Any discarded, dumped, rejected, abandoned, unwanted or surplus matter, whether or not intended for sale or for purification or resource recovery by a separate operation from that which produced the matter; or (b) any matter declared by regulation to be waste for the purposes of this Act; or (c) any matter declared by an environment protection policy to be waste for the purposes of this Act, whether or not of value **C&D waste** No definition is provided for C&D waste	**Waste definitions 2009** **C&D waste** The solid inert component of the waste stream arising from the construction, demolition or refurbishment of buildings or infrastructure but does not contain MSW, C&I waste (general), listed waste, hazardous waste or radioactive waste ***South Australia's Recycling Activity Survey 2016-17 Financial Year Report – Green Industries SA*** **C&D waste** Includes waste from residential, civil and commercial C&D activities, such as fill material (for example, soil), asphalt, bricks and timber. C&D waste excludes construction waste from owner/occupier renovations, which are included in the municipal waste stream. Unless otherwise noted, C&D waste does not include waste from the C&I waste stream
Tas	***Environmental Management and Pollution Control Act 1994*** **General waste** Discarded, rejected, unwanted, surplus or abandoned matter, whether of any value or not; or (b) discarded, rejected, unwanted, surplus or abandoned matter, whether of any value or not, intended – (i) for	**C&D waste** No definition is provided for C&D waste

	EPA documents	Waste Policy and other documents
	recycling, reprocessing, recovery, re-use or purification by a separate operation from that which produced the matter; or (ii) for sale **C&D waste** No definition is provided for C&D waste	
Vic	***Environment Protection Act 1970*** **General waste** Any matter, whether solid, liquid, gaseous or radioactive, which is discharged, emitted or deposited in the environment in such volume, constituency or manner as to cause an alteration of the environment; (b) any discarded, rejected, unwanted, surplus or abandoned matter; (c) any otherwise discarded, rejected, abandoned, unwanted or surplus matter intended for – (i) recycling, reprocessing, recovery or purification by a separate operation from that which produced the matter; or (ii) sale; and (d) any matter prescribed to be waste **C&D waste** No definition is provided for C&D waste	***Statewide Waste and Resource Recovery Infrastructure Plan 2018*** **C&D waste** Materials generated and discarded from building, C&D activities **Victorian Recycling Industries Annual Survey 2010-11 – Sustainability Victoria** **C&D waste** Waste from residential, civil and commercial C&D activities, such as fill materials (for example, soil), asphalt, bricks and timber. C&D waste excludes construction waste from owner/occupier renovations, which is included in the municipal waste stream. Unless otherwise noted, C&D waste does not include waste from the C&I sector
WA	***Environmental Protection Act 1986*** **General waste** Whether liquid, solid, gaseous or radioactive and whether useful or useless, which is discharged to the environment; or (b) prescribed to be waste **Landfill Waste Classification and Waste Definitions 1996 (as amended 2018)** **C&D waste** Materials in the waste stream which arise from construction, refurbishment or demolition activities	***Review of Waste Avoidance and Resource Recovery Act 2007*** **C&D waste** Is the solid waste from residential, civil and commercial C&D activities
National	**National Environment Protection (Movement of Controlled Waste between States and Territories) Measure 2012** **General waste** Discarded, rejected, unwanted, surplus or abandoned matter; or (b) otherwise discarded, rejected, unwanted, surplus or abandoned matter intended for: (i) recycling, reprocessing, recovery, re-use, or purification by a separate operation from that which produced the matter; or (ii) sale, whether of any value or not ***Hazardous Waste (Regulation of Exports and Imports) Act 1989*** **General waste** A substance or object that: (a) is proposed to be disposed of; or (b) is disposed of; or (c) is required by a law of the Commonwealth, a state or a territory to be disposed of ***2018 NWP*** **General waste** Materials or products that are unwanted or have been discarded, rejected or abandoned. Includes materials or products that are recycled, converted to energy, or disposed. Materials and products that are re-used (for their original or another purpose without reprocessing) are not waste because they remain in use **C&D waste** Waste produced by demolition and building activities, including road and rail construction and maintenance, and land excavation associated with construction activities	

Unlike with general waste, the definition of C&D waste in the various jurisdictions is not straightforward. C&D waste is simply defined in the *2018 NWP*[83] as '*waste produced by demolition and building activities, including road and rail construction and maintenance, and land excavation associated with construction activities*' (p. 17). Among the jurisdictions, only WA and NSW provide a specific definition for C&D waste in EPA-administrated Acts and regulations. Other jurisdictions refer

[83] DEE, Commonwealth of Australia, 2018 NWP. https://bit.ly/3v5zTe1

to definitions that are loosely presented in other documents such as state/territory waste strategy documents; in Tas there is no definition found for C&D waste published in any of the waste-related documents. New South Wales has provided a comprehensive definition in which a broad range of C&D activities and materials specifications are covered, as well as their potential environmental impact. Western Australia's definition provided a concise statement that only includes three types of construction activities.

There are fundamental inconsistencies even in the definitions enshrined in non-legislative documents. The main differences found include exclusion/inclusion of clean fill (for example, soil and rock used for land rehabilitation), source of waste (for example, building, refurbishing, renovating or demolishing) wording (for example, construction (building) and demolition) and exclusion/inclusion of some materials (for example, glass, plastic) and certain contaminants. It seems that two authorities, in SA (Green Industries SA) and Vic (Sustainability Victoria), manage their activities based on the same definition. Unlike the definition of general waste, the *2018 NWP* does not exempt re-use material from being waste. However, it makes sense that practitioners tend to refer to a broader definition.

2.2.2 Definition of clean fill

The other inconsistency found among jurisdictions is the definition provided for clean fill. Clean (waste) fill comprises uncontaminated (reprocessed) soil, sand or rock produced during excavation and used to level-off construction sites prior to construction. In Qld, this material is not considered as a waste. Therefore, its re-use would not be recognised as waste disposal and there is no liability for landfill levy. However, in other jurisdictions this material is still regarded as waste. Some jurisdictions have not established a clear definition for clean fill (the ACT, NT and Vic); moreover, among those that have, the definitions differ. There is a need to harmonise this definition in case other jurisdictions decide to exclude it from their waste definition. Clean fill is termed as 'waste fill' in SA, 'clean earth' or 'clean earthen material' in Qld, and 'virgin excavated natural material' in NSW. Table 19 shows any available definitions for clean fill in the study jurisdictions.

Table 19. Definition of clean fill

	Legislation
NSW	***Protection of the Environment Operations Act 1997 No. 156*** 'Natural material (such as clay, gravel, sand, soil or rock fines): (a) that has been excavated or quarried from areas that are not contaminated with manufactured chemicals, or with process residues, as a result of industrial, commercial, mining or agricultural activities and (b) that does not contain any sulfidic ores or soils or any other waste and includes excavated natural material that meets such criteria for virgin excavated natural material as may be approved for the time being pursuant to an EPA Gazettal notice'
Qld	***Environmental Protection Act 1994*** Clean earthen material means – (a) either of the following, if pulverised so that no piece has any dimension of more than 100 mm – (i) bricks, pavers or ceramics; (ii) concrete that does not have any steel-reinforcing rods embedded in it; or (b) clean earth **Environmental Protection (Waste ERA Framework) Amendment Regulation 2018** Clean earth means any natural substance found in the earth that is not contaminated with waste or a hazardous contaminant. Examples: clay, gravel, loam, rock, sand or soil
SA	**Environment Protection (Fees and Levy) Regulations 1994** Waste consisting of clay, concrete, rock, sand, soil or other inert mineralogical matter in pieces not exceeding 100 mm in length and containing chemical substances in concentrations (calculated in a manner determined by the Authority) less than the concentrations for those substances set out in Schedule 6 but does not include waste consisting of or containing asbestos or bitumen
Tas	***Environmental Management and Pollution Control Act 1994*** Means fill, including soil, rock, concrete, bituminised pavement and similar non-putrescible and non-water-soluble material that is not contaminated by other waste and that does not contain contaminant

	levels exceeding limits set by the Director
WA	**Landfill Waste Classification and Waste Definitions 1996 (as amended 2018)** Material that will have no harmful effects on the environment and which consists of rocks or soil arising from the excavation of undisturbed material. Virgin excavated natural material (for example, clay, gravel, sand, soil and rock), or such material that is mixed with: waste that has been excavated from areas that are not contaminated as a result of industrial, commercial, mining or agricultural activities, with manufactured chemicals, and does not contain sulfidic ores or soils (for example, acid sulphate soils and peats), or materials not from a 'clean excavation' that have been validated to meet relevant ecological investigation levels For material not from a clean excavation, it must be validated to have contaminants below relevant ecological investigation levels (as defined in the document Assessment Levels for Soil, Sediment and Water, Department of Environment, 2003)

As evidenced above, the range of definitions is wide and each one refers to locally produced guidelines that determine the permissible level of contamination. Among the jurisdictions, WA and SA have published specific documents in which the definition of waste is stipulated in detail. In WA, the Landfill Waste Classification and Waste Definitions 1996 (as amended 2018) document clarifies the waste to be accepted at landfill under the *Environmental Protection Act 1986*. In SA, the Waste Guideline provides definitions for a range of terms commonly used within the waste industry which are sourced from EPA regulations and publications.

There are several other issues with inconsistent language used in C&D waste management regulations that have been identified in previous studies. Inconsistent definitions and terminologies create regulatory and administrative burdens for those who operate across jurisdictional borders. They can be interpreted differently, as C&D waste can be defined or classified differently in different jurisdictions. Consequently, it is difficult to develop a domestic market to trade C&D waste materials among jurisdictions. It is also seen as a barrier to the national comparison of waste management practices. A standardised terminology is crucial for managing, monitoring and collecting data, and for national and international reporting. The use of inconsistent language can contribute to data gaps and data bias, making it difficult, if not impossible, to aggregate and report jurisdictional waste data[2].

On the other hand, a clear and uniform definition of C&D waste will promote investment in recycling facilities, the circular economy and development of the domestic market.[84] It may also assist in the uniform adoption of waste minimisation strategies among authorities. These strategies are largely developed according to the *2018 NWP*[83], which is limited in its effectiveness by the varying extents to which local authorities regulate waste management activities across Australia. Through a common language, a range of jurisdictions can take advantage of shared information[85] that can be used to evaluate the performance of enforced legislation, strategies, policies and standards.

2.3 Waste classification

One of the differences in the operation of landfill facilities is the method through which the incoming waste is classified, accepted or treated. Similar to the waste definition, the way that waste is classified has a significant impact on many aspects of waste management. Classifications are used to determine waste treatment and disposal methods, and to grant permits and licences for landfill sites and recycling facilities. In the 1990s, some attempts were made to create uniform waste classification systems across Australia by developing a National Waste Classification system under the Australian Waste Database (AWD) project that was commissioned by the Department of

[84] Serpo, A. 2018. Harmonisation avoids 'perverse' outcomes. Interview with Waste Management Review. URL: https://bit.ly/3v6gaek
[85] SKM. 2012. Review of Australia's International Waste-related Reporting Obligations, p. 4.

Agriculture, Water and the Environment (formerly the DEE)[86]. However, the project was not successful, and an effective waste system was not developed. The main issues with the AWD were reported to be wrong assumptions underpinning the project and resistance from key stakeholders. Later on, some consulting companies were tasked with conducting requirements studies to revitalise the AWD objectives[82,87,88]. None of these studies have resulted in the formation of the AWD or a waste classification system at present.

Currently, the *2018 NWP* and the Draft National Solid Waste Classification System both advocate a classification that is based on three main streams: C&D, C&I and MSW. Yet this classification has not been used in waste-related regulations in some jurisdictions, with other criteria (for example, properties and the level of risk they may impose) used to classify waste instead.

In the ACT, waste classification is risk-based and has two main categories: liquid and non-liquid waste. C&D falls under 'inert' waste, which is one of the four subcategories of non-liquid waste (inert, solid, industrial and hazardous). In NSW, authorities took a risk-based approach, developing six categories with different levels of risk and subsequently considering waste's physical and chemical properties. C&D waste falls within general solid waste (non-putrescible). The NSW EPA has published a two-part guideline to classify different waste using multiple criteria for general waste and hazardous waste. In Qld, the new classification system (which came into effect in February 2019) takes a risk-based approach and C&D waste is under non-regulated waste (lowest risk). Similarly, in NT, C&D waste is grouped as 'inert waste', which is one of the three main categories of waste classification (putrescible waste, inert waste and listed waste). In the SA and Tas systems, there are five types of waste, wherein C&D waste has a separate category; the category of C&D in SA has two subcategories (inert and mixed). In Vic, waste classification is primarily based on source and properties, and then risk level (municipal, industrial and prescribed waste); C&D waste is under industrial waste. In WA, the system is designed to serve landfill purposes and C&D falls within Class I (landfill inert). As noted above, currently there are different classification systems established in each of the jurisdictions. These different systems are carefully applied to cover various waste pathways including collection, transport, treatment, recovery and disposal. Moreover, different authorities may have different classification systems in place. For instance, in Vic, the classification system being used by Sustainability Victoria is different from that which is recommended and operated by EPA Victoria. Sustainability Victoria follows the *2010 NWP* classification, which is different from the three categories proposed by EPA Victoria[9]. EPA Victoria has published a guideline (Industrial Waste Resource Guidelines Waste Categorisation), in which the categorisation system in Vic is detailed.

C&D waste may also include hazardous materials such as asbestos that need to be separately managed and disposed of. However, the hazardous waste in relevant regulations is differently designated. For instance, the term for this type of waste is 'regulated waste' in Qld, 'listed waste' in SA and NT, 'controlled waste' in Tas and WA, and 'prescribed industrial waste' in Vic. Among the jurisdictions, NSW,[89] NT,[90] Qld,[91] SA[92] and Vic[93] have released guidelines on siting, design, operation and rehabilitation of landfills. The guidelines outline a suite of best practice management measures in the development and operation of landfills. These guidelines, through technical information, instruct landfill operators on how they can meet the environmental protection objectives of their jurisdictional regulatory framework.

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[86] Moore, S and SY. Tu. 1995. Application of the Australian waste database to regional environmental management. *International Conference on Advances in Strategic Technologies*. volume 12, p. 15.
[87] Net Balance. 2009. National Waste Data System Requirements Study. Department of the Environment, Water, Heritage and the Arts.
[88] Hyder Consulting Pty Ltd.. 2011. Australian Waste Classifications. Roles in Decision Making.
[89] EPA Environmental Guidelines: Solid waste landfills. 2016.
[90] EPA Guidelines for the Siting, Design and Management of Solid Waste Disposal Sites In the Northern Territory. 2013 – NT.
[91] Guideline ERA 60-Waste disposal-Landfill siting, design, operation and rehabilitation – Qld.
[92] EPA Guidelines Environmental management of landfill facilities 2007 – SA.
[93] EPA Guidelines Sitting, design, operation and rehabilitation of landfills. 2015. Vic.

2.3.1 When a waste ceases to become waste

In the *2018 NWP* the concept of 'a waste is not always waste' is promoted in the Waste as a Resource- the Circular Economy section. This section explains that, by applying the principles of a circular economy, Australia can support better and repeated use of its resources; the focus is on maximising the economic value of resources. According to this new way of thinking, most materials are resources that can be re-used, recycled and reprocessed over and over. The ability to redefine the output of resource recovery facilities as 'not waste' is instrumental to developing markets for those output products.

However, at the jurisdictional level, the current regulations are bound to the notion of 'once a waste, always a waste'. This is the case irrespective of the material's later use or commercial value. Indeed, as seen above, the waste definitions in Australian jurisdictions do not separate disposable waste and products that are recycled or converted to energy. According to this notion, until the material is actually re-used, it is regarded as a waste, and whether certain material is waste must be assessed at a particular point in time[94]. For instance, contaminated soil that has been processed is still waste even once it has been (re)used; that it is now 'clean' material does not stop it being waste. As a result, it must be kept, treated, transported and disposed of only in conformity with a licence from the EPAs. The definition of waste and the circumstances under which the waste and recycling industry requires a licence and is liable to pay landfill levies are the main outcomes of the current conceptualisation of waste in Australia.

Indeed, the definition in use in jurisdictions carries an inconsistency: while a waste is identified as unwanted, regardless of its value, it can potentially be a resource for the same or other purposes. This is a crucial issue that needs to be immediately addressed in the legislative framework. In fact, the way regulations consider waste at different levels of the waste hierarchy provides a platform for dealing with waste and associated costs (for example, a levy). Eventually, if properly defined and implemented, the separation between waste and resources will determine the quantity of waste sent to landfill. This, in turn, can reduce the amount of new materials extracted and will largely mitigate the environmental risks created along the chain. An example of the consequences of not addressing this issue is evident in the case of Eclipse Resources Pty Ltd (Eclipse) in WA, which became liable to pay approximately $21.6 million in backdated levies, in 2017[95]. The Supreme Court ruled against Eclipse's assumption about clean fills and recycled materials received and accepted for burial not being 'waste' but resources (for re-use purposes). Further, the court determined that, technically, the definition of waste remains valid when it is unwanted by or excess to the needs of the source of that material',[96] regardless of its later use. Despite the court's ruling, according to a piece of legislation[97] in WA, a licensee may by application claim an exemption from levy regulations for uncontaminated soil or other clean fill under some conditions specified in the legislation. Such rulings are a serious deterrent for industries in terms of recycling material; instead it makes them resort to disposing of material at licensed landfill facilities to avoid liability for significant levies.

In Europe, turning waste into a resource by 2020 is one of the key objectives of the EU's Roadmap to a Resource Efficient Europe. Furthermore, when waste ceases to be waste largely depends on the definition of waste. The only definition of waste that does not consider waste to always be waste is provided by the *2018 NWP*, which distinguishes waste from resource: '*Materials and products that are re-used (for their original or another purpose without reprocessing) are not waste because they remain in use*". Table 20 provides a summary of this issue in the jurisdictional legislative frameworks. In addition to the review of legislation, other waste-related documents are reviewed, as they are

[94] WA Department of Water and Environmental Regulation. 2017. Factsheet - Assessing whether material is waste. https://bit.ly/3tAyLid
[95] The Western Australian Jurist – Vol 8. 2017. When is waste a waste? pp. 201-224.
[96] Eclipse Resources Pty Ltd v The Minister for Environment [No. 2} [2017] WASCA 90.
[97] Waste Avoidance and Resource Recovery Levy Regulations. 2008 – WA.

assumed to contribute to developing and upgrading (new) legislation that has a different perspective about when waste is a resource.

Table 20. When a waste is not waste

	Objectives and Strategies
ACT	***Waste Management and Resource Recovery Act 2016*** A waste is always waste regardless of its value ***ACT Waste Management Strategy 2011–2025*** The strategy recognises waste as a resource. Deriving value from waste resources requires innovations by government and industry in order to transform waste into valuable product=
NSW	***Protection of the Environment Operations Act 1997 No. 156*** Regulations may provide for the exemption of specified wastes from the calculation of contributions (including, for example, wastes that are recycled, re-used, recovered or processed) for landfill owners ***NSW Waste Avoidance and Resource Recovery Strategy 2014–21*** A waste is always waste regardless of its value
NT	***Waste Management Strategy for The Northern Territory 2015–2022*** ***WMPC Act 1998*** A waste is always waste regardless of its value
Qld	***Environmental Protection Act 1994 / Waste Reduction and Recycling Act 2011/*** **WRR Act 2011 Guideline: End of Waste** A waste can be approved as a resource if the department considers that it meets specified quality criteria for its specific use ***Queensland's Waste Reduction and Recycling Strategy 2010–2020*** A waste is always waste regardless of its value
SA	**Environment Protection Regulations 2009** Under Part 2: waste depot levy, landfilling 'waste fill' is exempted from depot levy. ***Environment Protection (Waste to Resources) Policy 2010*** Provides a mechanism by which a waste that meets specifications or standards published or approved in writing by the EPA will be considered a product (instead of a waste) ***South Australia's Waste Strategy 2015–2020*** A waste is always waste regardless of its value
Tas	***LGAT Waste and Resource Management Strategy 2017*** **Environmental Management and Pollution Control (Waste Management) Regulations 2010** A waste is always waste regardless of its value
Vic	***Environment Protection Act 1970 Version No. 172*** A waste is always waste regardless of its value
WA	***Environmental Protection Act 1986*** A waste is always waste regardless of its value ***Waste Avoidance and Resource Recovery Strategy 2030*** Principle (5) Waste as Resource: WA will adopt and implement the waste hierarchy, avoiding the generation of waste where possible, maximising the recovery of waste that is generated and protecting the environment from the impacts of disposal. It recognises that some level of waste generation is unavoidable and so encourages a circular economy approach, where any waste that is generated is valued as a resource that can be re-used or recycled for the benefit of the WA economy

The results of the review of strategies and regulations shows that, aside from Qld, NSW and SA, other jurisdictions have largely not adopted the *2018 NPW* notion (waste as a resource). In Qld, under the *Waste Reduction and Recycling Act 2011* (Chapter 8), the End of Waste[98] framework is proposed to promote resource recovery opportunities and aims to shift the common perception from 'waste is always waste' to it being valued as a resource. Accordingly, in this state, waste ceases to be waste when, in accordance with the 'end-of-waste code' or 'end-of-waste approval', it stops being waste and becomes a resource. This framework replaced the Beneficial Use Approval framework to increase business opportunities for waste generators, waste processors and business

[98] Waste Reduction and Recycling Act. 2011.

receiving recovered material from within Qld. Furthermore, there is a discount for the residue waste levy fee; this encourages waste recycling throughout the state.

Although in other states the common perception is in favour of 'once waste is always waste', regulations are set in a way that exceptions are provided to encourage less waste disposal. In SA, disposal of 'waste fill' is exempted from the landfill levy program; the government also fixed the solid waste levy applicable to shedder floc (waste residue from metal recovery) disposal at $62 (instead of the standard rate of $76 per tonne).[99] This discount has made C&D waste recycling more cost-effective. In NSW, the definition of C&D waste excludes excavated soil that is to be used for levelling off the site prior to construction. In these states, regulations exempt certain waste (that is, wastes that are recycled, re-used, recovered or processed) from the calculation of contribution. In Vic, waste generators are entitled to an annual rebate on the levy for waste that has been lawfully recycled, reprocessed or recovered. Likewise, NSW provides for rebates on recyclable materials that are lawfully removed from a licensed facility.

In WA, operators can apply for an exemption for recyclable materials.[100] The Department of Water and Environmental Regulation receives occasional requests to 'approve' the use of these materials in certain circumstances. Western Australia's former DWER developed a framework (End-of-waste: 2014-16) to deal with the issues related to waste and resource. This framework consisted of several policies that would guide industry in relation to decision-making process within the department in regards to waste and resource. However, the framework was suspended for review, as it did not provide legal certainty/defence for industry using waste-derived materials. The decision of Justice Beech in the Eclipse case also weakened its position in the department's decision-making process.[24]

Currently, the prevalent approach in WA is more inclined towards considering waste from the point of view of the person who is the source/producer of the material and not the receiver of the material.[101] Indeed, the fact that the receiver of the material considers it useful and economical does not mean that the material is not waste. Recently, an interesting fact sheet was published by DWER[102] which provides further and promising information on how the department proposes to assess whether material is waste when exercising its powers and performing its functions under the relevant legislation. The factors considered in this decision include 'the nature of the material', 'concept of unwanted', 'payment relating to the materials' and 'sustainability transformed'. Under the 'concept of unwanted', it is noted that material wanted by its producer/source for use in some other project or for sale to another person is not considered to be waste. Payment is a factor that indicates whether a material being traded is a waste or not. According to this factor, if the producer of material pays a third party to receive it and dispose of it for them, this indicates that the producer does not want the material and it is waste. However, if material is sold by a producer to a third party, this will generally indicate that the material is a valuable commodity wanted by the producer for sale. The quality of transforming a waste into a product and the extent of the transformation or conversion is another consideration in this fact sheet. It is stipulated that a mere intent to convert waste into a product or good is not sufficient.

The results of this review of relevant legislation shows that Australian jurisdictions need to collaborate with national organisations to reflect the concept of 'waste is not always waste' in their regulations. In this regard, waste strategy documents across Australia need to take a more active approach to promoting this concept within authorities, the waste and recycling industry, and the wider community.

2.3.2 Waste Recycling Residuals

[99] Government of Australia. 2018. South Australia's Recycling Activity Survey 2016-17 financial year report.
[100] Waste Reduction and Recycling (Waste Levy) and Other Legislation Amendment Bill 2018, Explanatory note, p. 9.
[101] WA Department of Water and Environmental Regulation. 2019. Waste not, want not: valuing waste as a resource: Issue paper.
[102] WA Department of Water and Environmental Regulation. 2017. Factsheet - Assessing whether material is waste. https://bit.ly/3grge46

Currently, under all jurisdictional regulations the residuals of waste recycling facilities are considered as waste and thus the facility owners are liable to a landfill levy. However, there are requests from the construction and waste and resource recovery industries to change the fact that these residuals are still considered as waste in relevant regulations. Many think that a levy on the disposal of recycling residuals reduces the competitiveness of materials sold into the international market. Furthermore, the disposal of residuals generally represents a significant cost for recycling facilities, which can obviously create commercial incentives to seek lower disposal cost options. It also justifies transport waste to interstate locations with a lower disposal rate.

2.4. Waste data management

Accurate C&D waste data collection and reporting underpin and inform efforts, and decisions aim to devise a consistent approach to defining and measuring C&D waste. Consistent and updated reporting can make it much easier to manage the C&D waste and resource market. According to Strategy 14 of the *2018 NWP* 'Market Development and Research', 'all Australian governments and businesses generate and report information to support creating and maintaining markets for recycled materials, both domestically and internationally'[83]. Waste data is critical to well-targeted, evidence-based and planned waste projects and programs. Data on waste generation, landfill and resource recovery is also essential to the development and implementation of waste policies and programs. Up-to-date and consistent data is also required to understand the current state of waste and recycling. Historical data allows current performance to be plotted against prior performance and meaningful, achievable and realistic targets to be set. Historically, C&D waste data collection in Australia was found to be indicative rather than accurate and considered to be questionable in terms of transparency, comparability, accuracy, completeness, clarity and timeliness[103].

Waste data collection methods vary by jurisdiction and material type. In the NT and Tas, no waste data is collected and establishing a platform to collect the data remains a priority. In the ACT, there is no established method to collect data and improved data gathering capability has been recommended to facilitate effective management of waste[104] in the territory. Since 2017, with the commencement of a new Act,[105] however, the ACT has made it a requirement for waste businesses to report their activities quarterly. In four other jurisdictions (NSW, Qld, SA and Vic), robust data systems serve to systematically collect and analyse waste data. Table 21 shows the waste data collection systems rolled out in these jurisdictions.

Table 21. Waste data systems in different jurisdictions

Program	Function

[103] Net Balance. 2009. National Waste Data System Requirements Study.
[104] ACT Government. 2018. Waste Feasibility Study Roadmap and Recommendations – Discussion Paper.
[105] Waste Management and Resource Recovery Act 2016 – ACT.

NSW	Waste and Resource Reporting Portal (WARRP)	An online reporting tool designed to facilitate the submission of the Waste Contribution Monthly Report. All licence holders of levy-liable waste facilities must submit the following reports to the NSW EPA: waste contribution monthly report, landfill facility information certificate and volumetric survey report. https://warrp.epa.nsw.gov.au/
Qld	Queensland Waste Data System (QWDS)	A web-based system for operators to report on their waste data returns and the Annual Waste Survey. The system allows for the expanded capture of information about waste disposal and resource recovery. The QWDS provides a streamline reporting system for private and local government waste managers – replacing spreadsheets and third-party online survey sites previously used to collect data. In addition, the QWDS provides all the functionality required to transition to the system – which allows for more robust online data collection and reporting. (https://www.Qld.gov.au/environment/pollution/management/waste/recovery/data-reports/qwds)
SA	Zero Waste Environment User System (ZEUS)	A web-based system developed by Green Industries SA to facilitate the monitoring, analysis and reporting of waste reduction targets in SA. ZEUS collects information on: recycling activity; waste (tonnes) to landfill by waste stream (MSW, C&I and C&D); litter; economic and environmental costs and benefit; infrastructure needs; and areas needing regulatory underpinning.
Vic	Waste Data Portal (WDP)	The WDP developed by Sustainability Victoria to collect and store waste and recycling data from a number of sources and regularly produce statewide waste, recycling and litter data reports. The portal aims to strengthen and standardise existing waste and resource recovery data in Vic, introduce new data as necessary and improve collection and sharing of data in Vic between state and local governments and industry. https://www.sustainability.Vic.gov.au/Government/Victorian-Waste-data-portal

The systems tabulated above have definitely had a positive impact towards achieving jurisdictional waste strategies. In 2016, the NSW EPA provided a user guide[106] for its data management system (WARRP). This guide, through step-by-step navigational instructions, helps different stakeholders register and monitor data associated with waste management throughout the state. Particularly, landfill site owners and recycling facilities operators can use it for their obligatory waste data submissions. In Vic, one product of the WDP project is an interactive waste data map in which information is presented by year and material type for different regions of Vic. The main data collection methods in Australia are annual survey (NSW, Vic and WA) and annual reporting (Qld and SA). The other discrepancy is the data collection mechanism that determines the obligatory or voluntary nature of data reporting. Local government waste data collection is voluntary in NSW, Vic and WA; it is obligatory in Qld and SA.

Despite the progress made in the field of waste data collection in some jurisdictions, the challenge of aggregation of individually collected waste continues to be the main concern at the national level. If properly merged, these systems will provide useful information that can lead to the development of a national approach in management of general waste as well as C&D waste. It would also assist Australia to measure its performance against other countries. As previously mentioned, there have been some unsuccessful efforts to form a national waste database under the AWD projects in the 1990s. This is a challenging task, as it requires standardisations in collecting, processing and reporting data methods in various jurisdictions. The other main issues were found to be costliness and difficulty of data collection activities, followed by inconsistent classification systems, data source incomprehensiveness and inability to separate waste streams, and the like.[107] However, in 2009, the then federal DEE commenced the development of a national waste data system, which was later complemented with a 'method report' that describes what data would be collected and how it would be transformed. This work was furthered with a procedural document describing the whole

[106] NSW Waste and Resource Reporting Portal (WARRP) User Guide. 2016.
[107] DEE. 2018. National Waste Report 2018, p.5.

process, and a revised method was developed and agreed by all jurisdictions in 2015. The revised method included a Microsoft Excel tool that implements the agreed method. Despite these efforts, the national waste data system has not been launched, due to disapproval of the required budget. Instead it was confined to the release of a biannual national waste data report.

2.5. Recommendations

2.5.1. State-specific reforms

Following a review of the waste-related legislative and non-legislative documents in the eight jurisdictions of Australia, some reforms are suggested to address the inconsistencies among them regarding definition of waste and resource in the study of waste management systems. While some of the reforms below are specifically recommended for one jurisdiction, there are some recommendations that apply to more than one jurisdiction.

These recommendations primarily emerge from the following sources:

1) Review of national jurisdictional legislations.
2) Review of jurisdictional waste strategy documents.
3) Review of national and jurisdictional reports, consultation and review drafts, submissions to the Senate Environment and Communications References Committee.

It is expected that these recommendations will be further informed by responses to a survey we have designed to capture various aspects of C&D waste management. Almost all these recommendations can be incorporated in jurisdictional legislations and their benefits can be achieved when they are supported in primary legislation and subordinate regulations.

1) Amend waste definition to exclude clean fill and uncontaminated material to ensure continuous re-use and recycle of C&D waste in land rehabilitation projects in NSW.
2) Amend the licencing regime in relation to levies to exclude clean fill, uncontaminated materials and recycled C&D waste for re-using purposes, and exempt recycling facility operators who receive and accept waste for burial from paying levy fees in the ACT, Qld, SA, Vic and WA.
3) Exclude activities that facilitate environmental rehabilitation and remediation from the requirement to obtain a licence in the NT, NSW and Qld.
4) Introduce a uniform C&D waste definition in primary and secondary legislation in the ACT, NT, Qld, SA, Tas and Vic.
5) Offer a discounted disposal levy rate for residual waste produced as a result of C&D waste recovery and recycling to make these practices more cost-effective for waste generators in the ACT, NSW, Tas, Vic and WA.
6) Provide a clear process for determining licence requirements or exemptions based on environmental risk in the NT.
7) Provide a legal definition for 'clean fill' and guidelines that determine the accepted level of contamination in the ACT, NT, Vic and WA.

2.5.2. Nationwide reforms

Similar to the reforms provided for each jurisdiction, there are certain suggestions that can result in improved management of C&D waste nationally. These suggestions are based on previous reports, including submissions to the Senate's Standing Committee on Environment and Communications 2018 and a review of the regulatory framework in Australia. Due to their complex nature, these suggestions can only be implemented through coordinated decision-making processes supported by all states and territories. To achieve this, environment ministers at all levels of government should meet regularly to reach an agreement in principle.

1) Align the classification used for reporting purposes and landfilling activities to remove inconsistencies.
2) Provide consistency in resource exemptions and separation between ‘source’ and ‘waste’, to remove confusion in the definition of general waste and C&D waste provided by the *2018 NWP* on exemption of re-use of materials from being waste.
3) Provide uniform reporting of waste data to better aggregate and report waste data. The first step is for the Australian Government to implement the 65 agreed improvements to the *National Waste Report 2018* as established by Blue Environment Pty Ltd’s *Improving National Waste Data and Reporting* report.
4) Establish a robust and consistent national waste data management system that is obliged to improve assessment of outcomes of projects, policies, laws and business transactions in different jurisdictions.
5) Provide consistent guidelines for waste auditing that are applicable throughout Australia.

3. Economic Factors and Drivers That Govern the C&D Waste Management

3.1 Introduction

This section aims to address the third objective of this research project, which is to identify the economic barriers and enablers that govern C&D waste re-use and recovery in Australia and elsewhere. Several research studies have argued that market-based instruments should inform C&D waste management. These instruments, which include incentives and penalties, help companies, organisations and individuals to change their behaviour in dealing with waste. The economic factors in this review are clustered within three main categories: prevention, enforcement and encouragement. Many past studies have demonstrated that an integrated and effective waste management system should consist of these three components. In Australia, much focus has been put on enforcement, except in Tas and the ACT, and the other two categories have not been well developed. Thus, this review attempts to provide examples, where available, of the development and practice of these two components in other countries. While these examples have been successful in some countries, the same practices have proved less successful in other countries.

3.2 Enforcement

Currently, enforcement in Australia is imposed through three common practices: levies for landfilling, penalties on illegal dumping activities and the proximity principle. However, as discussed before, these three mechanisms are not consistently enforced across the states and territories of Australia. While the literature consistently confirms the positive impact of penalties on illegal dumping and stockpiling on market development for salvaged and recycled C&D waste, the effectiveness of landfill levies and the proximity principles seem to be more debatable. The following sections provide insight into the experience of Australia and other countries in enforcing a landfill levy on C&D waste.

3.2.1 Landfill levies

The approach to taking advantage of a landfill levy is not straightforward due to the role of varying factors in the effective management of waste. While in some circumstances a landfill levy is the best economic driver, it can act as a disincentive in other circumstances. In the literature, conflicting results are reported in response to the imposition of a landfill levy, both in domestic and international contexts. The mechanism and other characteristics of imposing a landfill levy in different Australian states and territories have been stated previously [Error! Bookmark not defined.]. In this section, the relevant literature is reviewed to understand the impact of this enforcement mechanism in Australia and elsewhere. In the first part of this section, worldwide evidence regarding the effectiveness of this mechanism is provided; the second part discusses the findings that show how landfill levies are perceived in Australia.

3.2.1.1 Part I: Effectiveness; worldwide experience:

From 1987 to 1993, the waste levy enforced in Denmark resulted in a C&D waste reduction of 64 per cent108. In the Netherlands, it was reported that, since the introduction of the landfill levy in 1995, until the time of the report (2003), the amount of landfilled waste decreased by almost three times109. In the UK it was found that, unlike in the case of municipal and C & I (1994-2000), the tax levy had a positive impact on C&D waste stream minimisation110. This status was later questioned through a study111 in which the authors claim that the landfill levy and other fiscal measures are yet to have seriously reduced the amount of waste production. However, this claim was not confirmed

108 Andersen, M.S., 1998. Assessing the effectiveness of Denmark's waste tax. Environment: Science and Policy for Sustainable Development, 40(4), pp.10-15.

109 Bartelings, H., van Beukering, P.J.H., Kuik, O.J., Linderhof, V.G.M., Oosterhuis, F.H., Brander, L.M. and Wagtendonk, A.J., 2005. Effectiveness of landfill taxation.

110 Martin, A. and Scott, I., 2003. The effectiveness of the UK landfill tax. Journal of Environmental Planning and Management, 46(5), pp.673-689.

111 Osmani, M., 2012. Construction waste minimization in the UK: current pressures for change and approaches. *Procedia-Social and Behavioral Sciences*, 40, pp.37-40.

by subsequent studies. For instance, in 2015 a study indicates that the landfill tax is a major driver for adopting waste management strategies among construction profiles. The same study also calls for the development of more viable options to the landfill levy that can cover the design stage. One of the participants in this study emphasised the positive role of the landfill levy and maintained that:

> *'With almost yearly increases in landfill tax, more people are finding alternative solutions. If the trend continues, waste landfilling could become something of the past, especially as money almost matters".* (p. 110).

This result refers to the fact that the construction industry is largely driven by financial gain. In *Hong Kong*, the results of a 3-year levy scheme (2006-2008) demonstrated that C&D-specific waste levy taxes can influence the construction industry's behaviours regarding C&D waste, resulting in a significant reduction in solid waste disposal[112]. It is reported that C&D waste reduced by 60 per cent in landfills, and by about 23 per cent and 65 per cent in public fills and total waste respectively. Another study[113] reported that the tax levy is one of the most effective C&D waste policies in the reduction of waste disposal at landfills. Despite such evidence, a more recent study[114] in Hong Kong found that there is no c From 1987 to 1993, the waste levy enforced in Denmark resulted in a C&D waste reduction of 64 per cent.[115] In the Netherlands, it was reported that, since the introduction of the landfill levy in 1995 until the time of the report (2003), the amount of landfilled waste decreased by almost three times.[116] In the UK it was found that, unlike in the case of MSW and C&I (1994–2000), the tax levy had a positive impact on C&D waste stream minimisation.[117] This status was later questioned through a study[118] in which the authors claim that the landfill levy and other fiscal measures were yet to have seriously reduced the amount of waste production. However, this claim was not confirmed by subsequent studies. For instance, in 2015 a study indicates that the landfill tax is a major driver for adopting waste management strategies among construction profiles. The same study also calls for the development of more viable options to the landfill levy that can cover the design stage. One of the participants in this study emphasised the positive role of the landfill levy and maintained that:

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[112] Hao, J.L., Hills, M.J. and Tam, V.W., 2008. The effectiveness of Hong Kong's construction waste disposal charging scheme. *Waste Management & Research*, 26(6), pp.553-558.

[113] Lu, W. and Tam, V.W., 2013. Construction waste management policies and their effectiveness in Hong Kong: A longitudinal review. *Renewable and Sustainable Energy Reviews*, 23, pp.214-223.

[114] Poon, C.S., Yu, A.T., Wong, A. and Yip, R., 2013. Quantifying the impact of construction waste charging scheme on construction waste management in Hong Kong. *Journal of Construction Engineering and Management*, 139(5), pp.466-479.

[115] Andersen, M.S., 1998. Assessing the effectiveness of Denmark's waste tax. *Environment: Science and Policy for Sustainable Development*, 40(4), pp.10-15.

[116] Bartelings, H., van Beukering, P.J.H., Kuik, O.J., Linderhof, V.G.M., Oosterhuis, F.H., Brander, L.M. and Wagtendonk, A.J., 2005. Effectiveness of landfill taxation.

[117] Martin, A. and Scott, I., 2003. The effectiveness of the UK landfill tax. *Journal of Environmental Planning and Management*, 46(5), pp.673-689.

[118] Osmani, M., 2012. Construction waste minimization in the UK: current pressures for change and approaches. *Procedia-Social and Behavioral Sciences*, 40, pp.37-40.

[119] Hao, J.L., Hills, M.J. and Tam, V.W., 2008. The effectiveness of Hong Kong's construction waste disposal charging scheme. *Waste Management & Research*, 26(6), pp.553-558.

Another study[120] reported that the tax levy is one of the most effective C&D waste policies in the reduction of waste disposal at landfills. Despite such evidence, a more recent study[121] in Hong Kong found that there is no consensus view among construction professionals on the effectiveness of the tax levy; 30 per cent of respondents to this study agreed that the levy rate was not high enough to alert them about waste minimisation practices. From the literature above, it can be inferred that the evidence for the effectiveness of the levy outweighs those that underestimate its influence.

3.2.1.2 Part II: the Australian experience:

In 2011, a C&D supply chain guide[76] prepared for the Australian Government reported that many stakeholders had indicated that landfill costs (landfill operation and levies) are a significant driver for the use of salvaged and recycled C&D waste. In 2018, various respondents to the call for submissions to the Senate Environment and Communications References Committee expressed support for the continuous imposing of landfill levies (Senate Environment and Communications References Committee, 2018). The submissions highlighted that levy schemes can act as a disincentive for waste disposal. Further, they concluded that the ensuing revenue is an important source of funding for investment in waste and recycling management initiatives. Table 22 shows examples of support from different submitters:

Table 22. The evidence of the effectiveness of landfill levies in Australia

Respondents	Indicative language
WA Government	There has been a notable diversion from landfill for two waste streams (i.e. C&D and C&I) since 2011 when levy rates were considerably increased.
Re.Group (http://www.re-group.com/)	NSW's relatively high recovery rate for two waste streams (C&D and household waste) has been driven by the landfill levy.
SA Government	A progressive increase in waste recovery (reduction in waste disposal) has been concurrent to the continuous increase in levy fees; the increase was more than 20% in 2015-16 (81.6%) compared to 2003-2014 (60%).
WALGA	There is evidence that the landfill levy has been responsible for diverting inert material from the landfill; however, it is not known where this waste is being diverted.
Envorinex (https://envorinex.com/)	Landfill levies should be priced high enough to encourage major businesses to send their waste to recyclers and not to landfill sites.

Source: Senate Environment and Communications References Committee (2018)

In addition to the support from the submissions to this committee[49], there are some concerns about the unintended consequences that emerge from the improper design of levy schemes. These concerns express that the jurisdictional legislation levy should not give rise to unintended outcomes such as interstate waste transfer because of cost disparity, discouraging private investors from investing in recycling infrastructure, high administrative costs corresponding to the application of complex schemes and stockpiling and illegal dumping.

3.2.2 Illegal dumping penalty

Illegal dumping and stockpiling are seen as disincentives toward waste recovery. Multiple submitters to the Senate Environment and Communications References Committee (2018) indicated that, in order to remove the unintended negative outcomes of a landfill levy, the government should do

[120] Lu, W. and Tam, V.W., 2013. Construction waste management policies and their effectiveness in Hong Kong: A longitudinal review. *Renewable and Sustainable Energy Reviews*, 23, pp.214-223.

[121] Poon, C.S., Yu, A.T., Wong, A. and Yip, R., 2013. Quantifying the impact of construction waste charging scheme on construction waste management in Hong Kong. *Journal of Construction Engineering and Management*, 139(5), pp.466-479.

more to stop illegal waste disposal. The current regulatory environment for illegal dumping in the different states and territories of Australia is provided before.

3.2.3 Proximity principle

This principle requires waste generators to send their waste to a facility that is located in a certain perimeter of origin. Several submissions to the Senate Environment and Communications References Committee (2018) argued that the proximity principle (PP) can assist in preventing movement of waste between jurisdictions for the purpose of avoiding and minimising levy liabilities.

3.3 Prevention

There are several economic-based strategies to prevent waste generation prior to, during and after construction. These strategies include EPR and similar schemes, 'cradle-to-cradle approach' and 'tax on the use of raw materials'. If implemented fully, it is expected that these mechanisms can have a strong influence on C&D waste generation.

3.3.1 Extended producer responsibility

EPR is found to be a successful market-based policy approach that has been applied to different waste types and streams[122] (Hanisch, 2000). Technically, EPR makes manufacturers responsible (financially and/or physically) for the entire life cycle of their products during the supply chain of materials including design, manufacture, recycling and final disposal (OECD, 2016). EPR provides an opportunity to divert additional waste away from landfills for re-use and recovery. EPR has been recognised as an incentive for producers to take into account environmental considerations when designing their products, resulting in preventing waste at the source through better product design (Senate Environment and Communications References Committee, 2018). One submission to this committee inquiry stated that generally about 70 per cent to 80 per cent of the environmental impact of a product is locked in at the design phase (Senate Environment and Communications References Committee, 2018).

These regulatory instruments enforce the price signal that ensures the entities that have the power to redesign their construction materials or to trade other materials play an active role in the management of waste produced. For this to be achieved, producers should use instruments such as design for recyclability, reduce material usage, product disassembly, reduce or eliminate the use of toxic materials, and re-manufacturability (Acree Guggemos and Horvath, 2003).

The idea of EPR originated in Germany in 1991 as a result of a landfill shortage. At the time, packaging made up 30 per cent by weight and 50 per cent by volume of Germany's total municipal waste stream.[122] To help slow down the filling of landfills, Germany created a law, the German Packaging Ordinance, that required manufacturers to be responsible for their own packaging waste through either (1) taking back their packaging from consumers and distributors; or (2) paying the national packaging waste management organisation to collect the packaging (Shea, 1992). The formal introduction of this terminology, however, was made by Thomas Lindhqvist in Sweden, in 1990 (Lindhqvist and Lidgren, 1990) in a report to the Swedish Ministry of the Environment. Other variations of EPR are Product Take Back (PTB), PS and Polluter Pays Principle (PPP). Table 23 provides a summary of the description of various types of EPR schemes.

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[122] Hanisch, C. 2000. Is extended producer responsibility effective? *Environmental Science & Technology*, 34, 170A-175A.

Table 23. Description of various EPR programs

Name	Description
PPP	In this program, producers are recognised as responsible for the pollution that ensues from their products.
PS	This approach acknowledges that those involved in producing, selling, using and disposing of products have a shared responsibility to ensure that those products or materials are managed in a way that reduces their impact on the environment, human health and safety, throughout their lifecycle.
PTB	In this scheme, producers are required to take back products at the end of their useful life and reuse or recycle them.

The main distinction between PS and EPR is the focus of EPR on preventing rising levels of waste and pollution, whereas shared PS initiatives primarily enforce that a producer covers a proportion of costs associated with the management of waste at the end of a product's useful life. A common example of PS is container deposit laws whereby consumers are forced to pay extra when they buy beverages in cans/bottles – the amount that can be redeemed upon returning cans/bottles. EPR is more comprehensive than PTB, as it can take three forms: as re-use, buy-back or recycling programs.

Despite the differences mentioned above, the main three objectives of EPR and its variations include pollution prevention, a decline in the extraction of natural resources and a drop in energy use for extracting and processing new materials (Fishbein, 2000, Acree Guggemos and Horvath, 2003). The implementation of EPR and similar schemes has been repeatedly mentioned as an effective policy approach in the management of C&D waste in previous studies (Duan et al., 2019, Dubois et al., 2016a, Acree Guggemos and Horvath, 2003, Zainu and Songip, 2017, Park and Tucker, 2017, Golev and Corder, 2016). Until now, there has been no universal and standard policy approach to implement and take advantage of EPR objectives for the C&D waste stream. Among different international organisations, the Organisation for Economic and Cooperation and Development (OECD), through its Working Party on Resources Productivity and Waste, has been heavily engaged in EPR activities for a long time. Furthermore, the PPP was first mentioned in the OECD's May 1972 recommendation and was reaffirmed in its November 1974 recommendation. Almost two decades later, it was laid down as Principle 16 of the UN's Rio Declaration on Environment and Development. EPR and similar schemes are new concepts for the management of C&D waste in Australia. The federal government, in collaboration with state governments, is working to develop a national EPR policy that can be applied throughout Australia.

3.3.1.1 Considerations in the development of EPR policies

The development of EPR and other similar policies is not straightforward, due to the complexities and wide range of stakeholders involved in product production, trade, delivery, consumption and waste management. Furthermore, the methods through which EPR policies are applied can vary. Several previous research studies have attempted to model these complex factors to boost the performance of EPR policies in practice. This section of results focuses on a few of these models. For instance, Dubois et al. (2016) presented five criteria for the development and evaluation of product and its ensuing waste. Figure 8 depicts these five criteria.

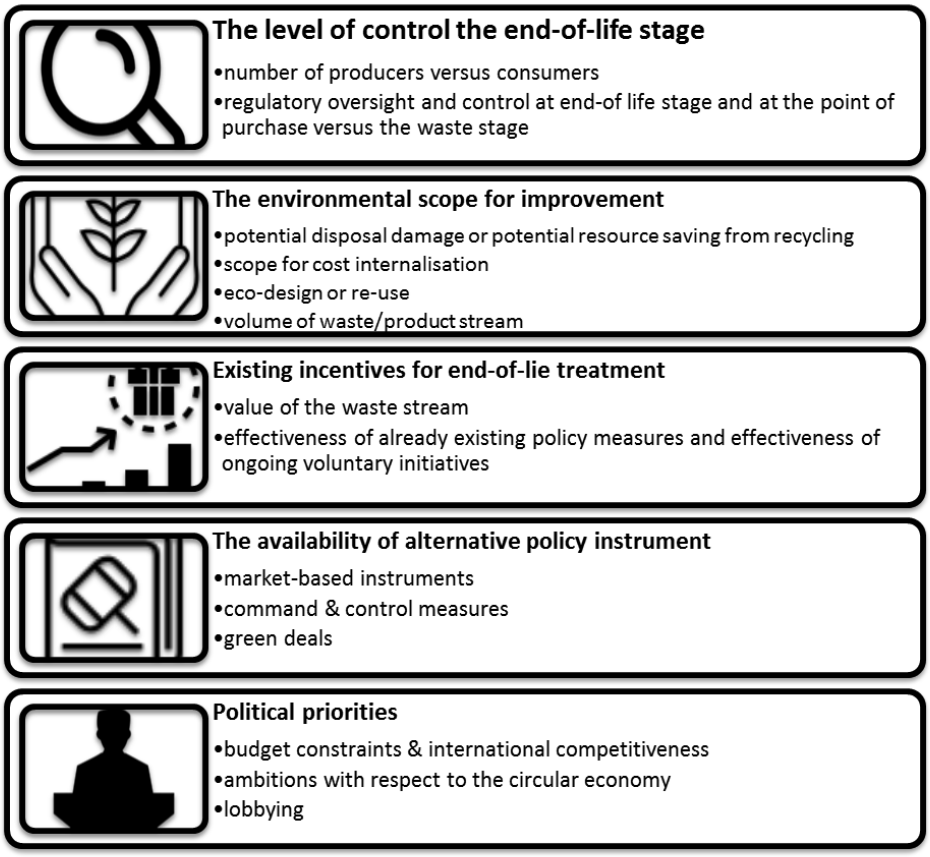

Figure 8. Five criteria that can be used for the development of EPR policy for a particular waste stream.
Source: Materials adapted from Dubois et al. (2016b)

Applying these criteria to the C&D waste stream in the Netherlands, the researchers indicated there is a motivation to implement EPR for only two criteria (for example, environmental scope and political priorities). Acree Guggemos and Horvath (2003) put forward a policy framework to better achieve EPR goals for C&D waste management. This framework, which is based on Thorpe and Kruszewska (1999) model, consists of three types of policy instruments: regulatory, economic and information-based (Figure 9).

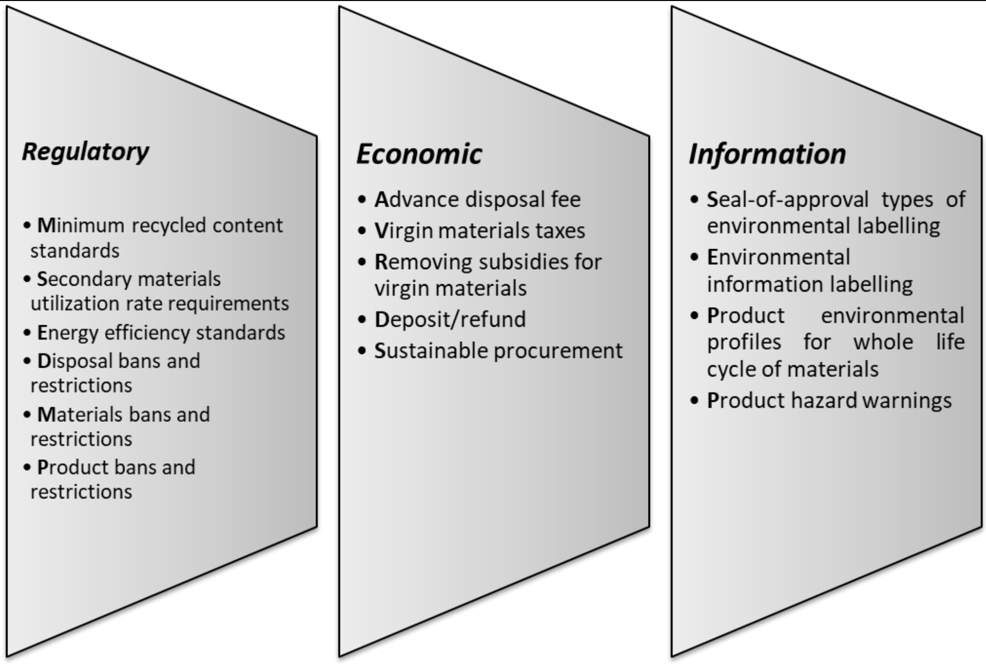

Figure 9. Three policy instruments that facilitate EPR achievement
Source: Adapted from Acree Guggemos and Horvath (2003)

In addition to the models presented in Figure 8 and Figure 9 there are other studies that have presented models with some similarities and differences (Forslind, 2005, Langrová, 2002, Nahman, 2010, Widmer et al., 2005, Lindhqvist, 2000). Furthermore, some studies investigating factors that impact EPR's performance provided useful information on how to maximise the adequacy of EPR and similar schemes for waste management. For instance, Gupt and Sahay (2015) conducted a comparative analysis on 26 case studies in developed and developing countries to identify the factors contributing to the success of EPR implementation and the main aspects of EPR development and implementation. The results revealed that the 'financial responsibility of the producers', 'separate collecting' and 'recycling agencies' significantly contribute to the success of EPR. The main aspects of EPR were also found to be 'regulatory provisions', 'take-back responsibility' and 'financial flow'. In 2016, one study on the effectiveness of various policy approaches weighted and compared different policies in Maine, US (Isenhour et al., 2016). The results showed that EPR policies are regarded as highly effective but that their acceptability is uncertain.

3.3.1.2 Regulation of EPR and other similar schemes in Australia:

There is no specific EPR-driven legal instrument for the C&D waste stream in Australia; nor are there any nationally adopted EPR regulations. However, under the *2018 NWP*, Strategy 4: Product Stewardship, the Australian Government is responsible for leading a national approach to PS. The federal government continues to work with state and territory governments and industry to consider possible PS approaches for other products. Currently, there is one PS primary legislation, the Department for the Environment and Energy (2011): the Act that is guided by the NWP. This Act provides the framework to effectively manage the environmental, health and safety impacts of products and, in particular, those impacts associated with the disposal of products. The program has 26 signatories who have committed to improving areas such as manufacturing emissions, additives and end-of-life management (Edge Environment, 2012). The Act operates through three types of stewardship: voluntary, co-regulatory and mandatory.

- **Voluntary:** Industries with government oversight can voluntarily take action to reduce the impact their products have. These schemes, which are funded and led by industry, facilitate the sustainable management of products without the need for regulation. Industry-based schemes that obtain the federal government accreditation are monitored to ensure they are achieving agreed outcomes.

- **Co-regulatory:** These schemes are the product of industry action and federal government regulation. Government sets the minimum outcomes and operational requirements, while industry has some discretion about how those requirements and outcomes are achieved.
- **Mandatory:** This imposes a legal obligation on stakeholders to take certain actions in relation to a product that leave little or no discretion on how the requirements are to be met. There are currently no fully mandatory PS schemes in place under the Act.

In 2018, the Senate Environment and Communications References Committee provided some recommendations for the federal government with respect to the implementation of PS schemes:

- PS schemes under the Act should be mandatory and such an obligation should be applied to tyres, mattresses, e-waste and photovoltaic panels.
- Extend producer responsibility under this Act through improved design.

The federal government supports the PPP through the *National Environment Protection Council Act 1994*, under Section 3.5.4 (improved valuation, pricing and incentive mechanisms section). This Act maintains that:

> *Polluter pays, i.e. those who generate pollution and waste should bear the cost of containment, avoidance, or abatement; the users of goods and services should pay prices based on the full life cycle costs of providing goods and services, including the use of natural resources and assets and the ultimate disposal of any wastes (National Environment Protection Council Act 1994 (Australia, p. 40).*

In relation to this Act, the PS schemes and regulations were developed for multiple products including e-waste (Product Stewardship (Televisions and Computers) Regulations 2011), batteries, tyres (Tyre Stewardship Australia), oil (*Product Stewardship (Oil) Act 2000*), used packaging (the Australian Packaging Covenant: co-regulatory scheme), agricultural chemicals and containers (drumMuster: voluntary scheme) and paint (National Paint Product Stewardship Scheme). The latest product list, released in 2017-18, targets 'plastic microbeads and products that contain them', 'batteries', 'photovoltaic systems', 'electrical and electronic products' and 'plastic oil containers'.

At the jurisdictional level, except for in the NT, relevant primary and secondary legislations have acknowledged the need for having EPR and similar schemes in place (Table 24). Only three jurisdictions – the ACT, TAS and SA – included the EPR definition and its principles in their relevant legislation. Among the jurisdictions, the most developed legislation occurred in Qld, NSW and WA; these states allocated at least one section detailing the requirements and circumstances under which a product is regulated or managed PR/EPR programs. In Qld, particularly, the *Waste Reduction and Recycling Act 2011* provided the relevant conditions through which an industry can be accredited to launch a voluntary PS program; it also explains how regulations and the monitoring of a PR scheme can take place.

Table 24. Regulatory framework supporting EPR and similar schemes in different states/territories

Regulation	State	Summary
Environment Protection Act 1997 *Waste Management and Resource Recovery Act 2016*	ACT	**Part 1 Preliminary** 3D-Principles applying to the Act. The principles of EPR (only in *EPA Act 1997*) and PP for the environment are enshrined in these Acts
No relevant statements in legislation	NT	N/a
Waste Avoidance and Resource Recovery Act No. 58 2001	NSW	**Part 3: Objects of Acts** (e) to ensure that industry shares with the community the responsibility for reducing and dealing with waste **Part 4: Responsibilities with respect to industry waste reduction** (15) EPR schemes (16) Regulations for implementation and operation of schemes (17) Circumstances in which schemes may be implemented (18) Priorities with respect to the implementation of schemes
Waste Reduction and Recycling Act 2011	Qld	The principles of PS are enshrined. **Chapter 4 Management of priority products and priority waste** **Part I: Responsibility/the purpose of this chapter is** (a) to encourage, and in particular circumstances to require, persons who are involved in the life cycle of a product to share responsibility **Part 2: (Objectives of Act):** (d) to ensure a shared responsibility between government, business and industry and the community in waste management and resource recovery **Part 3: PS schemes** Division 1: PS schemes generally Division 2: Accreditation of voluntary PS schemes Division 3: PS schemes by regulation Division 4: Monitoring of schemes
Environment Protection Act 1993	SA	**Part 2: Objects of Act/10-vi**: allocate the costs of environment protection and restoration equitably and in a manner that encourages responsible use of, and reduced harm to, the environment, with polluters bearing an appropriate share of the costs that arise from their activities, products, substances and services
Environmental Management and Pollution Control Act 1994	TAS	**Part 2: Objectives of the Act:** (d) to allocate the costs of environmental protection and restoration equitably and in a manner that encourages responsible use of, and reduces harm to, the environment, with polluters bearing the appropriate share of the costs that arise from their activities
Environment Protection Act 1970 *Environment Protection (Resource Efficiency) Act 2002* *Sustainability Victoria Act 2005*	Vic	**The principles of EPR (1G) and PS (1H)** are enshrined in the Act **49AH:** The Authority may also require the person, in relation to the enterprise, process, products or service to assess alternative practices and PS approaches to improve the use and efficiency of specified resources or to reduce any ecological impacts identified by the Authority **49AN:** Authority may produce and publish guidelines concerning PS approaches **49AO**: Authority may conduct audits to provide an assessment of PS approaches The functions of Sustainability Victoria are to (b) foster a stewardship ethos in relation to the use of resources
Waste Avoidance and Resource Recovery Act 2007	WA	**Part 5: Product stewardship** 45. PS plans 46. EPR schemes 47. Statements with regard to EPR schemes Schedule 3: Matters in respect of which regulations may be made Division 3: PS

Currently, there are only two jurisdictions that have a specific EPR policy in place. New South Wales was the first jurisdiction to establish an EPR policy (*NSW Extended Producer Responsibility Priority Statement 2010*) under the state's *Environmental Protection Authority Act* (Waste Avoidance and Resources Recovery Act 2001, NSW). Under this Act, the EPA is required to publicly announce an EPR priority every year. The latest EPR priority statement was released in 2010 and 17 priority materials were identified. From these 17, only treated timber, packaging and PVC are from the C&D waste stream. In WA, in 2008, the Municipal Waste Advisory Council prepared a *Policy Statement on Extended Producer Responsibility* for the state. According to the second outcome of this policy, EPR is linked with an improved valuation, pricing and incentive mechanism: it enables the market to better communicate the environmental and social costs of waste and makes waste minimisation an attractive action to producers and consumers; and it eventually furthers the attractiveness of re-using and recycling materials.

In addition to these policies, there are various PS schemes across the Australian jurisdictions. For instance, in Vic, Sustainability Victoria has led several schemes including ByteBack (computers), BatteryBack (batteries), PaintBack (paint) and FlashBack (compact fluorescent lights).

3.3.1.3 Support for EPR application among different stakeholders in Australia:

A review study in 2017[123] (Park and Tucker, 2017) suggested that EPR should be used to inform C&D waste management legislation in Australia. In 2013, the results of an interview with the public sector (Canberra Business Chamber, 2014) showed support from waste managers in 13 local governments of the capital region. The interviewees indicated that a 'products stewardship program from industry would assist a shift towards better management of C&D waste materials" (p. 87).

There are several submissions to the Senate Environment and Communications References Committee (2018) that are showing support for implementing EPR across the Australian waste and resource recovery industry. These submissions highlighted that rewarding more upstream material recovery efficiently leads to better economic, environmental and social outcomes for waste and resource recovery in Australia. The committee also reported that it received evidence of broad support for national PS schemes, and many submitters to this committee called for the expansion of current schemes. Table 25 presents the submissions in support of a national PS scheme.

[123] Park, J. and Tucker, R., 2017. Overcoming barriers to the reuse of construction waste material in Australia: a review of the literature. *International Journal of Construction Management*, 17(3), pp.228-237.

Table 25. Australian stakeholders perceptions of implementation of EPR

Commenter	Type	Indicative language
Australian Local Government Association[˚]	Government association	All future PS schemes should be co-designed with local governments. There are existing schemes which now 'present a difficulty for local government' due to a lack of consultation.
Australian Local Government Association[˚]	Public association	Many PS programs have been significantly underfunded; therefore, their reach and the way in which they operate is difficult'. Rural and regional jurisdictions are not always able to participate in PS programs as services and funding are not available.
Australian Local Government Association[˚]		More emphasis should be placed on EPR, with a clear focus on improving the design and manufacturing of products and packaging – including supply chain considerations and imports – so that unnecessary, problematic or hazardous materials are avoided, volumes are reduced and material content is more easily reprocessed into new products.
Equilibrium[˚]	Consulting company	In lieu of other national approaches to waste and recycling issues, the *Product Stewardship Act 2011* provides an approach that is working and has been quite successful to date. There is a number of schemes that have got up under the auspices of the Act – mostly voluntary schemes, not regulated. PS can be used to incentivise that greater supply chain thinking that it would be of value.
Green Industries SA[˚]	Environmental authority	SA Government is 'looking forward' to more stewardship schemes.
NSW Local Government[˚]	Government	It seems that the *2009 NWP*, promising PS (beyond just TVs and PCs), better packaging and SP has gone silent and a national approach targeting producers has ceased.
The Hunter Joint Organisation of Councils[˚]	Organisation	There has been little or no action to address waste issues at a national level' since the National Television and Computer Recycling Scheme was established.
The National Waste and Recycling Industry Council*	Industry council	The council affirms its policy for EPR schemes to be applied uniformly across jurisdictions and be regulated, enforceable and enforced in order to operate effectively.
WMAA [¤]		Australia can draw lessons from Germany because it is time for our federal government to take our EPR laws and frameworks seriously if Australia is genuine about creating jobs and investment.
TIC Group[˚]	Consulting company	The *Product Stewardship Act 2011*, and the schemes established as a result, demonstrate that 'collaboration between industry, government and other stakeholders can provide cost-effective and efficient processes to recover and recycle more materials'.
Transport Canberra and City Services Directorate[˚]	Environmental authority	ACT Government would 'like to work with the federal government' on the further expansion of PS schemes.
Waste Management and Resource Recovery Association of Australia[˚]	Association	Before introducing a new product to the market, producers should be required to demonstrate an item's 'end-of-life home'. In SA, contractors are required to demonstrate end-of-life processes prior to undertaking large solar panel installations. The waste and recycling industry must be involved in discussions of PS and producers cannot be left to develop schemes alone.

Source: Senate Environment and Communications References Committee 2018.

* Waste Management Review. 2019. The National Waste and Recyling Industry Council's visionary policy. http://wastemanagementreview.com.au/the-nwrics-visionary-policy/

ʌ Waste Management Review. 2019. Towards a circular economy. http://wastemanagementreview.com.au/towards-circular-economy/

¤ Waste Management Review. 2018. WMAA's five policy priorities ahead of MEM. http://wastemanagementreview.com.au/mem-2018-wmaa/

3.3.1.4 Support from jurisdictional waste strategy documents in Australia:

Most jurisdictions have a strategy document that guides government organisations and industries in improving waste management over the strategy period. In many cases, strategies set targets for resource recovery or other waste performance indicators. They also underpin waste management legislation in the respective jurisdiction. Among the states and territories, Vic does not have a current waste strategy document. In SA and WA, EPR is a long-term objective; EPR related schemes are supposed to be developed in the future. Table 26 presents a summary of support from different states and territories of Australia reflected in jurisdictional waste management strategy documents.

Table 26. Support for the development of EPR schemes in the Australian waste strategy documents

Document	State	Relevance to C&D waste
ACT Waste Management Strategy: Towards a sustainable Canberra 2011–2025	ACT	EPR is recognised among the areas of improvements for further waste management and resource recovery Strategy 1.4. Reducing packaging: waste a commitment to PS by the supply chain and other signatories
Waste Management Strategy for the Northern Territory 2015–2022	NT	No mention of EPR and PTB NT will facilitate and promote PS programs for recycling and treating nationally significant waste streams
NSW Waste Avoidance and Resource Recovery Strategy 2014–21	NSW	No mention of EPR and PTB NSW will continue to work with the Australian Government to introduce PS initiatives at the national level under the Commonwealth *Product Stewardship Act 2011*
South Australia's Waste Strategy 2015–2020	SA	Long term objectives: -Avoid and reduce wasteful use of resources in production processes and products, such as leaner production, design for the environment and EPR -Promote the adoption of EPR, including state-based approaches where considered necessary, and encourage continuous improvement in existing producer responsibility and related schemes -Encourage re-use of waste fill and intermediate level contaminated soils where appropriate as a priority and remediate low-level and high-level contaminated soils for re-use Priorities for Action: -Problematic and hazardous waste target: effective PS schemes in place by 2020
Queensland's Waste Reduction and Recycling Strategy 2010–2020	Qld	Strategy principles: -Making better use of finite resources (energy, water, materials) by encouraging waste avoidance and improving recovery through PS or PTB schemes -Implement statewide action such as PS schemes on priority waste Qld government aims to: -encourage and support PS arrangements -work with industry sectors to help build on achievements made through existing schemes and help promote PS activities -work with other industry sectors to foster new PS arrangements
The Tasmanian Waste and Resource Management Strategy 2009	Tas	Strategic actions: -Participate in and support the development of EPR and PS programs -Tasmanians will have an increasing role and responsibility in environmental stewardship

Waste Avoidance and Resource Recovery Strategy 2030: Western Australia's Waste Strategy	**WA**	We will support PS and EPR as part of our approach to shared responsibility
2018 NWP	**Australia**	Strategy 4. Product stewardship Develop and implement partnerships across government and business to ensure ownership and responsibility for action to minimise the negative impacts from products, ensure the minimisation of waste and maximise re-use, repair and recycling of products and materials throughout their life cycle

3.3.1.5 Application of EPR and similar schemes in the Australian context for the C &D waste stream

There are limited examples of the application of EPR and similar schemes to the C&D waste stream in Australia. The few examples that exist cover particular C&D waste materials only. Below are some examples, documented in the *Construction and Demolition Waste Guide – Recycling And Re-Use Across The Supply Chain* (Edge Environment, 2012).

PVC: Since 2002, the Vinyl Council of Australia has voluntarily agreed to apply EPR principles and comply with the *Product Stewardship Act 2011* requirements. Armstrong Australia, the world's largest manufacturer of resilient PVC flooring products, collects the offcuts and end-of-life flooring materials that would have otherwise been sent into landfill for recycling and processing into a new product.

Gypsum: CSR Gyprock™, through a gypsum board take-back scheme, collects offcuts and demolition materials. According to the instructions provided in this scheme, upon completion of gypsum board installation, the fixing contractor arranges collection with CSR Gyprock™'s recycling contractor who charges the builder a reasonable fee. It is claimed that such a scheme could reduce the cost of site clean-up and landfill fees, facilitate better onsite waste management, and save builders time and money.

Waffle pod: Expanded Polystyrene Australia and its Pod Group members, through a PS scheme (the Pod Scarp Bag program), target reduction of expanded polystyrene (EPS) waste from waffle pod offcuts on construction sites. Within this program, builders are supplied with scrap bags to separate EPS waste from other materials; the bags are then collected and transferred to the EPS manufacturer who claims to produce new EPS with 40 per cent of recycled materials content.

Carpet: Since 1985, Ontera Modular Carpets, through Ontera's EarthPlus® environmental program, guarantees to take the product back at the end of its first life for re-use or recycling at no cost to the customer. This program operates without any destructive processes or measurable additional energy input. Ontera reported that this program has resulted in creating reputation and market stature, improved economic returns, reduced utility and landfill costs.

3.3.1.6 EPR related legislation in other countries:

EPR and similar schemes have largely targeted hazardous materials; there are limited examples of their specific application to C&D waste. Australia is a member of the OECD and can benefit from the experiences of those signatory countries that have successfully implemented EPR policies. The following table (Table 27) is extracted from the guideline issued by the OECD, which showcases the application of EPR and similar schemes (OECD, 2016).

Table 27. Examples of implementation of EPR schemes

Country(ies)	Legislation	Materials
European Union	All member states have PTB (EPR) systems The framework is established through the EU but operational aspects are advised by states	Four main types in all states: packaging, batteries, end-of-life vehicles, and waste electrical and electronic equipment Some states also have different material lists
US	There is no national EPR policy Individual states develop and implement their own policy Today there are 89 EPR laws in 33 US states	A wide range of materials
Canada	Occurs at provinces/territories level Canada-wide Action Plan for (EPR) There are more than 30 federal and provincial PS programs in Canada	A wide range of materials
China	The new EPR policy was introduced in 2016-17 by China's State Council	Certain materials: electrical products, batteries and vehicles
Japan	*Home Appliance Recycling Act*	A wide range of materials including C&D waste
Korea	*Resource Saving and Recycling Promotion Act 1992* Resource Circulation of Electrical and Electronic Equipment and Vehicles 2008	Household and industrial materials

In European countries, EPR principles first appeared in policy and law in the early 1990s (OECD, 2014). Several EU directives refer to EPR as a recommended policy instrument. Particularly, the Waste Framework Directive 2008/98/EC aims to effectively decouple economic growth from waste production (Mazzanti and Zoboli, 2008). At the EU level, all member states have implemented EPR schemes on the four waste streams: packaging, batteries, end-of-life vehicles, and electrical and electronic equipment.

In the US, between 1991 and 2015, states have developed and implemented 89 EPR policies that require manufacturers to execute EPR programs (OECD, 2016, Isenhour et al., 2016). In addition to the mandatory programs, voluntary programs are in place by manufacturers to collect and recover their product. **In Canada**, legislation regarding waste occurs at four tiers of government (federal, provincial, territorial and local governments). EPR is largely regulated at the provincial (territorial) level; however, in 2009, a national council has developed a Canada-wide Action Plan for EPR to harmonise EPR approaches taken by different jurisdictions across the country (CCME, 2008b). This council also issued an EPR evaluation tool guideline (CCME, 2008a) that systematically allows the user to consider launching an EPR program for one or more candidate products by answering a series of questions (criteria).

In China, since 2012, EPR regulations have made producers of some electrical products contribute to government recycling funds according to the quantity of production (Ministry of Finance, 2012). These funds are meant to provide subsidies to certified e-waste recyclers by the government. Critics have questioned the adequacy of this system, as it provides little incentive for design change or take-back actions by the producers (Tong et al., 2018). However, the subsidies have created market niches that attract investment and entrepreneurship devoted to recycling. China's State Council introduced the first robots plan for China's EPR policy in 2017. In 2019, this council seeks to build a credit information collection system in order to extend the responsibility of producers. **In Japan**, different EPR policies are applied to various items; there are variations in who is financially or physically responsible in these policies. For instance, for automobiles and home appliance, the target stakeholders are manufacturers, and producers and retailers, respectively (Kojima, 2008). Japan and Europe have PTB policies in place for different products, including some C&D waste materials.

In Korea, through the *Resource Saving and Recycling Promotion Act 1992*, households are required to comply with volume-based garbage rate system requirements. Using the concept of 'polluter pays', this system urges each household to buy designated garbage bags at a supermarket and waste can only be discharged using the prepaid bags (Yang et al., 2015). The successful implementation of this Act motivated the expansion of legislation to cover industrial waste, including C&D waste, and to make companies fully accountable for all the waste they produced (Waste Management Review, 2015*)*.

3.3.1.7 C&D waste specific EPR programs

The general trend for the development of EPR policy for C&D waste largely targets particular construction materials (for example, PVC, glass, asphalt, and packaging waste) rather than collective C&D waste. One example of specific C&D waste EPR legislation takes place in the Flanders region of France, where collaboration agreements with producers have been achieved to recycle C&D waste (Dubois et al., 2016b). These agreements also require producers of several materials to set up logistic schemes or invest in infrastructure to collect used materials as input for new materials: gypsum, autoclaved aerated concrete, bituminous roofing, PVC and mineral wool.

Another successful implementation of C&D source EPR policy is the Netherland's float glass EPR scheme, which showcases how an EPR policy for C&D waste can work efficiently. This EPR scheme imposes an environmental fee of € 0.5/m2 for new double-glazed windows to financially support the management of float glass (i.e. collection and recycling of waste) (Dubois et al., 2016b). In some countries, such as Malaysia, local C&D waste legislation exists that functions as an EPR policy with shared similar principles (Zainu and Songip, 2017).

3.3.1.8 Challenges in the application of EPR and similar schemes to the C&D waste stream

There are several challenges identified that can act as a barrier to the extensive adoption of EPR and similar schemes in the construction industry (Figure 10). As a result, not all EPR instruments shown in Figure 10 works equally well for C&D waste management. The following section explains the main challenges for the effective development and implementation of an EPR policy in the construction industry.

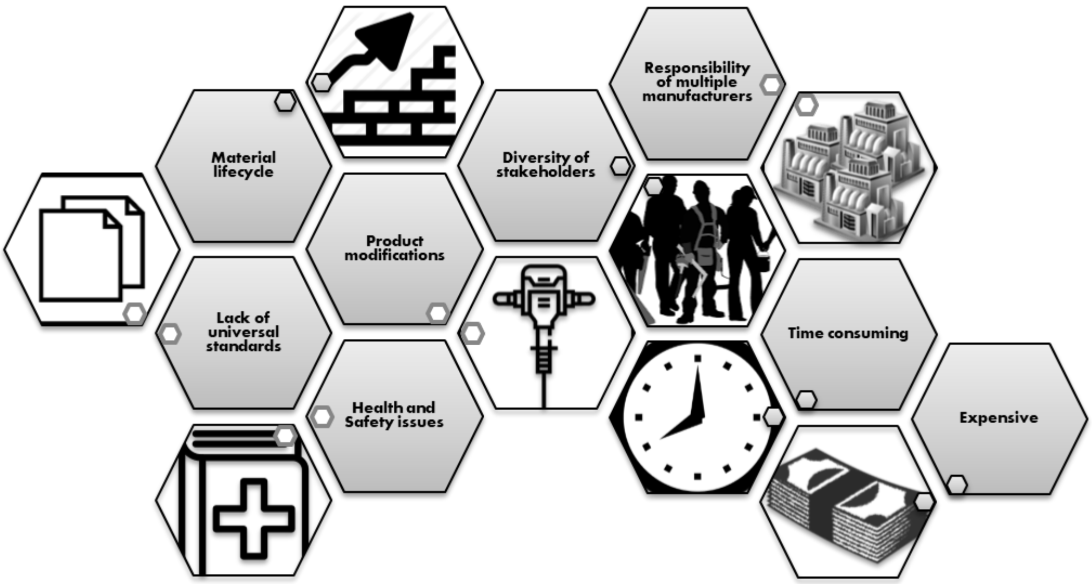

Figure 10. The main challenges toward the effective application of EPR to the C&D waste stream

Time and cost: The costs associated with the establishment and enforcement of EPR programs tend to be high (Shanoff, 1996); they also can be time-consuming, both for domestic producers and a fortiori for importers (Acree Guggemos and Horvath, 2003).

Construction material life cycle: The long product life of construction materials being designed to typically last for more than 10 years is another problem. This makes it difficult to apply PTB and EPR principles to the waste that is produced as a result of ending the lifetime of these products. The longer life cycle also impacts the re-usability and recyclability of these materials. However, reducing the quantity of waste prior to (that is at design, planning and procurement stages) and during construction activities remains the responsibility of those who are involved.

The longer life of construction materials also brings about a regulatory issue whereby EPR policies are based on the retroactive requirements that demand producers to abide by EPR principles for products that were produced before these policies are effective (Hunter, 1997). Indeed, the products that were previously created were not designed with EPR requirements in mind, nor did producers take into account the costs associated with the management and recovery of waste from their products (Acree Guggemos and Horvath, 2003).

Diversity of stakeholders: The other instinctive barrier in construction is the diversity of players involved in construction activities relative to other industries. Traditionally, a producer is not responsible for product design in construction (Lu and Yuan, 2011); architects and engineers share responsibility of design and material selection, and a builder (contractor) builds the designed built environment. The disjointed practice of design and construction, therefore, makes it difficult to determine the responsibility for a product. These players also have their own concerns that impede consistent application of EPR. For instance, architects' designs focus on function and aesthetics; engineers aim to satisfy structural and safety requirements; clients pay attention to budget, quality and time; and builders are mostly concerned with time, cost and profit (Acree Guggemos and Horvath, 2003). One piece of research that studied two case studies in the US reported that designers have more control over the recyclability of a building (with control over 12 of the 15 areas (Srour et al., 2012).

Due to the complex nature of construction activities, it is a common practice that builders acting as the main contractor engage subcontractors to complete different activities. As expected, it is a challenging task to keep track of the performance of tens of contractors involved in a construction project to make sure they are fully abiding by EPR principles.

Enforcement of EPR: Currently there is no universal standard for construction materials that can be implemented for different contexts (Acree Guggemos and Horvath, 2003). This can be even more complex in the Australian context where waste management legislation is formulated by different jurisdictions. EPR policies require manufacturers/importers to provide detailed reports that demonstrate compliance with the EPR requirements; if these vary across jurisdictions, they would be burdened with the task of complying with the EPR requirements in each country/jurisdiction where their product is to be sold. This also can undercut the financial performance of EPR-abiding manufacturers in markets without EPR implementation.

Responsibility of manufacturers: Project contractors generally source numerous materials from different suppliers, plus the materials required differ from one project to another. As a result, it is not always easy to identify suppliers from the assessment of materials. Many materials do not have markings that show the manufacturers (Acree Guggemos and Horvath, 2003). Indeed, without knowing the producer, the responsibility for the material cannot be assigned, and a fortiori, at the end of the material life cycle.

Modification inbuilt facilities: Another problem with EPR application comes from modifications that can take place during the maintenance or renovation of a built facility. Modifications are typically performed every 10 to 15 years, which may end up adding to, removing from or changes to the facility (Acree Guggemos and Horvath, 2003). These changes are unlikely to be made by the original architect, engineer and contractors, adding to the already complex task. However, having well-documented as-built and as-renovated plans can assist the compliance officer to identify those responsible for the product.

Hygiene, health and safety issues: Contamination by other materials in C&D waste mix management is a common concern, particularly during demolition operations. Furthermore, the separation of C&D waste for collection on construction/demolition sites bears safety risks (Shen et al., 2004). Therefore, a higher level of safety measures must be taken when offcuts or demolished materials are to be collected. These higher safety measures understandably have cost implications that impede the effective implementation of EPR in construction projects.

3.3.1.9 Future direction for EPR policy development in Australia:

From the review of the literature, it can be inferred that there is a general consensus among various stakeholders of waste and resource recovery in Australia on developing and implementating EPR policies. However, there exist certain caveats that need full consideration in order to achieve EPR objectives. The following are a number of recommendations for the better development of EPR policies.

Firstly, the approach recommended particularly at the 7 December 2018 meeting of environment ministers urges the federal government to take a lead in the development of consistent national EPR policies instead of varied jurisdictional legislation. EPR policy is usually most efficient when implemented nationally, as most companies affected by EPR operate at the national level (EPA Vic, 2014). To date, only a small number of schemes have been introduced nationally, but this has to change urgently. Secondly, as suggested by many waste and resource recovery stakeholders, the policy approach on EPR has to shift from voluntary to mandatory arrangements. Thirdly, any procedure taken towards development of EPR policies must ensure that input from different stakeholders is obtained prior to implementation. An extensively agreed EPR policy would guarantee its sustainable application and successful outcome. Fourthly, due to the complex and particular nature of C&D waste management, the EPR policy developed must be specific to the setting of this stream. Such a policy can specifically take into account the common issues in C&D waste management. Therefore, it is worth engaging research organisations such as universities to better determine the strategies required to overcome these precise issues. Lastly, there are successful examples of EPR application in the construction industry and other sectors in Australia and elsewhere for individual waste materials. Learning from these experiences and building on the policies governing them would enhance viability of potential EPR policies for C&D.

3.3.1.10 Recommendations for alleviating issues with EPR implantation

As identified in the review, there are challenges towards implementating C&D-sourced EPR policies. The following are some recommendations for minimising the impact of these challenges.

Efficient supply chain system: A reverse logistics system has to be developed to return the product from the individual consumer to the producer (Acree Guggemos and Horvath, 2003). This system has more complications than the original logistics wherein producers deliver a product to a local retailer and the consumer takes care of the final distribution leg from the store to home. Several studies have shown that the cost to run reverse logistic-based supply chain systems runs several times higher than the usual supply chain (Nagel et al., 1999, Klausner and Hendrickson, 2000, Khor et al., 2016). Therefore, future efforts must target cost reductions for reverse logistics operations. There are successful examples of such operations for other waste materials in Australia that can inspire the C&D waste approach. For instance, the DHL Supply Chain Product Stewardship Program has efficiently delivered PS objectives in partnership with large Australian retailers (for example, Target, Officeworks and Harvey Norman) under the the Product Stewardship (Televisions and Computers)

Regulations 2011. This program has achieved all targets in the first three years of operation by establishing an effective collection network from 177 permanent drop zones.

Encouraging design for disassembly: Manufacturers need to be motivated to consider the requirements of design for disassembly. This design arrangement can go a long way in the separation and collection of products at the end of their useful lifetime. Furthermore, designs can be made to facilitate the collection of offcuts during construction activities. Accordingly, designers can collect information on materials' lifetime and recyclability in the region, reducing the number of materials used and component sizes, using two-stage building systems and recording changes during construction and operation (Srour et al., 2012).

The key to effectively encourage manufacturers to design with disassembly in mind is the development of a market for recycled C&D waste materials and the engagement of builders in EPR schemes and utilisation of recycled materials.

Determining responsibility for C&D waste: Currently in Australia there is no clear policy making people responsible for waste coming from C&D waste activities. Upon determining responsibility, a policy can equate them to polluters that need to contribute to management of the end-of-life product. Therefore, communicating the responsibility of each of the stakeholders in a coordinated manner is crucial. Even if an EPR policy is designed to make multiple stakeholders responsible, cost affordability for each stakeholder to fulfil their obligation should be taken into consideration.

Health and safety risk management: Safe Work Australia, as the main regulatory authority, can take a proactive role in developing policies for the safe and hygienic separation and collection of C&D waste in Australia. Policies such as the *How to Safely Remove Asbestos Code of Practice 2011* and *Recycling Construction and Demolition Material* (2007)[124] would facilitate the successful implementation of EPR.

Product documentation: Developing and keeping as-built and as-renovated plans, including a bill of quantities, should be mandatory. Having these registered in a permanent database would assist the task of applying EPR and similar schemes at later stages.

Further studies are needed in a number of areas of EPR policy development and implementation. These studies should analyse which stakeholders might be affected by EPR and similar schemes, supply chain management, industry awareness, and readiness for EPR, domestic and foreign C&D recycled market. Australia has a long way to go to establish a successful national EPR policy for C&D waste materials. This is due to the complex nature of C&D waste management and the poor performance of the federal government in the development and imposition of relevant obligations. This study has sought to identify the position of Australia in the application of EPR for waste management both in practice and regulations. The results show that Australia has good potential for taking a leading role worldwide in the application of C&D sourced EPR. Some strategies are outlined in this study that can assist in minimising the impact of barriers towards an effective and efficient EPR in Australia.

3.3.2 Cradle to Cradle approach

The new agenda of environmental sustainability promotes the application of the cradle-to-cradle approach, instead of the traditional cradle-to-grave approach. This approach shares a similar underpinning philosophy with the circular economy and aims to motivate manufacturers that produce materials to ensure that, at their products' end-of-life stage, it can become the raw material for another industry. Then the material produced always remains a nutrient that can be re-used or converted to usable new material.125 Therefore, this concept is mainly underpinned by two specific

[124] Worksafe Victoria. 2007. Recycling construction and demolition material. Guidance on Complying with the Occupational Health and Safety (Asbestos) Regulations 2003.

design philosophies, namely 'design waste out' and 'design for disassembly'. One study in Australia revealed that the construction industry is still predominantly following cradle-to-grave approaches despite the existence of cradle-to-cradle trends[126].

3.3.3 Virgin material taxes

Despite it being technically achievable to recycle most construction materials, the type and amount of material to be salvaged is often highly dependent on its value[127] (Tam & Tam, 2006; Tam, 2010; Lu & Yuan, 2011). The value of C&D waste-derived materials in most circumstances is a function of the price of new extracted or imported materials. To change the game in favour of C&D salvaged and recycled materials, a relatively new financial incentive has emerged that is intended to discourage consumers from using raw materials in their construction projects. This incentive can be applied in two forms: 'taxing on the use of virgin materials' or 'removing subsidies for virgin materials'. These two price mechanisms have proven to increase the competitiveness of salvaged and recycled C&D materials in several countries. For instance, since 2002 a regulation (Aggregates Levy[128]) has been imposed in the UK to make recycled C&D waste more competitive relative to the virgin aggregates. The levy is a tax (£2 per tonne) on the commercial exploitation of rock, sand and gravel, and it aims to adjust the price of virgin aggregates to better reflect their intrinsic environmental costs. The tax is further expanded to target imported materials. A similar tax has also been implemented in some EU countries including France, Denmark and Sweden.[129]

In Australia, as discussed previously, some states have implemented a new policy to exclude clean fill from the definition of waste. This exclusion, together with lower prices, is expected to be conducive to making the construction industry more likely to use C&D waste instead of raw materials.

3.4 Encouragement

The new approach to the effective management of C&D waste has emphasised the role of incentive in the waste management system in contrast to command-and-control environmental regulations. There is a number of tested and trusted opportunities to motivate waste producers to not dispose of C&D waste at landfills. These opportunities include 'emission trading scheme', 'green building rating' and 'development of the domestic market for C&D waste'.

3.4.1 Incentives for using recycled waste materials

Designing fiscal incentives for stakeholders that attempt to use salvaged and recycled C&D waste materials is necessary for the creation of suitable demand for these materials.[130] Glass container manufacturing company Owens-Illinois, which has a recycling plant, stated that *'companies who actively use recycled materials in their manufacturing process should be rewarded and provided with a benefit that recognises their contribution to recycling and waste minimisation"* (Senate Environment and Communications References Committee, 2018, p. 55). The Australian government is expected to play a more active role, as it is not seen as a major player in this field. Currently, most of the government construction activities are tendered to private contractors, and there are no contractual obligations to use recycled content materials.[131] A review study[132] reported that the

[125] Mcdonough W, Braungart M. 2003. Towards a sustaining architecture for the 21st century: the promise of cradle-to-cradle design. UNEP Industry and Environment. 26:13-16.

[126] Udawatta, N., Zuo, J., Chiveralls, K. and Zillante, G., 2015. Improving waste management in construction projects: An Australian study. *Resources, Conservation and Recycling*, 101, pp.73-83.

[127] Tam, V. and Lu, W., 2016. Construction waste management profiles, practices, and performance: a cross-jurisdictional analysis in four countries. *Sustainability*, 8(2), p.190.

[128] Aggregate Levy Manual.2014. https://www.gov.uk/hmrc-internal-manuals/aggregates-levy

[129] Hyder Consulting. 2012. Construction and demolition waste status report. p.43.

[130] Al-Sari MI., Al-Khatib IA, Avraamides M, Fatta-Kassinos D. 2012. A study on the attitudes and behavioural influence of construction waste management in occupied Palestinian territory. Waste Management Research. 30(2): 122-136.

[131] Hyder Consultation Company. 2011. Management of construction and demolition waste in Australia.

minimum barriers to re-using C&D waste in Australia are outside of the construction industry and include the lack of interest and demand from clients and 'attitudes towards re-use practices" This study concludes that legislation should be better implemented to support the re-use of C&D waste materials.

3.4.2 Deposit/refund

The deposit/refund approach is a systematically proven market-based instrument that motivates further waste recovery activities. One example of this approach is deposit/refund policies for a container deposit scheme which have shown to significantly increase the number of bottles recycled (Acree Guggemos and Horvath, 2003). This approach can be followed by manufacturers who signed up for the EPR scheme. Deposit/refund policy is currently being applied in Canada[133] and the US. In the US, contractors involved in demolition activities are required to pay a deposit to receive a building permit – the deposit is refunded upon demonstration that the C&D waste was sent to a certified recovery facility by the contractor[134].

3.4.3 Green Construction

3.4.3.1 Green construction concept implementation in Australia

The green construction concept, otherwise known as green building, sustainable building and high-performance building, refers to construction-related activities that are environmentally responsible and resource-efficient during a building's life cycle. This concept was introduced in Australia in two forms: the Green Star (GS) system and the Infrastructure Sustainability (IS) rating system, by two authorities: the Green Building Council of Australia (GBCA) and the Infrastructure Sustainability Council of Australia (ISCA). Green building in the context of C&D waste is referred to as a notion that intends to employ low-waste building technologies and promote utilisation of C&D waste or recycled materials. Since its establishment (2002) as the nation's authority (non-for-profit) on sustainable buildings, communities and cities, the GBCA has developed sustainability programs to certify, educate and advocate green built environment projects in Australia. A year after the establishment of the GBCA, it started providing the GS system, which is Australia's only national and voluntary rating system for buildings and communities. Currently, there are four internationally recognised rating tools under the GS scheme, namely Communities, Design and As Built, Interiors, and Performance. These voluntary tools promote the efficient use of management practices in construction and fit-out materials, and target C&D through 'Construction and Demolition Waste' credits. The C&D waste credit aims to encourage and reward management practices that minimise the quantity of C&D waste going to landfill from base building and/or interior fit-out works. The credits operate to engage verified waste contractors and processing facilities that comply with minimum standards of GBCA reporting that were developed in 2013.[135] The GBCA claims that green projects (buildings) recycled 96 per cent of their C&D waste.

Generally, there are three areas of improvement in the GS system for C&D waste-related credits:

1. Recycling of C&D waste from the building.
2. Design of the storage for waste to encourage good recycling practices.
3. Use of recycled materials.

According to the criteria, credit points are awarded when a project can prove that less than 4.5 kg/m^2 of fit-out area have been sent to landfill. In particular, the following items can win credits for construction projects:

(1) **Reduction:** reduction of C&D waste: 1 credit.

[132] Park, J and R. Tucker. 2017. Overcoming barriers to the reuse of construction waste material in Australia: a review of the literature. *International Journal of Construction Management*. 17 (3): 228-237.

[133] Construction and demolition recycling deposit refund procedure and form https://bit.ly/32y4958

[134] Houston-Galveston Area Council (2005) C&D Debris Regulations, Recycle C&D Debris Handbook.

[135] GBCA. 2013. Green Star Construction & Demolition Waste Reporting Criteria.

(2) **Re-use:** façade re-use (retained by 50 per cent: 1 credit; retained by 80 per cent: 2 credits), Structure re-use (retained by 30 per cent: 1 credit, retained by 60 per cent: 2 credits).
(3) **Aggregate:** Coarse aggregate is crushed slag aggregate or other alternative materials – at least 40 per cent (0.5 credit), fine aggregate is manufactured sand or other alternative materials –at least 25 per cent by mass; in Australia both of these categories are sourced from C&D waste.[136]
(4) **Recycled content products:** 3 per cent product (1 credit), 6 per cent (2 credits), 9 per cent (3 credits).

Table 28 presents the categories of GS rates and corresponding scores.

Table 28. Categories of Green Star (GS) rates

Score	Rating	Category
10-19	One Star	Minimum Practice
20-29	Two Star	Average Practice
30-44	Three Star	Good Practice
45-59	Four Star	Best Practice
60-56	Five Star	Australian Excellence
75+	Six Star	World Leadership

The evaluation of performance and effectiveness of the GS system in Australia has been the focus of several investigations in recent years. A study in Australia[137] has recommended that the GS's C&D waste credit be mandatory; it also suggests that the additional costs a client must incur to get a GS certificate should be reduced in future. A report[138] on the benefits of a decade's application of GS in Australia revealed that GS-certified buildings are recycling 96 per cent of their C&D waste. This report found that, in total, 37,600 truckloads of C&D waste have been diverted from landfill due to good waste management practices. Another study in 2015[139] reported decisions in construction projects are constrained by financial gains unless a special requirement to comply with the GS system or any similar schemes is in force. One of the interviewees in this study indicated that designers do not tend to consider opportunities for waste minimisation unless they are required to fulfil building rating tools such as GS. Overall, the authors of this research concluded the GBCA can improve its GS system to address the impacts of three main deterrents towards waste management practices: lack of economic interest, professional roles and less accountability of construction stakeholders. In addition to GS for buildings, the ISCA (a not-for-profit industry council) developed a voluntary rating system for assessment of infrastructures in terms of sustainability in 2007. This scheme seeks to foster resource efficiency and reduction of waste and associated costs in infrastructure projects.

3.4.3.2 Experience from other countries

There are about 40 similar green programs[140] being implemented across the world that share similar principles with the Australia Green Star system. GS is also adopted and modified by New Zealand

[136] Le, K.N., Tam, V.W., Tran, C.N., Wang, J. and Goggins, B., 2018. Life-Cycle Greenhouse Gas Emission Analyses for Green Star's Concrete Credits in Australia. *IEEE Transactions on Engineering Management*, 99:1-13.
[137] Park, J and R. Tucker. 2017. Overcoming barriers to the reuse of construction waste material in Australia: a review of the literature. *International Journal of Construction Management*.17 (3): 228-237.
[138] Green Building Council of Australia. 2014. Green Building Market Report Australia New Zealand 2014. P. 15. https://bit.ly/3nfDN1n
[139] Udawatta, N., Zuo, J., Chiveralls, K. and Zillante, G., 2015. Attitudinal and behavioural approaches to improving waste management on construction projects in Australia: benefits and limitations. *International Journal of Construction Management*, 15(2), pp.137-147.
[140] Thaickavil N.N and J. Thomas. Green Rating Credits for Waste Utilization in Construction. Green Buildings and Sustainable Engineering. Proceedings of GBSE 2018. pp.189-201.
[148]Udawatta, N, Zuo, J, Chiveralls, K & Zillante, G 2015, 'Attitudinal and behavioural approaches to improving waste management on construction projects in Australia: benefits and limitations', *International Journal of Construction Management*, vol. 15, no. 2, pp. 137-47.

(New Zealand Green Building Council) and SA. There are several research studies comparing the performance of different green programs. A study conducted in Australia revealed that, in comparison to Leadership in Energy and Environmental Design, and Assessment Standard for Green Buildings, which is a performance-based rate, GS is more beneficial to the practice of designing in a green way[141]. Table 29 summarises the criteria used in the green rating systems for some of these green building programs.

Table 29. A summary of green programs across the world

Name of program	Criteria related to C&D waste
BREEAM: Building Research Establishment Environmental Assessment Method – developed by Building Research Establishment (BRE) in 1990, in UK	**a.** Construction waste management (3 credits): waste reduction (2 credits) diversion from landfill (1 credit) **b.** 25% content from recycled or secondary aggregates (1 credit), **c.** Exemplary performance: construction waste management (1 credit), >50% content from recycled aggregate (1 credit)
LEED: Leadership in Energy and Environmental Design – developed by the US Green Building Council in 1998	**a.** C&D waste management (2 points): 50% diversion from landfill (1 point), 75% diversion from landfill (2 points) **b.** Recycled material based on the cost of total value of materials: 10% of building materials (1 point), 20% of building materials (2 points) **c.** Materials reuse: 5% (1 point), 10% (2 points) **d.** Building reuse: 50% of existing floors, walls, and roof (1 point), 75% of existing floors, walls, and roof (2 points), 95% of existing floors, walls, and roof (3 points) **e.** Reuse: 50% of non-structural elements
CASBEE: Comprehensive Assessment System for Built Environment Efficiency –developed in Japan in 2001	**a.** Reuse efficiency of materials used in a structure (3 points): Electric furnace steel in major structural elements (other than reinforcement bars) (1 point), Portland blast furnace cement concrete of major structural elements (1 point), Recycled aggregate used in concrete of major structural elements (1 point) **b.** Reuse efficiency of non-structural materials (3 points) **c.** Reusability of components and materials (3 points): the structure and finishing materials can be separated easily (1 point), Interior finishes and equipment are not entangled and each can easily be removed separately for demolition, refurbishment, and remodelling **d.** Reusable unit materials are used (1 point)
BEAM Plus: Building Environmental Assessment Method – developed by the Hong Kong Green Building Council Limited	**a.** Construction waste recycling (2 credits): at least 30% (1 credit), at least 60% (2 credits) **b.** Demolition waste recycling (2 credits): at least 30% (1 credit), at least 60% (2 credits) **c.** Recycled materials (3 credits): site exterior surfacing work, structures, and feature at least 10% (1 credit), façade and structure components at least 10% (1 credit), interior non-structural components at least 10% (1 credit) **d.** Reuse of existing sub-structure or shell (3 credits), > 30%: 1 credit, >60% (2 credits), >90% (1 credit, bonus).

3.4.3.3 How main stakeholders may take advantage of the GS scheme:

Increasingly, construction companies are attempting to be listed on sustainable and ethical indices; hence, there is a desire for green buildings and the associated reputational advantage. This desire paves the way for further recycling, re-use of C&D waste and use of products with recycled content. All this leads to the development of a sustainable domestic market. The GBCA provides services for assisting GS-certified projects to market their product by showcasing their commitment to sustainability using their GS credentials. These services provide marketing strategies to broadcast green projects to the wider public, adding to the value of green buildings. Furthermore, currently, compliance with GS requirements is part of the tendering processes for large-scale construction sites.[142] Therefore, companies that are looking at getting a government contract need to improve their ability to meet GS requirements. Another study investigated and outlined multiple clusters of

[141] He, Y., Kvan, T., Liu, M. and Li, B., 2018. How green building rating systems affect designing green. *Building and Environment*, 133, pp.19-31.

[142] Hyder Consultation Company. 2011. Management of construction and demolition waste in Australia. p.46.

drivers for GS uptake in different countries[143]. Figure 11 depicts the GS specific drivers, according to this study.

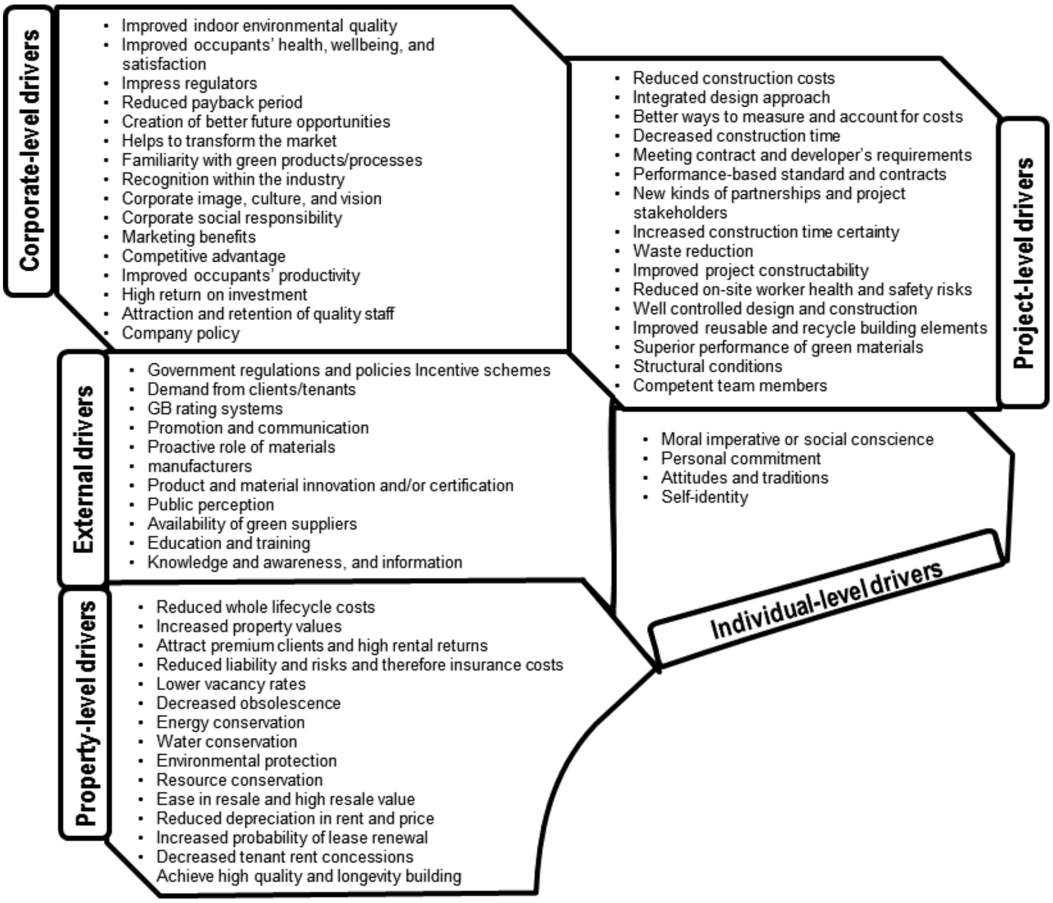

Figure 11 Factors influencing GS performance.
Source: adapted from Darko et al (2017).

Figure 12 shows examples of advertisements for green projects certified by GBCA in the Australian property market.

[143] Darko, A., Zhang, C. and Chan, A.P., 2017. Drivers for green building: A review of empirical studies. *Habitat International*, 60, pp.34-49.

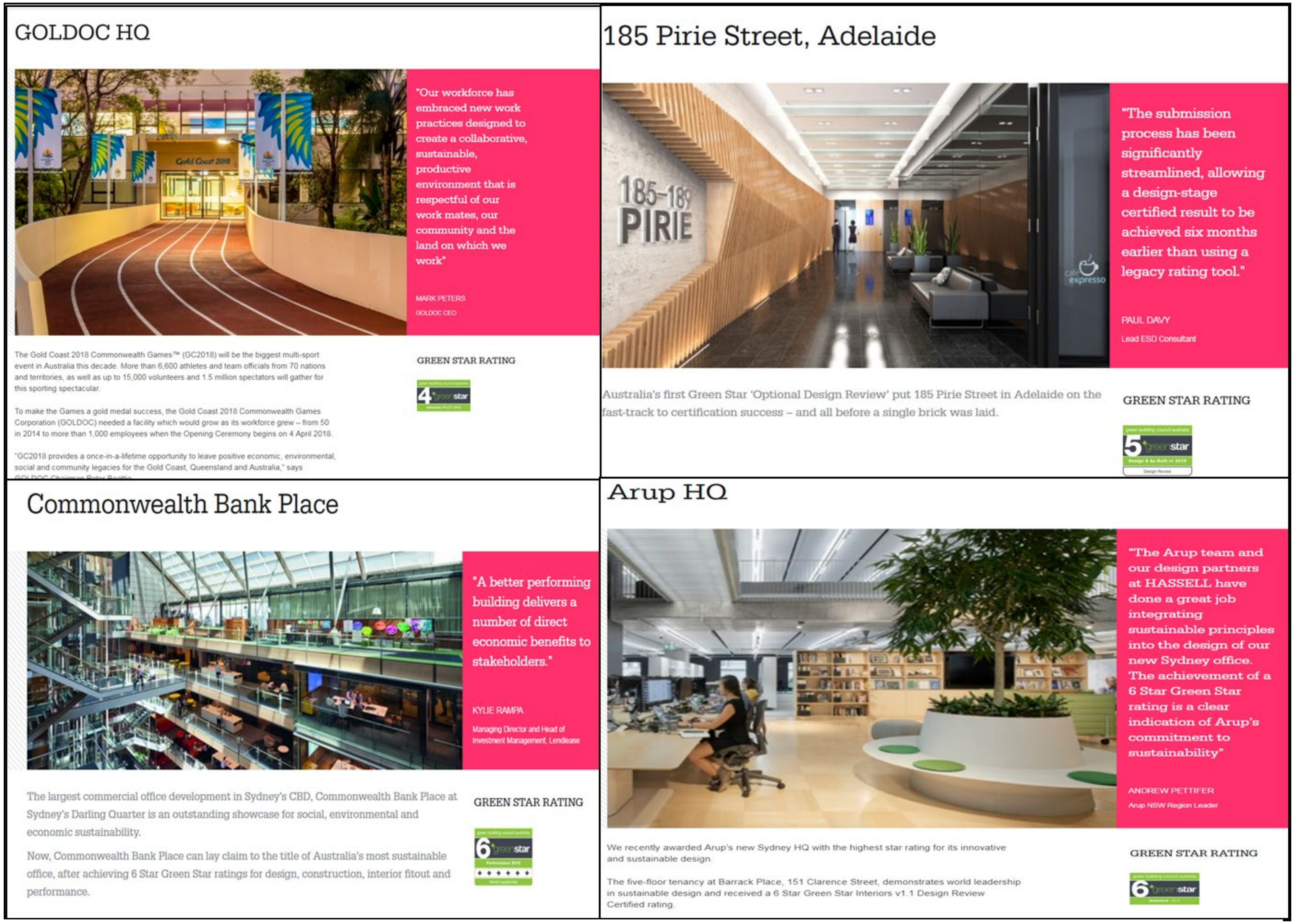

Figure 12. Examples of marketing green star rated projects in Australia.

Source: Green Building Council of AustraliaGBCA wWebsite: https://new.gbca.org.au

3.4.4 Emission trading scheme

The issue of carbon emission with regards to C&D waste management is complex. On the one hand, carbon emissions during recycling are inevitable; however, the measures for the substantial reduction in emissions are possible and very crucial. On the other hand, the options of landfill disposal and extraction of virgin materials have far more adverse environmental consequences.[144]

There are two widely adopted approaches to addressing the issues with emissions: Command-Control (CC) (for example, through regulations, direct and indirect taxes) and Emission Trading Scheme (ETS). The first approach, CC, comes with some limitations, as the unit cost for removing additional quantities of pollution is unreasonably expensive in some countries. Another issue with CC is that it is stricter than the trading scheme approach, which is a more incentive-based system. In CC, the emission goal set for each polluter is fixed, hence, shifting the burden of pollution reduction to the firms that can achieve it more cheaply is not possible. Thus, this approach is likely to be more costly in general[145] and, in most cases, the additional costs would be transferred to end-users;[146] hence, it is a less favoured technique in new waste management systems.

On the contrary, implementing an ETS, otherwise known as cap and trade, can contribute to reducing emissions from waste disposal and recovery facilities. Emission trading is a market-driven approach to managing pollution by providing economic incentives with the aim of reducing the emission of pollutants.[147] In the general context, the idea is to mitigate the adverse effects of climate change and improve the environment. In the waste management context, this scheme can convince waste producers to consider the top layers of the waste hierarchy (for example, re-use, recycle and recover).

In emission trading, the main authority allocates a limited number of permits to dispose of a certain amount of a specific pollutant during the time period stipulated.[148] Polluters (waste producers) need to own permits in an amount equal to their emissions. Polluters who wish to add to their emissions should purchase permits from others willing to sell them. An ETS allows for emission goals to be met in the most cost-effective way by letting the market determine the lowest-cost pollution abatement opportunities. There are four main types of ETS: 'cap-and-trade system', 'baseline-and-credit', 'project-based schemes' and 'hybrid schemes'. The EU implemented a cap-and-trade system[149] in 2005 under the Kyoto Protocol and aims to reduce GGE in an economically effective manner.

The ETS in Australia has been a point of disagreement between the major political parties because of its social and economic effects. Between 2003 and 2011, policies related to the ETS were passed and overturned several times. The Australian Parliament has provided a list of pros and cons of the ETS in relation to varying factors.[150] The first ETS in Australia was established in NSW in 2003, based on a baseline-and-credit scheme;[151] it only lasted for a decade and was terminated in 2012. A report[152] that reviewed this scheme's performance indicated a high level of commitment from different stakeholders during its lifetime. Nevertheless, there are still around five million certificates that remain available for voluntary surrender on this scheme registry. Later on in 2012, the Australian Government initiated a carbon pricing scheme, or carbon tax, through the *Clean Energy Act 2011*. The purpose of this Act was to make polluters pay a certain amount ($23) as tax per tonne of carbon

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[144] Damptey, E.O. 2011. Optimising the Use of Recycled C&D Waste Material in Civil Construction Projects. PhD thesis. Swinburne University. Australia.

[145] Rosen, Harvey S.; Gayer, Ted. 2008. Public Finance. New York: McGraw-Hill Irwin. pp. 90–94. ISBN 978-0-07-351128-3

[146] Yujie Lu; Xinyuan Zhu; Qingbin Cui .2012. 'Effectiveness and equity implications of carbon policies in the United States construction industry'. *Building and Environment*. 49: 259-269.

[147] Stavins, R.N. 2001. 'Experience with Market-Based Environmental Policy Instruments' (PDF). Discussion Paper 01-58. Washington, D.C.: Resources for the Future. Retrieved 2010-05-20. Market-based instruments are regulations that encourage behaviour through market signals rather than through explicit directives regarding pollution control levels or method.

[148] Cap and Trade: Key Terms Glossary. Climate Change 101. Centre for Climate and Energy Solutions.

[149] EU Emissions Trading System (EU ETS).2005. https://bit.ly/3tBcsca

[150] Carbon taxes. 2019. https://bit.ly/2QEJFF9

[151] The New South Wales Greenhouse Gas Reduction scheme. 2003. https://bit.ly/3sBf7B6

[152] NSW Greenhouse Gas Reduction Scheme - Strengths weaknesses and lessons learned - Final Report – 2013.

that they released into the atmosphere. However, this Act was repealed in 2014 and replaced with the Direct Action plan,[153] which provides funding to companies to incentivise emission reduction activities. The government has spent $1.7 billion on 143 million tonnes of emissions, at an average cost of $12 per tonne. This fund is granted on a 'reverse auction' basis; awarding contracts to those who bid emissions abatement projects at the lowest cost.

The Australian Government has committed to a target of GGE abatement by 26 per cent to 28 per cent (from 2005 levels) before 2030. Some state waste strategy documents prioritise emissions reduction through increased waste recovery activities. South Australia is the first Australian jurisdiction to enact specific climate change legislation that sets a long-term ambitious emissions reduction target. Through the *Climate Change and Greenhouse Emissions Reduction Act 2007*, SA establishes a target to reduce its GGE by at least 60 per cent (from 1990 levels), by 2050. In the ACT, the *Climate Change and Greenhouse Gas Reduction Act 2010* has provided a target of 40 per cent emissions by 2020, while the waste sector only accounts for three per cent of total emissions. In Qld, an environmental strategy document[154] necessitates the implementation of an ETS to reach a 60 per cent target of reduction in national GGE by 2050.

There is some uncertainty about how a carbon tax, ETS or reverse auction may impact the waste sector in Australia. In a previous report,[155] consultation with re-processors revealed that introduction of the carbon tax may result in more emphasis on the recovery of C&D waste, as landfill operators should report on and pay a price for their activities-produced emissions. Several studies have also compared the effectiveness of the two greenhouse gas managing mechanisms. One modelling study in 2014 showed that an ETS can reduce GGE from waste by 75.9 per cent (from 2015 levels) by 2030;[156] the study, however, stated that an ETS is likely to reduce Australia's GDP by just over 1.1 per cent in 2030 compared to a base case. In 2016, research findings[157] demonstrated that 'direct action" was not as effective as a carbon tax in enforcing companies to act urgently and manage emissions. The interviewees in this piece of research stated that the carbon tax motivated companies to act, as it raised their utilities costs, causing financial burden for some companies and ruining their reputation as high-emitting companies, in addition to these companies being liable under the tax. The study also indicated that, when the carbon tax was repealed, the focus on carbon emissions in these companies shifted. Another piece of research[158] compared three models of GGE reductions (ETS, action plan and carbon tax) and found that an ETS is the most viable option both for reductions in GGE and economic growth. This research predicts that the government will encounter much higher auction prices in the next rounds of auction compared with those previous auctions. Hence, the current budget ($2.55 billion) may not be sufficient to purchase the required abatement by 2020, therefore making achievement of the 2030 target difficult.

Another study in Vic[159] warned that ETS might also cause the industry to rethink recycling emissions levels and, therefore, negatively impact further recycling activities. In general, and in the interest of the C&D waste and resource recovery industry, it is advisable that legislation is modified to account for the fuel tax cuts.

3.5 Domestic end-market

[153] Direct Action Plan. 2014. https://bit.ly/3sGyZmM

[154] The Queensland Government. 2008. Toward 2 Tomorrow's Queensland.

[155] Construction and Demolition Waste Status Report. 2012. Hyder Consulting Pty.

[156] Adams, P.D., Parmenter, B.R. and G., Verikios. 2014. An emissions trading scheme for Australia: national and regional impacts. *Economic Record*, 90 (290), pp.316-344

[157] Direct Action not as motivating as carbon tax say some of Australia's biggest emitters.2016. *The Conversation*. https://bit.ly/3svAP9H

[158] Nong, D, and S. Mahinda. 2016.A Dynamic Evaluation of the Impacts of an Emissions Trading Scheme on the Australian Economy and Emissions Levels.

[159] Damptey, E.O. 2011. Optimising the Use of Recycled C&D Waste Material in Civil Construction Projects. PhD thesis. Swinburne University. Australia.

The development of a market for salvaged and recycled waste materials (including C&D waste) has been frequently emphasised in different policies, strategies, waste management principles and concepts in Australia. The circular economy of waste has five principles, the third of which is to 'increase the use of recycled material and build demand and markets for recycled products'; that is, market development. In the *2018 NWP*, Strategy 14 places emphasis on market development and research.[160] Estimations, based on the current solid waste generation rates in Australia, project that Australian recycling capacity must increase by 400 per cent by 2040 to address the issue of solid waste in the future[161]. The influence of China's waste policy urgently necessitates the development of domestic market capacity in Australia.

The submissions to the Inquiry made by the Senate's Environmental and Communications References Committee offered diverse viewpoints about domestic market development. The following are highlights from these submissions that cover various relevant issues:

> *'Several submitters highlighted the lack of local demand for recyclable materials. They explained that this has contributed to poor economic conditions in the recycling industry and resulted in unsustainable practices, such as stockpiling and export to overseas markets." Senate's Environmental and Communications References Committee*
>
> *'Markets for most recyclables in Australia are unable to absorb the quantity of material collected. As a result, unsustainable practices such as stockpiling and export to overseas markets are occurring." Maitland City Council*
>
> *'The reliance on export to overseas markets, and in particular China, was raised in evidence. It was noted that China has in the past provided a stable market for Australian recyclable materials." Visy Recycling*
>
> *'[With] the impact of commodity prices for imported materials (both virgin and recovered) relative to the prices for local recovered material on the domestic market for recycled product … where imported products can be purchased more cheaply than products produced using locally recovered material, there is likely to be a detrimental impact on local businesses." South Australian Government*
>
> *'The lack of genuine progress of the national waste strategy in the last eight years has hampered the creation of secondary markets and a circular economy in Australia. If this had occurred, Australia would not have the continued reliance we have, to an extent, on global trading markets, such as China, for our commodities." WMRR*
>
> 'Market volatility is also an issue … recyclables are sold into global commodity markets and as such, recovered steel and aluminium are affected by the price of virgin material." *ACT Government*

However, the development of a domestic market for waste and recyclables is strongly influenced by several internal and external factors. In waste management language, some of these challenges induce 'push-and-pull' effects. Resource recovery is greatly driven by a push (supply of materials) to divert waste from landfill. In an ideal situation, this push should be matched by consumer and industry pull (demand for products made from recovered resources). It is expected that, when these factors are systematically dealt with, this will pave the way for a circular economy and the subsequent closing of the loop of waste/resource flow in the Australian market. The most influential factors displayed in. The most influential factors displayed in Figure 13 are described below.

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[160] 2018 NWP, p.16.

[161] The Senate Environment and Communications References Committee. 2018. Never waste a crisis: the waste and recycling industry in Australia. p.85.

Figure 13. The main factors influencing the market for C&D waste materials (re-use/recycled)

Harmonisation– There is uncertainty about the extent of influence by various players in the waste and resource recovery market in Australia. On the one hand, the Australian Government Department of Agriculture, Water and the Environment opines that jurisdictions are in the best position to respond to market developments by providing recycling regulations[162] that align with the limited constitutional responsibilities of the federal government in the regulation of waste. On the other hand, the Australian Government has indicated that it would contribute when there are domestic market failures or absences of a market that require national policy or partnership programs.[162]

At the jurisdictional level, Vic has a leading position in the development of a market for recovered and second-hand materials. In 2016, the Victorian Government released a strategy document on the development of a domestic market for recovered resources.[163] This document provides Victorian Government plans to overcome challenges related to the unbalanced supply and demand for recovered materials in Vic's domestic market. Four Victorian Government interventions were advised to boost market development in the next 30 years: R&D, product specifications, product procurement and PS. Table 30 presents some specifications of this strategy document, including challenges towards market development.

[162] The Senate Environment and Communications References Committee. 2018. Never waste a crisis: the waste and recycling industry in Australia. p.24.
[163] Sustainability Victoria.2016. Victorian Market Development Strategy for Recovered Resources.

Table 30. Victorian (Sustainability Victoria) market development strategy specifications

Item	Description
Barriers	(1) Product design not suitable for disassembly (2) The quality and quantity of recovered resources required to justify the investment (3) Costs of the establishment of recovering facilities of low-value material (4) Cost of transport of often low-value material (5) Low margin markets versus cheap virgin material or imports (6) Lack of regulatory support (7) Market price fluctuations (8) Lack of proper waste data management systems (9) Limited awareness about the effectiveness of products with recycled content
Strategies	(1) Improve the quality of recovered resources to support manufacturing (2) Improve consolidation and aggregation of recovered materials to contribute to growth in manufacturing (3) Improve the performance of products incorporating recovered resources (4) Increase the use of products incorporating recovered resources (5) Cross-government coordination within an integrated, statewide waste management framework (6) Adopt appropriate, evidence-based approaches to government intervention (7) Capitalise on policy and market signals supporting resource recovery
Priority material selection criteria	(1) Environmental impacts associated with the management of the waste material/ product (2) Amount of material generated (3) A functioning market existing for the material/product
Priority materials	Organics (including timber), rubber (tyres), e-waste, flexible plastics, glass fines, concrete and bricks.

Source: Victorian Market Development Strategy for Recovered Resources 2016

In consultation with different stakeholders, Sustainability Victoria has contemplated waste/resource flow in a circular economy context. Figure 14 portrays different components of this circular flow. Other states and territories are also considering market development for various waste streams, including C&D waste.

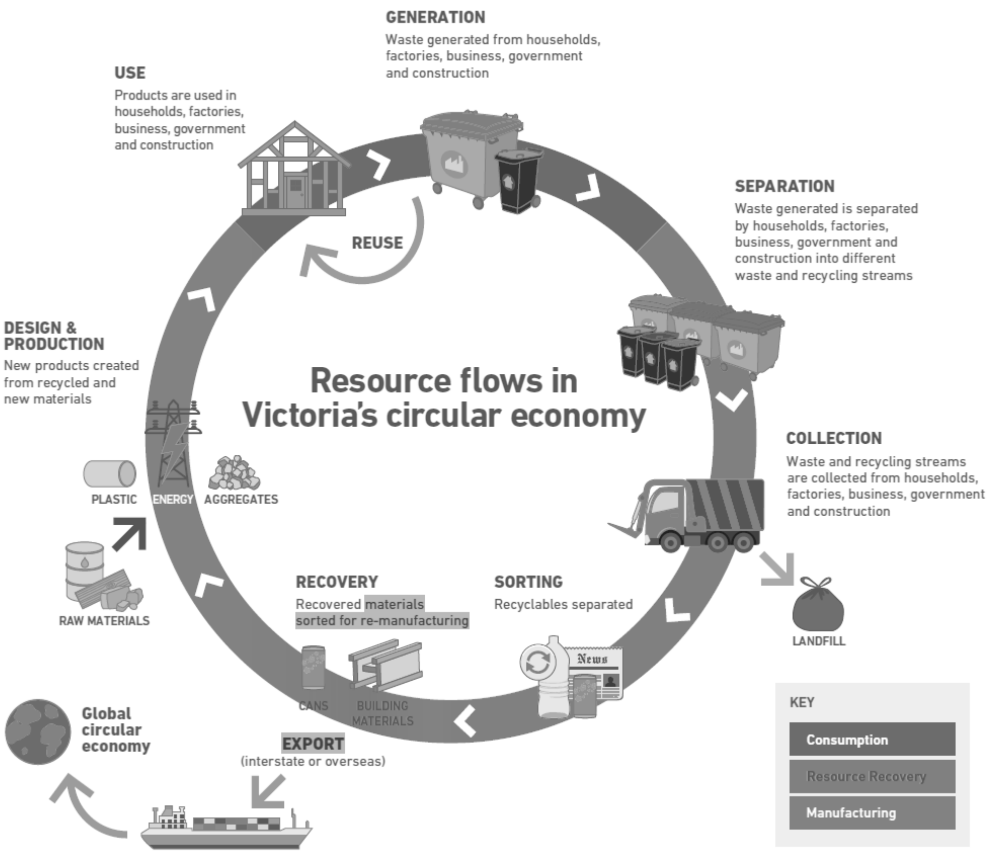

Figure 14. Resource flow in potential Victorian waste and resource market
Source: Sustainability Victoria (2015) [164]

Landfill levy: Unreasonably priced (both high and low price signal) landfill fees and their variation across Australia can negatively hinder C&D waste market development. For instance, GCS Consulting submitted that a continuous increase in the waste levy could diminish its efficacy as a pricing mechanism.[165] Other evidence also exists that confirms the negative consequences of landfill levies including (a) increasing economic pressures on recyclers due to high levies; (b) poorer quality recyclable material entering the market and driving up the cost of treatment, and (c) changes to the market. A full discussion on the effectiveness of the landfill levy has been previously presented.

On the other hand, there are multiple other sources that necessitate having a landfill levy in place in regards to market development. For instance, several submissions[166] indicated that levy revenue could be used to invest in the development of a market for recycled materials through low-interest (subsidised business) loans or financial incentives and R&D. The National Waste and Recycling Industry Council firmly states that market distortions take place due to variation in landfill levies across jurisdictions.[167]

Data and reporting: Accurate C&D waste data collection and reporting underpin the development of a local market for recyclables. Consistent and updated reporting can make it much easier to manage the C&D waste and resource market. According to Strategy 14 of the *2018 NWP*, 'Market Development and Research', 'all Australian governments and businesses generate and report

[164] Sustainability Victoria. 2015. Statewide Waste and Resource Recovery Infrastructure Plan – Victoria -44, p.47, 2015.
[165] Submission to the Senate Environment and Communications References Committee. 2018. Never waste a crisis: the waste and recycling industry in Australia. p.50.
[166] Ibid pp.65-67.
[167] Ibid p.59.

information to support creating and maintaining markets for recycled materials, both domestically and internationally" (National Waste Policy, 2018 p.16). Waste data is critical to well-targeted, evidence-based and planned waste projects and programs. Data on waste generation, landfill and resource recovery is also essential to the development and implementation of waste policies and programs. Up-to-date and consistent data is also required to understand the current state of waste and recycling. Historical data allows current performance to be plotted against prior performance and meaningful, achievable and realistic targets to be set. Historically, C&D waste data collection in Australia was found to be indicative rather than accurate and considered to be questionable in terms of transparency, comparability, accuracy, completeness, clarity and timeliness[168].

Waste data collection methods vary by jurisdiction and material type. In the NT and Tas, no waste data is collected and establishing a platform to collect the data remains a priority. In the ACT, there is no established method to collect data and improved data gathering capability has been recommended to facilitate effective management of waste[169] in the territory. Since 2017, with the commencement of a new Act[170], however, the ACT has made it a requirement for waste businesses to report their activities quarterly. In four other jurisdictions (NSW, Qld, SA, and Vic), robust data systems serve to systematically collect and analyse waste data. Table 31 shows the waste data collection systems rolled out in these jurisdictions.

Table 31. Waste data systems in different jurisdictions

	Program	Function
NSW	WARRP	An online reporting tool designed to facilitate the submission of the WCMR. All licence holders of levy liable waste facilities) must submit the following reports to the NSW EPA: waste contribution monthly report, LFIC and volumetric survey report https://warrp.epa.nsw.gov.au/
Qld	The Queensland Waste Data System (QWDS)	A web-based system for operators to report on their waste data returns and the Annual Waste Survey. The system allows for the expanded capture of information about waste disposal and resource recovery. QWDS provides a streamlined reporting system for private and local government waste managers—replacing spread sheets and third-party online survey sites previously used to collect data. In addition, QWDS provides all the functionality required to transition to the system—which allows for more robust online data collection and reporting. (https://bit.ly/3grPz7o)
SA	Zero Waste Environment User System (ZEUS)	A web-based system developed by Green Industries SA to facilitate the monitoring, analysis and reporting of waste reduction targets in SA. ZEUS collects information on: recycling activity; waste (tonnes) to landfill by waste stream (MSW, C &I and C & D); litter; economic and environmental costs and benefit; infrastructure needs; and areas needing regulatory underpinning.
Vic	Waste Data Portal (WDP)	Waste Data Portal developed by Sustainability Victoria's to collect and store waste and recycling data from a number of sources and regularly produces statewide waste, recycling and litter data reports. The portal aims to strengthen and standardise existing waste and resource recovery data in Vic, introduce new data as necessary and improve collection and sharing of data in Vic between state and local governments and industry. https://bit.ly/3vaWk1v

The systems tabulated above have definitely had a positive impact on achieving jurisdictional waste strategies. In 2016, the NSW EPA provided a user guide[171] for their data management system (WARRP). This guide, through step-by-step navigational instructions, helps different stakeholders register and monitor data associated with waste management throughout the state. Particularly, landfill site owners and recycling facilities operators can use it for their obligatory waste data submissions. In Vic, one product of the WDP project is an interactive waste data map in which

[168] Net Balance. 2009. National Waste Data System Requirements Study.
[169] ACT Government. 2018. Waste Feasibility Study Roadmap and Recommendations – Discussion Paper.
[170] Waste Management and Resource Recovery Act 2016 – ACT.
[171] NSW Waste and Resource Reporting Portal (WARRP) User Guide. 2016.

information is presented by year and material type for different regions of Vic. The main data collection methods in Australia are an annual survey (NSW, Vic, and WA) and annual reporting (Qld and SA). The other discrepancy is the data collection mechanism that determines the obligatory or voluntary nature of data reporting. Local government waste data collection is voluntary in NSW, Vic and WA; it is obligatory in Qld and SA.

Despite the progress made in the field of waste data collection in some jurisdictions, the challenge of aggregation of individually collected waste continues to be the main concern at the national level. If properly merged, these systems will provide useful information that can lead to the development of a national approach in the management of general waste as well as C&D waste. It would also assist Australia to measure its performance against other countries. As previously mentioned, there have been some unsuccessful efforts to form a national waste database under the Australian Waste Database (AWD) projects in the 1990s. This is a challenging task, as it requires standardisations in collecting, processing and reporting data methods in various jurisdictions. The other main issues were found to be costliness and difficultness of data collection activities, followed by inconsistent classification systems, data source incomprehensiveness and inability to separate waste streams, etc.[172] However, in 2009, the then federal Department of Energy and Environment commenced the development of a national waste data system, which was later complemented with a 'method report' that describes what data would be collected and how it would be transformed. This work was furthered with a procedural document describing the whole process and a revised method was developed and agreed by all jurisdictions in 2015. The revised method included a Microsoft Excel tool that implements the agreed method. Despite these efforts, the national waste data system has not been launched, due to disapproval of the required budget; instead it was confined to the release of a biannual national waste data report.

R&D: Any integrated waste management system greatly benefits from R&D. Almost every single strategy, policy, action plan and regulation on waste management in Australia has highlighted the role of R&D alongside encouragement and enforcement for effective development and implementation of waste-related plans. In Australia, authorities have recently started taking advantage of R&D benefits and hence have engaged research and consultation entities to provide the information required for the regulation of C&D waste streams. To date, the product of such collaboration has partially contributed to the decision-making processes on an extended range of issues. Table 32 presents some seminal examples of these studies that are commissioned by public authorities and are published in the form of publicly available reports.

Table 32. Summary of research reports released to inform legislation, decision making or raising awareness

Report	Ordering authorities	Objective(s)
Construction and Demolition Waste Status Report (2011) – Hyder Consulting Pty Ltd	I. Department of Sustainability, Environment, Water, Population and Communities Queensland II. Department of Environment and Resource Management	Evaluation of the current conditions of C&D waste management in Australia and providing relevant reforms
Waste Definitions and Classifications: Report on issues, opportunities and information gaps (2012) – Hyder Consulting Pty Ltd	Department of Sustainability, Environment, Water, Population and Communities	Review on (legal) definitions used for various waste streams in different jurisdictions
Investigation into the Performance (Environmental and Health) of Waste to Energy Technologies Internationally (2017) – WSP Global Pty Ltd	WA Department of Environment and Conservation	A review of legislative and regulatory frameworks, state-of-the-art technologies and research on health and environmental impacts
A Review of the Scientific Literature on Potential Health Effects in Local Communities Associated with Air	EPA Victoria	Evaluation of potential issues associated with EfW technologies

[172] DEE. 2018. National Waste Report 2018, p.5.

Emissions from Waste to Energy Facilities (2018) – **Environmental Risk Sciences**		
Global Landfill Regulation & Waste: Levy review (2012) – SLR Consulting Australia Pty Ltd	I. WA Department of Environment and Conservation II. Waste Authority	Review on landfill levy regulations in Australia and worldwide
Waste to Energy Consultation and Case Study for Melbourne's West (2017) **–** Reincarnate Pty Ltd	The Department of Environment, Land, Water and Planning (DELWP)	Investigation of the approved expansion of large residual waste landfills at Ravenhall and Werribee
Investigation into the Transport of Waste into Queensland (2017) – a research team from different entities	I. Environment and Heritage Protection II. National Parks and the Great Barrier Reef	To review and assess strategies to limit the transport of waste across Qld
'Optimising the Use of Recycled C&D Waste Material in Civil Construction Projects' (2011) – Swinburne University of Technology (PhD thesis)	Swinburne University of Technology	To explore avenues for further uptake of recycled C&D waste in Australia
Construction and Demolition Waste Guide: Recycling and re-use across the supply chain (2012) – Edge Environment Pty Ltd	Department of Sustainability, Environment, Water, Population and Communities	To identify the issues of supply chain and review case studies of existing C&D waste supply chain

Note: The name of some of the authorities mentioned in this table may have now changed to other names.

The Australian legislation process is underpinned by consultations with the main stakeholders who are affected by developing regulations. Consultation drafts as a form of R&D call for submissions from industry, authorities, researchers and the public to ensure that any ensuing legislation provides a level playing field for all parties concerned.

Universities are important players in providing research services to decision-makers, regulatory authorities, industry and wider communities. In a study in Spain,[173] the role of universities as a key new actor in the enhancement of C&D waste management through the creation of a 3R model (reduce, re-use and recycle) was stressed. The researchers of this study noted: *'Studies on C&D waste often forget to include a key player in waste management … Universities can advance the possibilities of solving technical problems and applying new methods of recycling and new market-oriented applications according to the current legislation"* (Calvo et al., p. 422). According to this study, other contributions from universities in this respect include:

- availability of infrastructure and qualified academic staff to effectively develop R&D in this field so that the cost of concentrating research efforts can be reduced
- an ability to demonstrate recycling achievements to be applied in the recycled market, endorsing C&D recycled materials
- training of professional staff for the C&D waste and resource recovery industry through postgraduate courses for construction.

Another function of R&D is to raise public, industry and authorities' awareness. Indeed, several research studies demonstrated the positive role of evidence-based awareness received through R&D activities. This awareness underpins management practices towards the development of a market for C&D waste materials. The following are exemplary statements from these studies:

> *'More high-quality, site-specific and practical information about waste management strategies needs to be provided via training courses and awareness campaigns to keep operatives informed about waste management practices and techniques … More educational activities are needed to help raise operatives' consciousness of the longer term social and ethical implications of their activities on site" (p. 749)*[174] .

[173] Calvo, N., Varela-Candamio, L. and Novo-Corti, I., 2014. A dynamic model for construction and demolition (C&D) waste management in Spain: Driving policies based on economic incentives and tax penalties. *Sustainability*, 6(1), pp.416-435.

[174] Teo, M.M.M. and Loosemore, M., 2001. A theory of waste behaviour in the construction industry. *Construction Management and Economics*, 19(7), pp.741-751.

'Improve major project stakeholders' awareness about resource saving and environmental protection" and 'improve operatives' construction skills through vocational training" were critical management measures in waste management" (p. 106)[175].

'Interviewees pointed out that enhancement of public awareness, by communicating the short-term and long-term benefits of waste management through social media and company newsletters, helps to improve waste management practices in construction projects" (p. 78).[176]

'If attitude towards construction waste recycling needs to be enhanced, then positive personal beliefs towards recycling must be cultivated through personal training and workshops" (p. 16).[177]

'In order to secure cooperation and engagement from the industry on implementing waste reduction and recycling practices, there needs to be a high level of awareness and knowledge of these issues among industry practitioners together with information and help to facilitate waste minimisation and recycling practices" (p. 47).[178]

R&D can also be employed to explore new opportunities for re-use of C&D waste materials. For instance, a study report[179] indicated that recycled brick and concrete could be used in the landscaping industry with competitive prices compared to alternatives. In the case of EfW, the research is needed to facilitate the use of energy produced in the local power grid.

Product stewardship: PS, EPR and take-back schemes are strong motivators for the establishment of a market. It is recommended that these schemes be regulated and implemented nationally because many of the potential participants work across Australian jurisdictions.

Regulatory support: It is vital that waste regulatory frameworks are set to be in favour of local market development and implementation of an effective circular economy. The issues that must be addressed in this regard are as follows:

1) Consistency in jurisdictional waste regulations throughout Australia.
2) Clarification on when a waste becomes a source and is not liable for landfill levy.
3) Illegal dumping and stockpiling activities are severely discouraged.
4) Consistent reporting obligations.

Geographical location and population density: Australia is a vast country with a relatively low population. The population is concentrated in capital cities, which challenges market development. As a result, long distances between waste origins, waste facilities and the place that receives recycled and salvaged C&D waste are regarded as a barrier to the development of a domestic market.

Supply chain: Providing an efficient and effective supply chain to the waste and resource recovery industry is instrumental in developing a local market for C&D waste. The supply chain for this purpose needs to consider the principles of the circular economy and be driven by the industrial ecology (symbiosis) concept.[180] An effective supply chain system can assist in the implementation of

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[175] Yuan, H., 2013. Critical management measures contributing to construction waste management: Evidence from construction projects in China. *Project Management Journal*, 44(4), pp.101-112.

[176] Udawatta, N., Zuo, J., Chiveralls, K. and Zillante, G., 2015. Improving waste management in construction projects: An Australian study. *Resources, Conservation and Recycling*, 101, pp.73-83.

[177] Tam, V., Le, K., Wang, J. and Illankoon, I., 2018. Practitioners Recycling Attitude and Behaviour in the Australian Construction Industry. *Sustainability*, 10(4), p.1212.

[178] Zou, P. X. W, Hardy, R. and Yang, R. J. 2014. Building and construction waste materials: Reduce, reuse and recycle - opportunities and strategies for the Capital region.

[179] Hyder Consultation Company. 2011. Management of construction and demolition waste in Australia. p.141.

[180] The wastes or by-products of one industry are used as inputs in another industry, thereby closing the material loop of industrial systems and minimising waste.

EPR and similar schemes, provision of stockfeed for waste recovery facilities, and motivating compliance with GS and Green Infrastructure (GI) tools requirements. The World Economic Forum[181] acknowledges that the circular economy approach can be applied to supply chains functioning at a local level, as well as those supporting complex global multi-tier material flows. Creating a supply chain is not straightforward, as it involves numerous actors, each playing their part in the delivery of supply chain objectives.

In Australia, a decade's worth of effort towards the creation of an effective supply chain has resulted in some limited success. New South Wales is the leading state in building a supply chain system for domestic waste. In 2009, the state established an organisation called the Australian Industrial Ecology Network to promote the concept of industrial ecology and identify the opportunities to make connections between waste producers and waste consumers. In 2012, the Department of Agriculture, Water and the Environment (then known as the Department of Sustainability, Environment, Water, Population and Communications) released a guideline[182] on the supply chain of C&D waste materials. This document primarily aimed to promote industrial ecology in the C&D waste stream and secondarily to showcase successful examples of C&D waste trade in Australia. Some of these examples demonstrated effective development of a supply chain system, particularly with respect to PS application.

The following are the key issues regarding building a supply chain system for C&D waste as identified in various Australian-based literature:

- initial resistance from stakeholders to accommodate new safety requirements for C&D waste trade[183]
- the inaccuracy of reporting of C&D waste such as stockpiles[184]
- decentralised purchasing systems are a challenge for most local governments[185]
- involvement of various subcontractors that limits control of builder or construction company over supply chain management[186]
- lack of strategic procurement and partnerships as key inhibitors towards a supply chain management framework[187]
- poor organisational communication across units to facilitate change[5]
- the Australian Government's main concern was health issues of occupants, particularly with regard to the lack of quality control[188].

The bottom line is that any efforts to create a supply chain for the C&D waste market need to be informed by various stakeholders' input so that the resultant product will be widely accepted and utilised. Recently, waste producers and consumers have appreciated the use of online platforms to trade valuable C&D waste. As depicted in Figure 15, currently C&D waste is loosely being traded through online platforms such as the Gumtree website and Facebook marketplace.

[181] World Economic Forum, Towards the Circular Economy: Accelerating the scale-up across global supply chains, January 2014.
[182] Edge Environment Pty Ltd. 2011.Construction And Demolition Waste Guide - Recycling And Re-Use Across The Supply Chain.
[183] Ibid p.35.
[184] Harris, C.M.T. 2017.A supply chain analysis of Construction and Demolition waste streams in Perth, Western Australia. Murdoch University. BSc thesis.
[185] NetBalance (2009) Green Purchasing in Australia for EcoBuy.
[186] Hyder Consultation Company. 2011. Management of construction and demolition waste in Australia. p.47.
[187] London, K., Siva, J., and P. Zhang. 2013. A supply chain management self-assessment framework for waste minimisation for the residential sector.
[188] Chileshe, N., Rameezdeen, R., Hosseini, M.R., Lehmann, S. and Udeaja, C., 2016. Analysis of reverse logistics implementation practices by South Australian construction organisations. *International Journal of Operations & Production Management*, 36(3), pp.332-356.

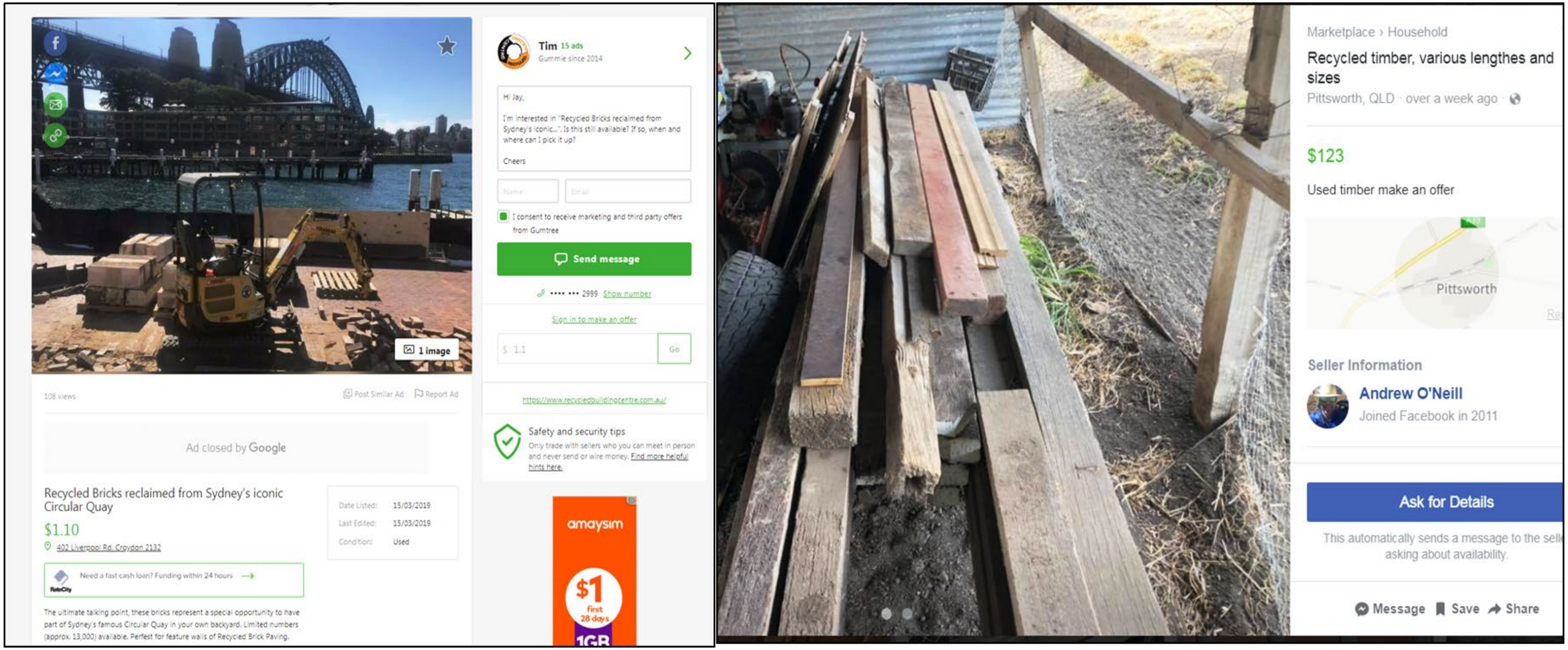

Figure 15. Examples of trading second-hand C&D material on different platforms
Source: Gumtree.com.au and facebook.com/marketplace

Sustainable procurement: SP can provide an incentive for further waste recovery. It is claimed that the implementation of SP has a 'spreadsheet's impact' on the flourishing of the C&D waste material market. In response to China's new waste policy, the then Minister for the Environment and Energy committed to supporting an increased use of recycled materials in the goods procured by government, and to collaborate on creating new markets for recycled materials[189].

In Australia, re-use of recycled materials is strongly encouraged under Ecologically Sustainable Development (ESD) and SP programs. At the national level, the *2018 NWP* sets a target to reduce waste generation through prevention, reduction, recycling, and reuse. This policy has also emphasised the application of the principles of a circular economy to support better and repeated use of the nation's resources. Two strategies to promote SP in Australia are at the forefront of this policy: Strategy 8 (Sustainable Procurement by Governments) and Strategy 9 (Sustainable Procurement by Business and Individuals). These two strategies urge the public and private sectors to promote demand for recycled materials and products containing recycled content.

The *2018 NWP* encourages the use of recycled C&D waste through SP. The other strong motivation for using recycled materials is the adoption of SP principles by government agencies, business, and individuals (Strategy 8 and 9, *2018 NWP*). The definition of SP accepted by the UN, the UK government and the Australasian Procurement and Construction Council (APCC) is:

> A process whereby organisations meet their needs for goods, services, works and utilities in a way that achieves value for money on a whole life basis in terms of generating benefits not only to the organisation, but also to society and the economy, whilst minimising damage to the environment.[190]

The Senate Environment and Communications References Committee suggests that local governments practice SP policies to ensure strong domestic markets for recycled material.[191]

The APCC *Australian and New Zealand Government Framework for Sustainable Procurement* is implemented by the federal government to pursue three aims when procuring goods, services, works, and utilities. These aims involve the reduction of environmental impacts, social impact and economic impacts through the procurement process. This framework also shares some premises with the circular economy in considering alternatives to the 'take, make and dispose of' approach. According to this framework, the government has a decisive role in providing a market driver for increased use of recycled materials in the goods and works that it procures. Therefore, the federal government and some local government developed SP guidelines to coordinate their decisions and actions towards SP and the purchasing of recycled materials. In 2012, state government of SA was the first authority to release a Sustainable Procurement Guide[192]. One year later, in 2013, the federal government also released the first Australian guideline on SP[1]. This work was further complemented by state-specific guidelines to tailor SP requirements in the ACT[193] (2015), NSW[194] (2017) and WA[195] (2017).

Green construction: Green construction has proved to hold a critical role in boosting the C&D waste market worldwide, particularly when it is implemented obligatorily and is a requirement for large-scale or government projects. In Australia, the two voluntary industry-based rating systems, namely GS and GI, promote the concept of green construction.

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[189] Submission to the Senate Environment and Communications References Committee. 2018. Never waste a crisis: the waste and recycling industry in Australia. p.83.
[190] Commonwealth of Australia, 2013. Sustainable Procurement Guide, p.8.
[191] The Senate Environment and Communications References Committee.2018. Less waste more recycling.
[192] SA Government. 2012. Sustainable Procurement Guideline.
[193] ACT Government. Sustainable Procurement Policy 2015.
[194] NSW Government. 2017. Sustainable Procurement Guide for Local Government in NSW.
[195] WA Government. 2017 WALGA Guide to Sustainable Procurement.

Investments in technology and infrastructure: Advancements in waste recovery technology and infrastructure are advantageous to domestic market development. Building modern and efficient facilities not only addresses public social and environmental concerns, but also provides better services to the waste and resource recovery industry through economies of scale. Government funding to improve waste and resource facilities together with effective law enforcement provides an impetus for further waste recovery activities and diminishes the reliance on waste export. An increase in the number of local infrastructures frees waste producers and collectors (waste responsible) from sending waste across the Australian jurisdictions such that it would be easier to implement the PP. Technically, a lot of waste minimisation practices and strategies, such as EPR, depend on the availability of technologically advanced local infrastructures. Several waste management strategies in Australia have highlighted the need to keep pace with changes in technology for smarter and more efficient waste management. Many waste and resource recovery stakeholders in Australia advocate that hypothecating landfill levies should be invested towards developing new technologies and infrastructure.

The use of new technologies, such as Building Information Modelling (BIM), GIS and the online marketplace can solve several issues towards the successful establishment of a market for salvaged and recycled C&D waste material.

Employment: The potential for jobs to be created through a local market is attractive to decision-makers, politicians and different stakeholders. Basically, the extent to which waste recovery activities can give rise to employment can be assumed to be proportional to the level of support provided by politicians and major parties in Australia. A study on jobs associated with a circular economy in the UK proved that re-use and recycling jobs would be geographically dispersed across the country, while remanufacturing jobs are likely to be more concentrated near existing manufacturing hubs.[196] Geographically dispersed job opportunities are particularly beneficial for Australian regional areas. The LGAT expressed that resource recovery operations employ more people and require greater investment in infrastructure per tonne of material compared to landfills. In WA, it is projected that an EfW facility can create 800 job opportunities during construction and 60 full-time jobs during operation. In 2017, Visy Australia, a company involved in resource recovery activities, announced its 10-year expansion plan which will create 5,000 manufacturing jobs and 15,000 indirect jobs.[197]

Another framework for operationalising the marketplace for C&D waste is put forward by Caldera et al (2019)[198]. This framework, as depicted in Figure 16, is emerged based on enablers and barriers identified in the relevant literature. These factors are categories under three major groups of governance, operational and market.

196 WRAP and Green Alliance (Julian Morgan and Peter Mitchell). 2015. Opportunities to tackle Britain's labour market challenges through growth in the circular economy

197 Waste Management Review. 2017. Anthony Pratt announces 5000 Visy Australia manufacturing jobs. 2017. Waste Management Review. http://wastemanagementreview.com.au/anthony-pratt-announces-5000-visy-australia-manufacturing -jobs/

198 Caldera, S., T. Ryley, and N. Zatyko. 2019. Developing a marketplace for construction and demolition waste: A systematic quantitative literature review. P: 1-12.

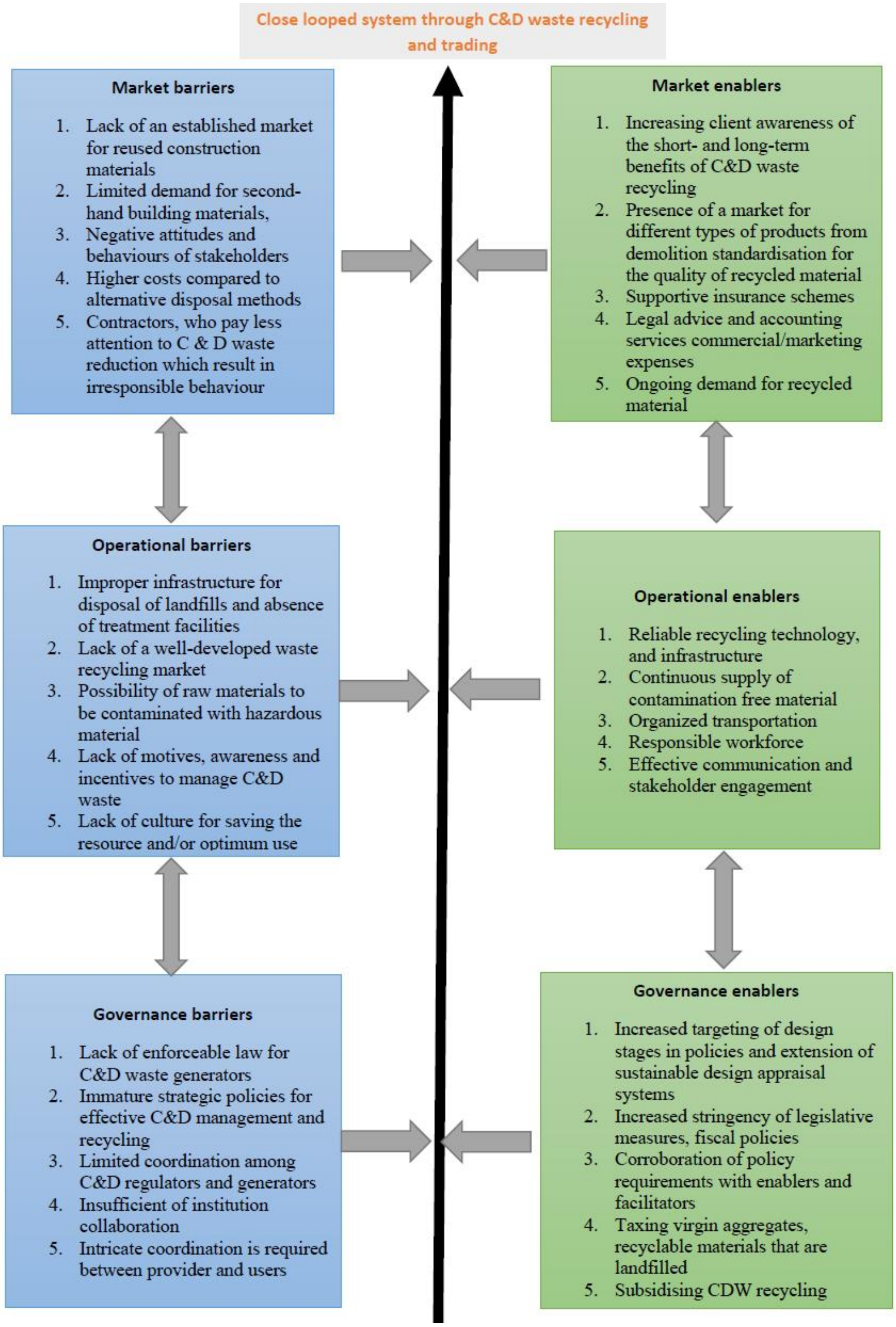

Figure 16. Emergent framework on enablers and barriers for developing a marketplace for C&D waste

Through the researchers' analysis it was evident that market-based policy instruments could be developed through taxes, subsidies, and other incentives, to encourage waste diversion from landfills, recycle and create a secondary life for waste material. To market the recycled material as a substitute for natural raw materials, it is essential to increase awareness and carry out promotional activities. Then a continuous supply of clean waste streams is necessary to produce high-quality recycled content that satisfies the given technical specifications and be economically competitive.

3.5.1 European Union context in developing C&D waste market

Originating in European countries, the concept of a circular economy dates back to the 1980s and 1990s[199]. However, it has only recently become prevalent at the highest level of European policies. In response to the rising prices of products, the EC introduced a 'flagship' initiative on resource efficiency. This initiative first ran through the *Roadmap to a Resource Efficient Europe*[200] and was then completed by a suite of policies gathered under the Circular Economy Package. In 2015, this package was replaced by *Closing the Loop – An EU Action Plan for the Circular Economy.*[201] The action plan consists of multiple main areas:[202] production, consumption, waste management, boosting markets for secondary materials, priority areas, innovation investment and 'horizontal' measures, and monitoring progress. C&D waste is among the priority areas. Under the market section, the main strategy is to propose standards for various secondary materials to foster markets.

According to the latest report on the achievements of this action plan, under the action plan, industry engagement has resulted in the adoption of the EU Construction and Demolition Waste Protocol.[203] This voluntary protocol has the final objective of increasing confidence in the waste management process and in the quality of recycled materials in the sector[204]. Following are the key findings from EU C&D waste-related achievements, lessons and best management practices:

- An increase in the costs associated with landfilling may induce the development of companies interested in C&D waste management.
- By fostering the C&D waste market, thousands of quality jobs could be created.
- Progress has been made towards harmonised EU markets for C&D recycled materials.
- A pre-demolition audit takes place to consider local markets for C&D waste and re-used and recycled materials, including the available capacity of recycling installations.
- When starting C&D waste recycling, one typically starts with the easiest materials for which secondary markets already exist.
- Decontamination is necessary so that hazardous particles will not contaminate the recyclable materials to prevent the reduction in markets' confidence in the recycled waste materials.
- In order to create a market for high-value materials, proof of satisfying quality is required; usually, the contractor is the one responsible for the quality confirmation.
- Tracking and tracing procedures are needed to further develop the market for recycled C&D waste materials through building trust in these materials.
- The end-of-waste criteria is the pre-condition for the development of a market.
- To make use of the harmonised European standards that apply to primary materials to also apply to recycled materials for quality control purposes.
- To develop a market for C&D recycled materials, a mix of landfill bans and high landfill taxes could provide the necessary incentives.
- Authorities at all levels can provide incentives to promote the use of C&D recycled materials.
- Market development is very sensitive to how the legal definitions of waste and recovery are interpreted in the member states.

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[199] Pearce, D. W. and R. K. Turner. 1990. Economics of natural resources and the environment. Baltimore, MD, USA: Johns Hopkins University Press.

[200] EC (European Commission). 2011. Roadmap to a resource efficient Europe. COM(2011) 571 final. Brussels: EC.

[201] EC (European Commission). 2015a. Closing the loop: An action plan for the circular economy. Brussels: EC.

[202] McDowall, W., Geng, Y., Huang, B., Barteková, E., Bleischwitz, R., Türkeli, S., Kemp, R. and Doménech, T., 2017. Circular economy policies in China and Europe. *Journal of Industrial Ecology*, 21(3), pp.651-661.

[203] European Commision. 2016. EU Construction & Demolition Waste Management Protocol.

[204] EU Construction and Demolition Waste Protocol and Guidelines.2018. https://bit.ly/3vjiA9B

3.6 Conclusions and recommendations

The management of C&D waste is largely driven by economic factors. These economic factors may motivate or discourage waste management practices among the main stakeholders. This review has identified the influential economic factors and explored how these factors may impede or boost the C&D waste and resource recovery industry in Australia. Furthermore, it provides recommendations to enhance C&D waste management in Australia.

3.6.1 Economic factors

A review of economic factors demonstrated that there is a great number of issues that impact the economy of C&D waste management. This impact is even more evident when it is to be managed in a circular economy. These issues include economic factors (for example, fiscal incentives and disincentives) and non-economic factors with economic results (for example, best management practices and policy approaches). The combination of these is purported to shape C&D waste management in Australia. While some of these issues are currently being implemented and experienced, others are recommended for changing the C&D waste management landscape in Australia. Lastly, some of the issues identified can act in both ways (for example, limiting and boosting C&D waste management practices), depending on settings; therefore, a separation between drivers and motivators is not possible at this stage and postponed to after a survey with the main stakeholders. Table 33 lists and briefly describes these economic focused factors.

Table 33. The list of economic factors affecting the Australian C&D waste management system.

No.	Factor	Description
1	Landfill levy	The imposition of a levy in most cases would provide motivation for further waste recovery; in certain circumstances it may inflict adverse consequences
2	A new destination for C&D waste	Finding new replacements for China's waste market in the short term is beneficial, but in the long term can be a deterrent factor for domestic market development
3	Levy waiver/subsidisation for waste recycling residual	It motivates further C&D waste recovery and subsequently market development
4	Levy waiver for waste recycling contaminants	It motivates further C&D waste recovery and subsequently market development
5	Penalty for illegal dumping and stockpiling	Enforcement through monetary penalty is an effective tool to enhance C&D waste recovery activities
6	Government investment in technology	Technological advancement in various levels of C&D waste management produces positive results
7	Government investment in the establishment of waste recovery facilities	Availability of waste recovery facilities would motivate further C&D waste recovery
8	Transport	Depending on the circumstance, the cost associated with waste transport is both a motivator (PP) and a barrier
9	Cost of separation at the construction site	A great barrier towards effective C&D waste recovery or re-use
10	China waste policy	It is a short-term barrier and a long-term motivator economic factor
11	Levy waiver for clean fill	It encourages re-use of clean C&D waste in construction projects
12	SP	It motivates waste recovery and subsequently market development
13	Employment	Jobs created by developing the market and establishment of more waste recovery facilities is a significant economic factor
14	Deposit/refund scheme	Application of this economic-based policy can produce positive results for the C&D waste stream
15	Green construction	Mandatory green rating systems would have a significant economic outcome for the construction industry
16	Development of the domestic	It is a cornerstone of the circular economy for C&D waste

No.	Factor	Description
	market	
17	EPR	Effective policy approach with economic responsibility for C&D waste among various stakeholders
18	A low population and long distances	The low population of Australia and long distances are regarded as economic barriers
19	PS	Effective policy approach with economic responsibility for C&D waste among various stakeholders
20	Supply chain network	A fundamental economic factor that boosts the domestic C&D market
21	Cradle-to-cradle approach	Though design out waste and design for disassembly can facilitate effective waste recovery, the cost for implementation of these might be perceived negatively by manufacturers and construction companies
22	Discounted 'emission trading scheme' credits	Necessary to relieve economic burden on waste recovery facilities
23	Government investment in R&D	Government funding
24	PP	Is both a barrier and a motivator: it is a barrier when there is no local market for a C&D waste produced in a region; it is a motivator for developing a market and establishing a local waste recovery facility

Drawing on the factors listed in Table 33, the following model has been developed. The model was modified using the input from survey participants has been received. The red lines represent existing practices and policies, and dotted green lines are denoting practices, policies and issues that are identified in this literature review (Figure 17). For better resolution and quality maximise the view.

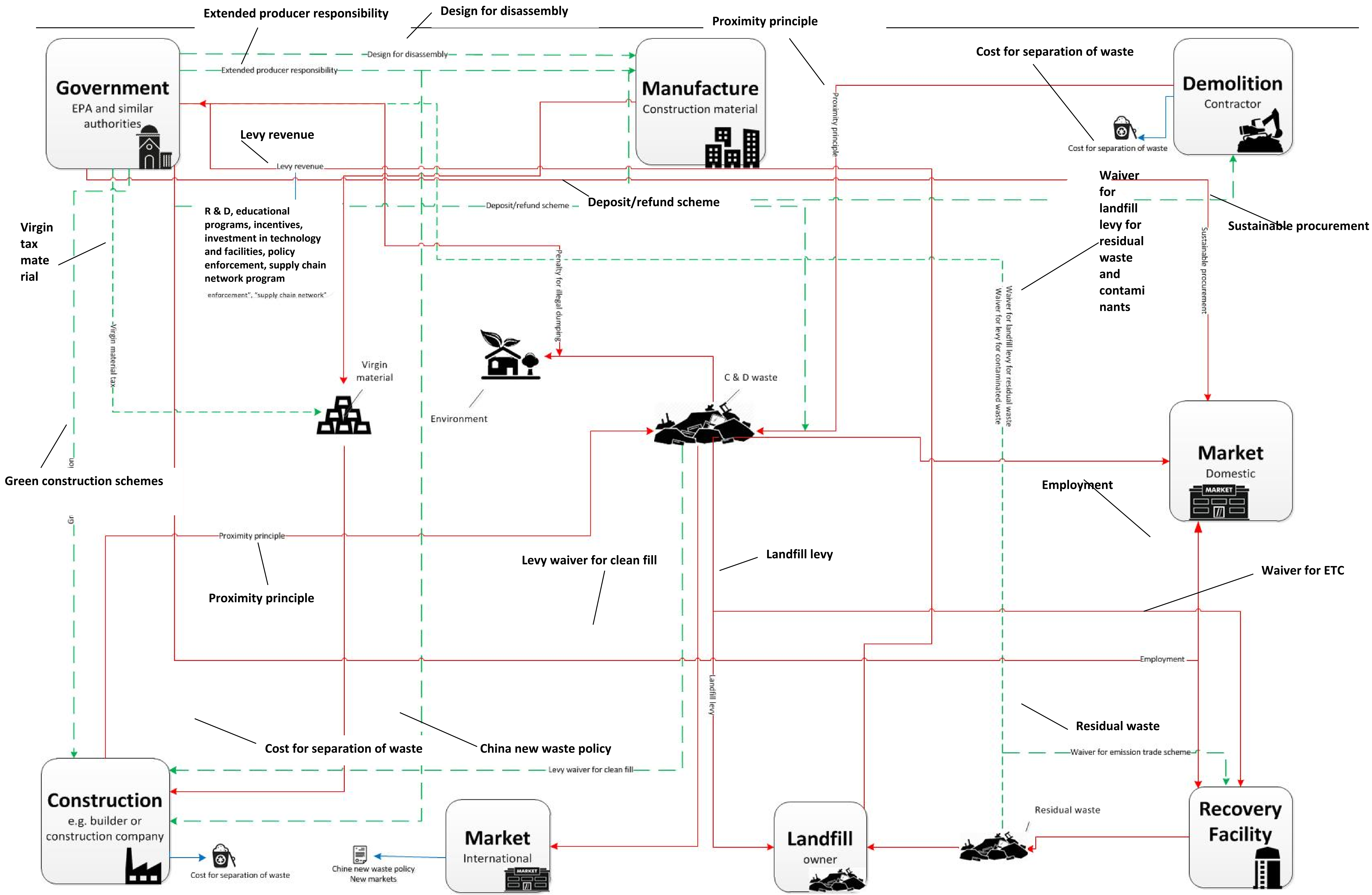

Figure 17. Model of economic factors for C&D waste flow.

3.6.2 National level reforms

Following the identification and review of the economic factors involved in C&D waste management, some recommendations are provided. These recommendations, which are aligned with circular economy principles, aim to provide a platform for the development of a market wherein different stakeholders, from material producers to waste generators and from waste recovery facility owners to end-users can smoothly trade salvaged and recycled C&D waste materials.

These recommendations primarily emerge from the following sources:

- review of national jurisdictional legislation, waste policies and strategies
- review of national and jurisdictional reports, consultation and review drafts, and submissions to the Senate Environment and Communications References Committee
- review of peer-reviewed and valid research publications.

In total, 17 strategies were found to enhance C&D waste management across Australia. It is expected that these recommendations will be modified when the project has completed interviews with jurisdictional EPA and waste industry representatives, and the interviewees' views are gathered and analysed. Almost all of these recommendations can be incorporated in jurisdictional legislation, and their benefits can be achieved when they are supported in primary legislation and subordinate regulations. These strategies are either economically driven practices or policies, or directly and indirectly produce economic benefits for C&D waste management:

1. Waive or reduce landfill levy rates imposed on recycling residuals, as is being practised in NSW for metal recovery, to boost waste recovery activities.
2. Provide waivers or discounted levy rates to recyclers for disposing of contaminants that enter the recycling stream.
3. Adjust levy rates to produce the best possible results.
4. Make EPR and similar schemes mandatory for greater impact and compliance.
5. Invest in technologies and infrastructure to accommodate the growing quantity of C&D waste.
6. Impose a tax on raw materials extraction and import.
7. Consider a waiver on GGE schemes for recovery facilities through an ETS and carbon tax (if introduced).
8. Invest in attitudinal change through R&D programs leading to raising C&D waste stakeholders' awareness.
9. Mandate GS and IS principles with respect to waste minimisation or to award construction projects that support and fulfil the existing GS and IS requirements.
10. Give the Australian Government the main responsibility for coordinating efforts to develop local C&D waste markets.
11. Support the development of an efficient and effective supply chain system.
12. Promote, appreciate or mandate SPs within the public sector.
13. Clarify when waste ceases to be waste in the jurisdictional waste legislative framework so that consumers can take advantage of clean fills for levelling projects and avoid landfill levies.
14. Review existing waste regulations to consider further support for waste recyclers.
15. Promote a cradle-to-cradle approach in the design and manufacture of construction materials.
16. Establish a marketplace that facilitates the trade of salvaged and recycled C&D waste material.
17. Mandate developing and keeping as-built and as-renovated plans, including a bill of quantities. Having these registered in a permanent database would assist the task of applying EPR and similar schemes at later stages.

4. Waste Marketplace Models: Worldwide Successful Examples

4.1 Introduction

This report presents the results of a literature review on the successful national and international models of the marketplace for various waste management streams, including C&D waste. Firstly, the Australian waste recovery as a significant contributor to the establishment of C&D waste marketplace is briefly analysed, followed by a case study on working mechanisms of waste management and resource recovery in demolition projects. Next, experiences obtained in the Australian context are presented. Lastly, the international practice in the establishment and maintenance of on-line marketplaces are browsed, and where possible, their functioning model is discussed.

4.2 Waste management and resource recovery industry

People operating in the caste management and resource recovery industry in Australia are a significant stakeholder in the establishment and operation of the end market for waste materials. They have a pivotal role in creating an effective supply chain that is based on the cradle-to-cradle approach. Hence, it is worthwhile to review its characteristics in the Australian context. Following this review, a case study on the performance of waste recovery industry on demolition projects is presented.

According to the NWR (2018) this industry involves businesses that undertake collection, storage and/or management of wastes, excluding the wastewater treatment industry. The four key areas of activities in the industry include waste collection and transfer, sorting of waste, recycling and reuse and the final disposal of waste that cannot be recycled or reused into landfill. The overview presented below is extracted from the report prepared for the Senate's Environment and Communications Reference Committee (2018)[49]. The industry is comprised of private firms and government enterprises. Local government, for example, typically manages waste collection and transfer, and may provide landfill facilities. However, in many locations, local government has outsourced these activities to the private sector. Recycling is dominated by the private sector. Some of the significant companies undertaking to recycle in Australia include Visy, ResourceCo, Cleanaway, and Suez. Some stakeholders note that it is not a cohesive single industry 'but rather a range of industries with multiple sectors.

The industry employs 50,000 people and contributes over $50 billion per annum to the Australian economy. The size of the sector varies across the jurisdictions. For instance, in SA the industry has an annual turnover of about $1 billion, contributing around $500 million to Gross State Product and employs approximately 5,000 people. The recycling industry directly employs over 20,000 people and indirectly almost 35,000 people. Employment rates vary with the type of materials being recycled; organics recycling and composting businesses directly employ over 3,500 people12, while tyre recycling businesses employ around 250 people.

Case study: demolition projects[205]: in order to better understand the working mechanism in waste management and resource recovery industry, the case study approach was adopted. The case study analysis provided some useful information on how the industry manage the waste generated in . The following are the statements in responses to four questions about the working mechanism of a waste management company located in WA. These statements are provided by an expert in waste resource recovery industry (Materials Management Group) through personal (email) communication.

What are the main key areas of your company activities?

[205] During email (personal) communication with Jamie Bradfor 28.01.2020. Materials Management Group. https://bit.ly/2Qhz573

Our role was to perform the following. There were lots of activities involved but this is a high-level summary:

- *Prepare a materials management plan for a large demolition job in Victoria*
- *Identify all materials (40 waste streams)*
- *Develop a site materials segregation plan, and execute the plan*
- *Liaise with end receivers (scrap metal dealers, waste management companies) to apply their needs at site, rather than at the end location*
- *Record scrap metal rebates*
- *Provide an automated IT system to record all activities and milestones within the materials management plan*

How do construction companies determine their C&D waste fate?

Overall, the decommissioning/deconstruction contracting strategy will determine the scope of works and financial management per project. Large government projects and large public national/multinationals (Tier 1 Owners) would generally engage one Prime Management Company (PMC) who would work to analyse the various contracting strategies and present a preferred model to the Tier 1 Owner. The Tier 1 Owners are generally industry leaders and support the sustainable management of materials and waste. However, the cost for segregation would be reviewed with the value received from separation. This is not a straight 'dollar versus dollar' comparison, as there is a high element of reputational damage and risk exposure appetite that is applied to these comparisons.

Liaise with end receivers (scrap metal dealers, waste management companies) to apply their needs at the site, rather than at the end location. The PMC would present their required methodology as a scope of works (SOW) that would be tendered to demolition contractors (Contractor) to perform the work. Efficient PMC's would have researched the needs of the end receiver to ensure the Contractor was aware of how to present the materials by segregation and size. On large decommissioning/deconstruction jobs, this research and analysis can take months. The PMC would need to demonstrate to the Tier 1 Owner that the Contractor has been advised how materials are to be handled in a manner that eliminates unnecessary site work.

What is the motivation for recycling in the construction industry?

This is a heavily financially driven outcome. Any preference/mandate for recycling/segregation etc. needs to come from the top entity (likely even the regulators/government) and to direct that it be followed by the lower levels. The revenue generated from segregation/recycling can be significant and is a factor in determining 'who does what'. The higher entities want 'value' but the lower entities want 'actual financial benefit'.

Generally, companies with a demonstratable philosophy for sustainable management of materials and waste would clearly indicate their corporate preference for recycling, however, if the cost outweighs the perceived benefit it may be a difficult concept to have endorsed by management. Generally, the end receiver is the subject (material) matter expert would advise the PMC what eventually occurs with the material. It is important to note; both the Owner and PMC are usually not materials experts, and would be guided by the end receivers information. For example, on dealings with scrap metal companies, we can consider there to be only two Tier 1 companies (Simsmetal and One Steel). There are then dozens of mid-sized (Tier 2) and hundreds of smaller (Tier 3) scrap metal companies. The material is destined for Tier 2 and Tier 3 is generally on-sold due to *market demand to Tier 1 scrap dealer for export offshore for their financial gain. The Tier 1 contractors will sell materials to each other to support their production/financial goals. One Steel will use a smelter to produce steel for a truly recycled outcome in Australia, however, Simsmetal bundled steel would be destined for an off-shore smelter. General waste disposal contractors (Cleanaway, Veolia etc) have progressed from landfill managers to become large financial entities focussed on recycling and disposal as a revenue making industry. My opinion is they do not recycle because they are 'green' rather the recycle because they can earn significant revenue from the activity.*

Do waste generators (construction firms) pay for their waste to be collected/managed or they can sell their waste?

There is no set rule, it is typically a financial decision. I have seen the following methodologies applied by PMC's (or smaller demolition companies); The scrap metal company is paid to collect segregated material. This is contracted with a deduction by the scrap metal company for transport and steel value rebate. The general waste recycler is paid to collect the material. There is no contract for transport and product value and the general waste recycler will use landfill and/or keep all recycled revenue. The owner determines the PMC may keep/dispose of the material and no financial return to Owner is expected. In these instances, the PMC may factor rebates into their methodology/pricing/tender to offer the Owner a reduced fee for decommissioning/deconstruction services.

The rates are determined by the market value of the recycled product, distance from site to end receiver, and/or landfill operator cost for their service. Steel rebates vary considerably for copper, aluminium, stainless steel, carbon steel heavy metal, light metal, ferrous non-ferrous etc.

4.2.1 Waste data management in the industry

Lack of accurate and reliable waste data is considered to be a hindrance for C&D waste management and planning. At national level, following evaluation of the 2010 report, a methodology was agreed to assist in comparing data across different state and territory data sets, noting that differences in definitions, classifications and approaches to waste data exist between states. This methodology was used in the compilation of the National Waste Report 2013, which used 2010–11 data. A major challenge in national waste reporting is reconciling data from jurisdictions and industries that has been compiled using different concepts, definitions and methods. These differences can also be problematic for regulators and waste companies dealing with cross-border issues. To end this, in 2017, the Department of the Environment and Energy tasked Blue Environment and sub-consultants to prepare Improving national waste data and reporting[206]. This report documents the method and outcomes of the improvements program, including the agreed improvements. Sixty-five agreed improvements are documented, mostly focusing on the National Waste Report 2018. The improvements encompass expansions to the scope, corrections and adjustments, a better expression of uncertainty, improved data warehousing, a new approach to data visualisation, standardising non-hazardous waste data and reporting, and improvements to hazardous waste data and reporting.

At the jurisdictional level, some states have prioritised waste data system development. For instance, in WA Waste Data Strategy developed in 2019 to guide the actions to be be undertaken by the Waste Authority and the Department of Water and Environmental Regulation to improve waste data management in WA, and to ensure that the waste data needs of stakeholders are met[207].

[206] Blue Environment. 2018. Improving national waste data and reporting. Prepared for Department of the Environment and Energy.
[207] Waste Authority. 2020. Waste Data Strategy. https://bit.ly/3gkZGe6

Furthermore, in the National Waste Report (2018)[208] a series of measures that need to be taken to correctly reflect waste management and resource recovery activities is provided. Furthermore, based on the recommendations, a conceptual model is developed Figure 18 to scope future national waste reports.

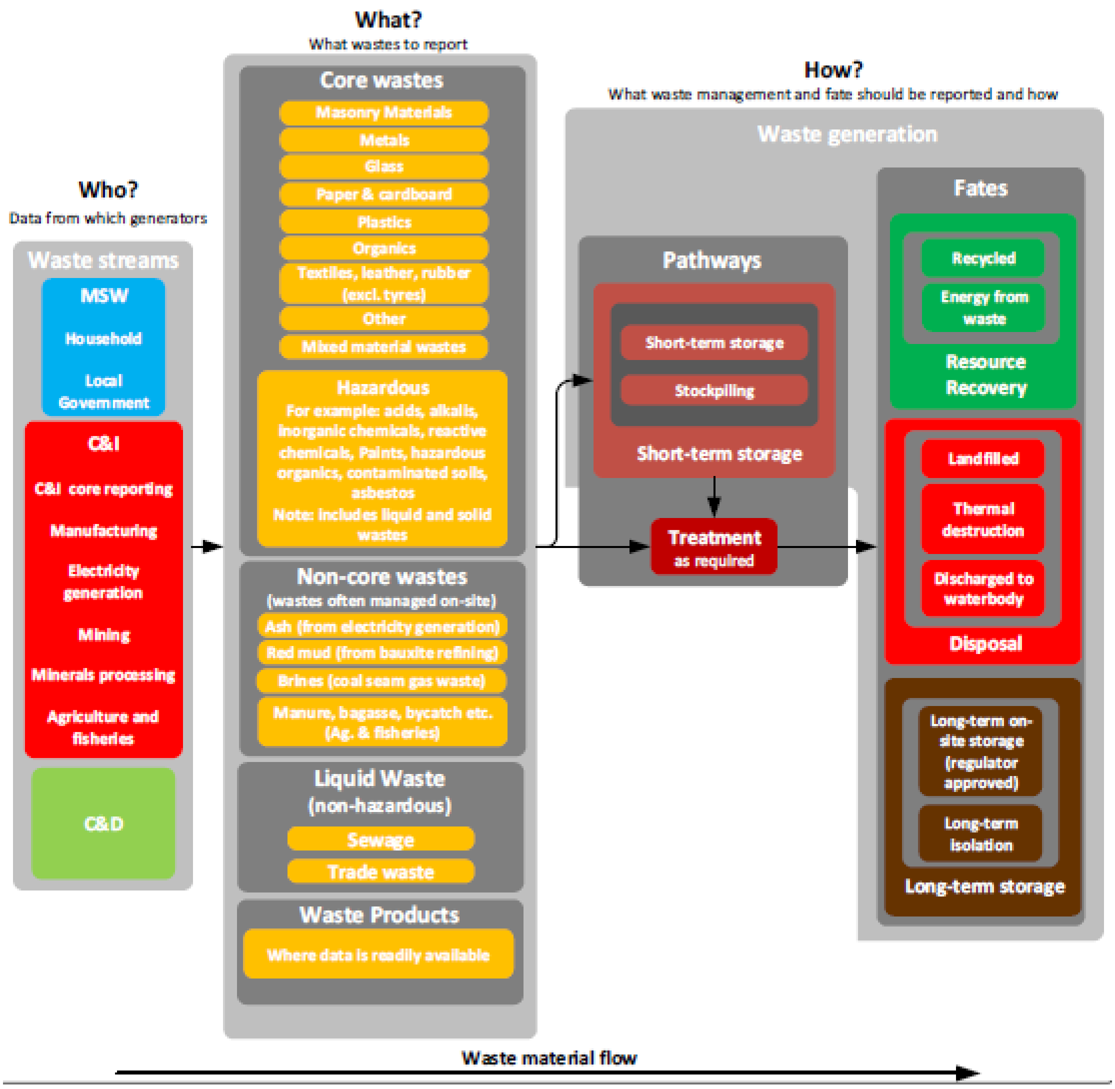

Figure 18. Potential future scope of national waste reporting.

The following measures and recommendations are applicable to C&D waste sector:

1. Waste reporting should include a core data set that is tracked over time and from which the primary indicators of waste performance are derived. The core waste data set should be defined with reference to types of source stream, management and waste category and type.
2. The core waste data set excludes:
   – uncontaminated soil (‘clean fill’) and rock.
   – waste generated by the main processes of primary production (for example, bark and sawdust from forestry operation, mining and mineral processing wastes) except when they are managed by the waste industry
   – pre-consumer waste that is recycled on-site as part of a manufacturing process

[208] Blue Environment. 2018. National Waste Report 2018. Prepared for Department of the Environment and Energy.

- waste used for producing energy where the energy production process is on the site where most of the waste was generated

3. In support of jurisdictional waste reporting, the core waste categories and types should inform requirements for waste facility data recording and reporting, and waste audits.
4. The core waste management methods are:
   - recycling
   - energy recovery
   - landfills
   - other disposal
   - treatment - short-term storage
   - long-term storage.
5. Waste management method and waste fate may differ. For example: waste managed via recycling may include contaminants that are subsequently disposed of; short-term storage is a management type but not a fate; the fates of waste sent to treatment facilities are not presently known. Waste reuse may also be reported where the data is readily available, for example, from tip shops. Materials and products that are reused (for their original or another purpose without reprocessing) are not waste because they remain in use. The fates of waste include:
   - Resource recovery, including recycling and energy recovery
   - Disposal, including landfill, thermal destruction, discharge to water body
   - Long-term storage, including long-term on-site storage (regulator approved) and long-term isolation.
6. Core waste data should be measured or estimated over the whole jurisdiction. The aim should be to count waste once only in the jurisdiction it was generated. Efforts should be made to avoid double-counting.
7. The primary measure for waste reporting is 'wet weight' tonnage.
8. A nationally agreed list of waste densities should be developed and used for converting volume measures to weight. (Hazardous waste densities are already published in the Australian hazardous waste data and reporting standard.
9. Data should be collected from:
   - all major waste management facilities
   - major waste generators that manage waste via on-site storage
   - ad-hoc facilities (such as construction sites undertaking on-site processing for offsite use) where the waste quantities collectively managed are significant.
10. Data on the jurisdiction of origin should be collected. Where practicable, waste facilities should record the jurisdiction of origin of incoming loads.
11. Significant data gaps should be filled through research and best estimates based on transparent logic applied consistently over time. Methods for filling significant data gaps may be developed and documented in a future national standard to ensure jurisdictions use similar approaches.
12. Jurisdictions should require disposal facilities to record and report data on single material loads by type
13. In collecting data from the recycling industry, jurisdictions should collect data on:
    - (primary focus) the quantity of material entering the recycling process, i.e. net of any contamination disposed of (this ensures all material is counted, and is counted once only)
    - the quantity of material received at the facility, so that increments to any stockpiles of unprocessed material are measured
    - the quantity of recyclables removed from the site, including from stockpiles
    - the markets for recyclables based on a set of broad market categories defined to protect commercial confidentiality.
14. Audits commissioned with the intention of providing a representative compositional understanding of a waste stream and fate should apply waste categories that ensure the

proportion of residual materials in the category 'other' (or similar) are less than 5 per cent of the total.

15. Jurisdictional waste reporting should include, but not necessarily be limited to, the primary indicators of waste performance that are listed in Table 15.
16. Waste loads in skip bins should be classified by stream as follows:
    - self-haul by a resident – classify as MSW
    - containing primarily masonry materials – classify as C&D waste
    - all others – classify as C&I waste.
17. Waste generated as a result of natural disasters should be classified as C&D waste.

4.3 Australian experience

This section presents the results of a literature review on the successful national and international models of the marketplace for various waste management streams, including C&D waste. In the first section, experiences obtained in the Australian context are presented. Next, the international practice in the establishment and maintenance of on-line marketplaces are browsed, and where possible, their functioning model is discussed.

RecycleBuild- This website (http://www.recyclebuild.com.au/pricing) provides an online platform for trading building materials under three main categories of new, used and unused across Australia. RecycleBuild is a Qld based company that manages this online marketplace and introduces itself as being '*committed to developing and operating websites that actively enable the participation of the building and construction industry to use building materials that reduce the ecological impact our built environment has*"**.** This platform provides an opportunity for sellers to advertise their waste for free if they are public or give away their materials. Construction companies and other businesses also can benefit from discounted fees for bulk advertisement. This company sells credit for advertisement and does not charge a commission fee to their account holders. The platform also uses another classification system to categorise the waste that is to be traded, as follows:

a. **Discounted building materials (BMs):** A price that is 20 per cent or more below the recommended retail price.
b. **Superseded BMs:** out-dated by new technology, fashion, new stock replacement selling at a discount price.
c. **Slow moving BMs:** stock that needs to be cleared from storage, selling at a discount price.
d. **Excess BMs:** over-ordered, wrongly ordered, wrongly made, no longer required, selling at a discount price.
e. **Second-hand BMs:** used and selling at a discount price.
f. **Recycled BMs:** where more than 20 per cent of the material is sourced from recycled materials.
g. **Able to be recycled BMs:** material that can be re-processed for future use.
h. **Leftover BMs:** building site excess. Leftover from the construction process.
i. **Manufacturer defect BMs:** not made to order, material carries a mistake, selling at a discounted price.
j. **Damaged BMs:** building materials from manufacturers, wholesalers or retailers selling at a discount price.
k. **Damaged BMs:** manufacturers defect, broken, knocked, scraped, selling at a discount price.

Table 34. Active platforms for trading waste in Australia

Platform	Fees	Geographical coverage	Performance
RecycleBuild	Free for public and giveaways Discounted fees for businesses for bulk advertisements	Across Australia	No available data
Facebook marketplace	Free	Across Australia	No available data
Gumtree.com.au	Free, unless advertiser request for special advertising services (for example, urgent sell)	Across Australia	No available data
ASPIRE	Free	Victoria	A cleaning product manufacturer reduces its waste by 75%
matX	Free	Across Australia	

matX is a combination of e-commerce and business systems. The platform purpose is to help people keep all types of resources in use and at their highest value. matX is different. It has been designed to mitigate the biggest challenges stopping better resource use including sector visibility, high speed delivery and mobile workforces. By working together, a commercially driven circular economy is now possible

ASPIRE The Advisory System for Processing, Innovation and Resource Exchange (ASPIRE) is an online marketplace (https://aspire.csiro.au/) which intelligently matches businesses with potential purchasers or recyclers of waste by-products. ASPIRE was developed by the CSIRO (Commonwealth Scientific and Industrial Research Organisation) under the State Government of Victoria's Digital Futures Fund in partnership with several Victorian councils, its operation officially kicked off in 2018. This system requires patrons to enter details about the type and quantity of their exchangeable inputs and waste materials (outputs). Using this data, ASPIRE's Supply Chain Options Model determines optimal sources and destinations for the materials, including options for aggregation with other local businesses, appropriate investment opportunities such as compactors for low-density wastes, and local recyclers. ASPIRE is deployed using existing established council and manufacturing business networks and supports local government business sustainability programs. It captures and codifies small-to-medium-enterprise (SME) material inputs, outputs (waste and by-products) and processes and has a powerful optimisation model that takes this data and provides an SME user with three things:

a. Suggested business-to-business (B2B) resource matches, both substitute inputs or sources and output destinations
b. Personalised search results to support the suggested matches
c. Case studies for related resource matches

4.3.1 Stories of failure in the establishment of a marketplace in Australia

Other platforms that stopped operation due to the various reasons include Yours2Take (Y2K), Waste Choices and Greenhands that could not complete their intended objectives for multiple reasons. The following provides some information on the characteristics of these marketplaces:

Yours2Take (Y2T)- This online platform was an initiative of the Riverina Eastern Regional Organisation of Councils (REROC), implemented in 2008 through its waste forum. REROC is a voluntary strategic alliance of 15 councils located in the eastern Riverina region of NSW. Y2T utilised a platform similar to eBay to allow users to upload items that they want to give away and acquire items that they want.[209] According to the statistics, this platform succeeded to attract 6,500 users since it was launched, with an average of 3,500 visitor registrations per month. During the operation of this platform, more than 1,200 items were given away. This platform was officially closed down in February 2016.

Waste Choices (WC)- The founders of this platform, which was launched in 2014, claimed that they had initiated Australia's first online marketplace for waste management and recycling, with the aim of helping businesses that want a simple, fast, transparent, cost-effective and compliant solution for waste collection, recycling, treatment and disposal. Through the WC platform, businesses of any size had the flexibility of posting a one-off project or an ongoing contract for the management of more than 30 waste streams. The service-seekers could select from a range of competitive bids from 14 national and state-based waste management providers, with the flexibility to award a project based on price or reputation of the provider.

Greenhands (GH)-GH was an online marketplace for recycling excavation, C&D waste and salvaged goods. GH also included a directory of resource/waste facilities, building contractors, construction sites, transporters, skip bins, rubbish removal and plant hire. This platform, however, never operated as promised due to unknow reasons.

4.4 International context

The experience of various countries through a review of marketplace case studies provides the opportunity to grasp the success factors in establishing a platform for exchanging waste materials.

4.4.1 Current conditions of marketplaces around the world

The four top countries for developing a marketplace for waste trading and C&D waste in particular include the US, France, the UK and Canada (Figure 19). According to statistics collected by an online tool called MarketplaceHUB,[210] the US, with more than 25 major marketplaces across its states, is leading the country in following circular economy principles with the focus on an increase in waste diversion to landfills.

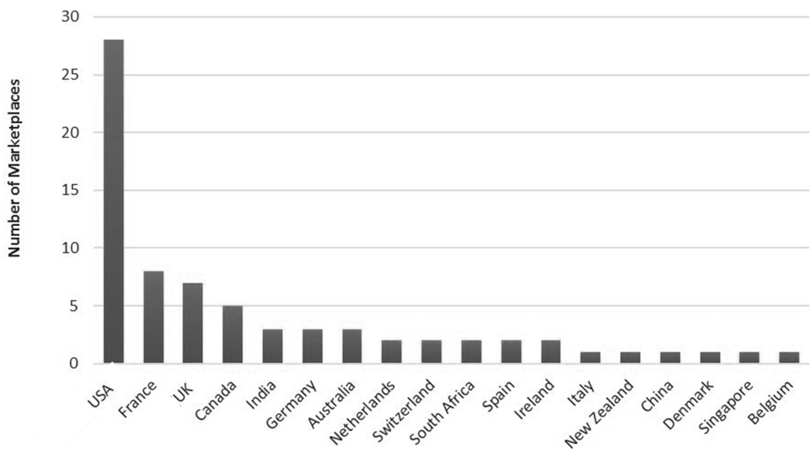

Figure 19. Number of secondary material marketplaces by country in 2016
Source: https://marketplacehub.org/marketplacestats/

[209] R&RAWG . 2010. Solutions for waste management in regional and remote Australia A compilation of case studies.
[210] Marketplacehub. 2019. A network of circular economy practitioners. [online] Available at: https://marketplacehub.org/ [Accessed 10 May 2019].

In analysing the types of materials that are traded in the study marketplaces, MarktplaceHub reports that metal and alloys are top materials being traded (Figure 20) in the study marketplaces. In the statistics, C&D waste holds the sixth position after plastic and polymers, biotic resources, E-waste, and other categories.

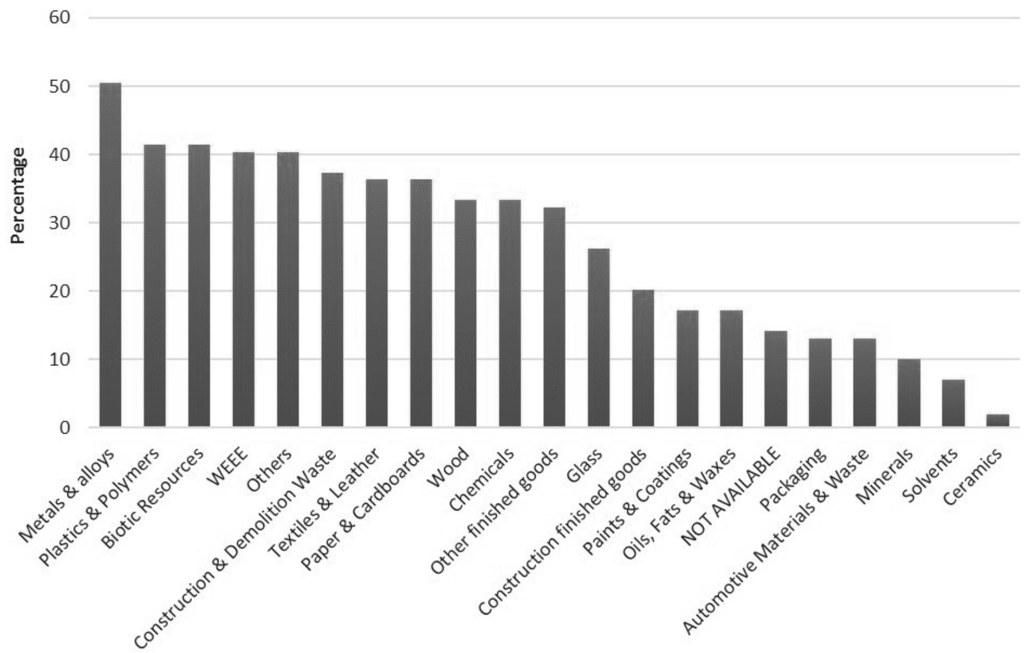

Figure 20. Main materials traded across marketplaces in 2016.
Source: https://marketplacehub.org/marketplacestats/

According to the data collected from 108 marketplaces' operation in various geographical locations around the world[211] (Figure 21), the four primary sources of income for markets are 'advertising', 'funding' 'membership', and 'public finance'.

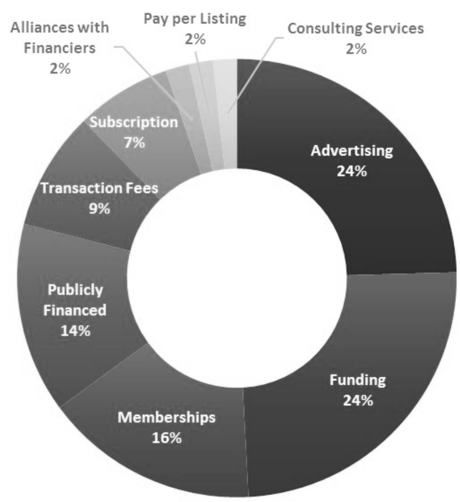

Figure 21. Sources of revenue for marketplaces across the world in 2016
Source: https://marketplacehub.org/marketplacestats/

The following section presents examples of waste marketplace operation in different countries. In total, seven marketplaces are reviewed to introduce demonstrated successful practices in these

[211] Marketplacehub.org. 2019. Marketplace Stats | MarketplaceHUB. [online] Available at: https://marketplacehub.org/marketplacestats/ [Accessed 10 May 2019].

online platforms. Furthermore, a few case studies are reviewed that did not survive the market conditions and were discontinued.

4.4.2 Success stories

2Good2Waste (US)- This is a US platform (https://2good2waste.com/) that provides the opportunity to trade waste across selected states in the US. Variations of this platform such as 2Good2Toss (https://2good2toss.com/) in Washington state, operate across different clusters of states in the US. The objective of these platforms is to facilitate the recycling and repurposing of materials and items that would otherwise be disposed at landfills and WtE facilities, in addition to promoting an important environmental ethic. The platforms using three simple steps:

- **Browse listings:** Find desired materials by the individual or multiple categories. Ask for email notification when new items in your category(s) of interest are posted
- **Post your own listings:** Register and establish a user name and password to protect your listings from unwanted changes
- **Make an exchange:** When you find an interesting posting, just enter your name, email address and zip code. You'll be given instant access to contact information. Make contact, negotiate a price, and arrange for pickup or delivery.

Materials Marketplace (MM) (US)- The MM is a national and global platform developed by the US Business Council for Sustainable Development to facilitate company-to-company industrial re-use. Through the cloud-based platform (https://pathway21.com/), MM matches traditional and non-traditional industrial waste streams with new product and revenue opportunities, ultimately enabling the culture shift to a circular, closed-loop economy. The platform provides an efficient user experience as well as the ability to capture and leverage data to produce actionable insights about materials and their potential uses. The MM actively analyses materials desired and available, and sends participants curated matches. Participants can also search for opportunities. Currently, 2,000+ businesses and organisations are participating in MM projects throughout the US. According to MM's partner website (http://usbcsd.org/materials), the Ohio MM division diverted 1,681 tons and creates US$150,000 in disposal savings and value creation in its first year. This platform extended its services to a few other countries, namely Turkey (http://turkey.materialsmarketplace.org/), Vietnam and Israel (https://www.israelmm.org.il/).

MarketplaceHub- International- The MarketplaceHub (https://marketplacehub.org/) is a tool designed to foster a sustainable use of resources through accelerating business-to-business re-use opportunities for secondary materials worldwide. Its website has developed a map that gives an overview of 108 existing materials marketplaces and industrial synergy networks around the world (Figure 22), searchable by materials or location Currently, there are 39 marketplaces that can handle C&D waste materials.

Figure 22. Interactive map that locates marketplaces around the world
Source: https://marketplacehub.org/marketplacestats/

This online tool also regularly conducts market studies and analyses to identify the main challenges to the sustainable operation of waste marketplaces. The investigation of marketplaces has shown that there are eight major challenge categories. Table 35 presents the summary of these challenges.

Table 35. Major categories of challenges to the sustainable operation of waste marketplaces.

Challenge catergory	Description
Price volatility and international competition	Secondary materials often have a hard time competing with the prices of primary raw materials; this may be due to fluctuating commodity prices and/or oversupply due to large import volumes
Lack of knowledge and information	Access to information is a significant hurdle for companies trying to acquire secondary materials including: supply location, quantity and frequency, price transparency and quality; at the same time, companies trying to find alternative uses for their materials often are unaware of interested buyers
Logistics and transport	Irregular delivery frequencies, material transportation permitting, and risk of holding-area contamination all present challenges to logistics companies
Quality	Procurement departments may be hesitant to buy secondary materials because of potential contamination, low or unknown purification rates, no third-party testing, or lack of performance guarantees
Regulatory	Regulations can create challenges for companies trying to exchange secondary materials in transporting across borders, variations in the definition of 'waste' and end-of-life criteria, or in determining what qualifies as hazardous materials
Technical	Processing waste and by-products into marketable secondary materials is not always economically feasible given the technology available; for many materials, improved collection and sorting innovations are needed to put secondary materials on par with virgin material prices
Trust	As with any supplier–buyer relationship, trust must be established before materials or money is exchanged; the exchange of secondary materials requires another level of trust due to quality concerns and poor price transparency
Regular supply quantity	Companies that look to buy secondary materials expect consistent and regularly scheduled supply quantities as they would with primary materials; because companies produce widgets (not waste), they are under no pressure to deliver by-products of regular quantities

Salza (Switzerland)- Salza (https://www.salza.ch), an online marketplace founded in Switzerland, proposes a new internet tool that broadens the current practice of re-use in Switzerland. On this platform, owners can, for a modest allowance, publish a document on the building intended for demolition or renovation. It aims to allow architects, designers and artists to discover valuable elements that could be re-used in a new project. Salza puts the owner and the applicants in direct contact. After negotiations, they agree on all the modalities before dismantling.

Backacia (France)- Backacia is an online start-up (https://www.backacia.com/marketplace) that specialises in the re-use of building components. This marketplace was launched in France in 2017. The products for sale on the marketplace are either from surplus orders or deconstructed buildings of professional quality. The start-up has already attracted numerous customers, won several awards and attracted the interest of large construction groups.

National Industrial Symbiosis Program (NISP- UK)- The NISP was designed by International Synergies Ltd to address the challenge of lack of knowledge and access to information for cross-sector second-hand material transaction. International Synergies is the world's leader in the practical application of industrial symbiosis (the circular economy in action) methodology, tools and techniques. It provides capacity building, strategic consulting, industrial symbiosis delivery as well as supporting software and bespoke business resource solutions.

NISP was launched in 2003 (http://www.nispnetwork.com/) and has gained the attention of international organisations, governments and academia. The program produced a resource re-use database and management system – SYNERGie®. This software facilitates resource matching for users using an extensive library of experience. The platform allows companies to identify re-use opportunities and minimise their waste. Additionally, through SYNERGie®, companies are required '*to meet quality assurance protocol and audit requirements*",[212] a significant hurdle faced by most companies involved in secondary material exchanges.

First implemented in the UK, the program has now been replicated in more than 20 countries at the regional or national scale. It successfully engaged more than 30,000 companies on every continent, leading to the waste diversion of 47 million tons from landfill in eight years, which is equal to 42 million tons of CO_2 emissions. This program is often quoted in literature as an example of best practice; the model has even been described by the OECD as *'an excellent example of systemic innovation vital for future green growth"*.

This platform has now become part of a larger EC Horizon 2020-funded program – SHAREBOX. The program aims to enable the next generation of industrial symbiosis through 'ICT and data intelligence".[213] As part of SHAREBOX, SYNERGie 2.0 will generate automatic suggestions of synergies based on a set of criteria by providing companies with reliable and secure information to successfully identify synergy opportunities and enable resource use optimisation[214].

Austin Materials Marketplace (US)- The Texan capital city of Austin was the first to implement a Zero Waste Plan in 2009,[215] a strategy aimed at improving waste management to 'reach the City Council's goal of Zero Waste by 2040".[216] The plan highlighted that the economic loss related to the value of materials sent to landfill was more than US$40 million per year. In 2011, the city adopted the *Austin Resource Recovery Master Plan* in the quest of accelerating the implementation of the *Zero Waste Strategic Plan*. The aim was to increase waste diversion to 90 per cent by 2040. In its recommendations, the City of Austin urged to 'expand and improve local and regional re-use, recycling and composting programs" as well as 'involve the community through collaboration and

[212] International-synergies.com.2019. https://bit.ly/3aoAUWO
[213] Spire2030.eu. (2019). SPIRE projects' conference | SPIRE. [online] Available at: https://www.spire2030.eu/news/new/spire-projects%E2%80%99-conference
[214] SHAREBOX – SECURE SHARING Sharebox-project.eu. (2019). SHAREBOX – SECURE SHARING. [online] Available at: http://sharebox-project.eu/
[215] US EPA. 2013. Zero Waste Case Study: Austin | US EPA. https://bit.ly/3tya8CB
[216] Zero Waste by 2040 | Austin Resource Recovery | AustinTexas.gov - The Official Website of the City of Austin Austintexas.gov. 2019. [online] Available at: http://austintexas.gov/zerowaste

partnerships to achieve Zero Waste".[9] It is in this context that the Austin materials marketplace was launched in 2013 and considered a tool to foster the implementation of the Strategic Plan.

The aim was to increase waste diversion to 90 per cent by 20405. In its recommendations, the City urged to 'expand and improve local and regional reuse, recycling and composting programs" as well as 'involve the community through collaboration and partnerships to achieve Zero Waste"[9]. It is in this context that the Austin materials marketplace was launched in 2013, considered a tool to foster the implementation of the Strategic Plan. Being considered as an instrument to accelerate the application of the Waste Management Plan, the Austin Materials Marketplace was fully funded by the City of Austin. By contracting the management and operations of the marketplace to the U.S. Business Council for Sustainable Development, the City recognized that success depended on external subject matter experts.

As of September 2016, the Austin Materials Marketplace moved to a new revenue model. In reaching a sufficient rate of regular users, it is now able to transition to a network-supported model, gradually making it independent from the City of Austin[217]. Operating costs will now be offset through memberships, advertising and margins on transactions fees, similar to typical privately-owned marketplaces. This example illustrates how marketplace platforms can develop in an enabling policy environment and eventually achieve financial sustainability. Importantly, it shows how marketplaces are recognized as an instrument to implement a government-led initiative in an effort to transition to a greener, more circular economy.

Mjunction (India)- Mjunction, a joint venture by Steel Authority of India Limited (SAIL) and TATA Steel Limited, is currently the largest e-commerce platform for primary and secondary steel in the world (http://www.metaljunction.com/#sthash.RAnRARFv.j4dHo2Zd.dpbs). Established in 2001, this Indian marketplace conducts between 700 and 800 auctions each month[218], making it one of the main actors in online materials marketplaces. Initially focused on steel, Mjunction rapidly expanded to new -finance, e-selling, e-sourcing and e-Knowledge services for various goods such as steel, coal, automobiles and tea. The success of this marketplace can be partly linked to its e-sales process. The company's e-auction service ensures buyers and sellers a 'transparent pricing based on the market situation"[219]. This system, in addition to providing information regarding the availability and quality of materials, allows both parties to benefit from a trusted environment and pursue their exchange safely. The forward auction system awards the highest bidder of the material. In this process, buyers and sellers can see the price and the number of parties involved in the exchange at any time. They also can be assisted by 'tele-executives" during the process[11]. This mechanism allows members to save time in the negotiations, while being ensured of a fair price. Additionally, Mjunction provides logistics and inspection services. Quality ensured materials are delivered by Mjunction all over the country[11]. Establishing the e-auction service was neither quick nor easy. Mjunction had to initially overcome credibility issues and prove its platform was reliable and scam-free. After consistent efforts, the company's program matured by 2006[220]. The program is now supported by 'standard operating procedures" developed to run the auctions. Mjunction illustrates how secondary materials can be exchanged at a fair price agreed upon by buyer and seller. It was a pioneer in the e-auction system for steel[11] and maintains its leadership. This system can be a model for other online marketplaces.

[217] Austintexas.gov. (2019). [online] Available at: https://bit.ly/3x9o9ZP

[218] Martia, A. 2015. Mjunction runs world's largest e-marketplace for Steel and Coal | The CEO Magazine - India. [online] The CEO Magazine - India. https://bit.ly/3uVQbWO

[219] Metal junction case study | E Commerce | Sales Scribd. 2019. Metal junction case study | E Commerce | Sales. [online] Available at: https://bit.ly/3as8F9o

[220] Biswatosh, Prarthan, Vidyanand, Architects of the Indian Cyber Mandi, How Mjunction institutionalized e-auction in steel trade and other verticals

4.4.3 Failure story

SMILE- Ireland- SMILE (Saving Money through Industry Links and Exchanges), founded in 2010, was a resource exchange platform embedded in Ireland's national program for industrial synergies. The program drew on industiral symbiosis to focus on improving companies' abilities to re-use second-hand materials that would have otherwise gone to landfill. The inititative partnered with Ireland's EPA and other councils and boards.

According to a report released in 2016, after six years this program attracted 1,400 members, concluded more than 300 succeessful synergies and diverted 8,000 t of material from landfill. This amount of waste diverted is estaimated to have saved €2.1 million for the businesses involved. The process in this platform kicked off with the identification of synergies through the free online platform (http://smileexchange.ie/). Members would then benefit from technical support in completing the transaction. Delivered by consultants based in each of the three waste regions across the country, this service facilitated the exchange by providing materials reprocessing expertise. The other services provided by this platform included sending consultants to visit companies and provide them with personalised feedback regarding their exchange opportunities. The support team also facilitated the negotiations between parties to assist with removing the challenges that typically appear when trading secondary materials. In addition, the program provided opportunities for companies to find their potential partners by holding networking events throughout the year. Using this platform, companies could acquire secondary materials at competitive prices. Often, businesses also saved costs associated with landfilling. According to the program's newsletter,221 this platform produced some successful results for member companies. Table 36 summarises these results for various industries and waste streams.

[221] Scribd. 2019. SMILE CaseStudy Booklet2014 | Reuse | Recycling. [online] https://bit.ly/3tzQA0S

Table 36. Results achieved using SMILE resource exchange platform

Waste producer	Waste consumer	Improvement(s)	Figures
O'Donovan Engineering, with specialty in the design, manufacture and supply of products in the agriculture, construction and manufacturing sector	WF Recycling is a recycling company that specialises in non-metal waste and scrap	It stored the plastic reels for collection by WF Recycling once or twice per year	a. Diversion of 5,000 plastic reels (3.75 t) from landfill b. Saving €2160 per year in waste collection charges c. Saving 16 t in CO2 emissions by avoding producing new plastic
Murphy's Ice Cream manufactures ice cream, sorbet, sauces, tartlets and brownies with fresh, natural ingredients	Real World Combat & Fitness is a martial arts fitness gym that provides seminars, classes and private training groups focusing on martial arts, fitness, and health and wellbeing	Real World Combat & Fitness were interested in using unwanted Murphy's Ice Cream's egg whites for making health cakes and omelettes to increase the protein intake of its members	a. Exchange of 30 kg of egg whites per month (360 kg per annum) b. annual cost saving of €2,508 for Real World Fitness c. Murphy's Ice cream no longer has to dispose of the resource
Ummera Smoked Products specialise in the smoking of food products	Bantry Glass is a glass and glazing company	The SMILE team made a connection with Bantry Glass, which was looking for sustainable packaging solutions for its product to trade 200 unwanted polystyrene boxes from Ummera Smoked Products	d. Saving €100 in disposal charges and €200 on purchasing this resource themselves e. Expected turnover of 1,000+ boxes trade per year f. Annual cost saving of €1,000 per annum for the consumer g. Significant environmental protection by removing pressure form recycling and disposal of polystyrene represents a significant challenge in the current environment
PK Rubber is a waste management company with specialty in tyre recycling	Wilson Agriculture specialises in the design and manufacture of cow mattresses	SMILE connected the consumer, who was looking for crumb rubber to be used as filling for cow mattresses, to the producer of crumb rubber	a. Diversion of 600 t of crumb rubber from landfill b. CO2 reduction: 1,400 t c. Virgin material saved: 600 t d. Revenue for PK Rubber: €36,000
Agility Logistics is a global logistics leader with two business streamlines: commercial logistics and a portfolio of logistics-related businesses	IrishPackaging.com is a product packaging company that specialises in the design, print and production of all packaging needs and caters for both large and small orders	SMILE connected two companies to divert 500 kg per week of Styrofoam packaging from landfill – the producer has very large volumes of Styrofoam packaging from electrical appliances that is regularly sent to landfill; due to the nature of the packaging it cannot be recycled	a. Disposal cost saving for producer (€200 per week) b. The consumer saves on the cost of purchasing materials c. CO2 reduction: more than 2 t of CO2 per week
SuBar is a juice bar	Cheeky Cherubs is an Early Years' child care facility catering for up to 130 children	Through SMILE, SuBar, which had large white buckets complete with lids, were paying to dispose, and then sent them to the consumer who was buying in plastic containers to store toys, paints and arts and crafts etc.	a. Cost saving of €70 per month on buying about 20 containers a month; the annual saving is €840 b. Cost saving in disposal charges c. The consumer states the second-hand containers are stronger, therefore they tend to last longer
Denis Crowley & Co Solicitors is a general accountancy and tax practice	Fotaview Boarding Kennels is a dog kennel, grooming and chauffeur service	The consumer connected to the producer through SMILE for buying shredded papers as an alternative source of dog bedding	a. Cost saving on buying kennel bedding (€100 a month/ €1,200 per year) b. Cost saving in disposal charges a. Additionally, the consumer uses the paper removed from the kennels as garden manure
Hotel Keycards Limited is a supplier of door key cards for the hotel industry	ReMake Design Network is a network of designers in Ireland making products from	The producer had 15,000 unusable hotel key cards and through the SMILE platform used	a. Remake Design saved on the cost of buying a similar plastic material for use its workshops

Waste producer	Waste consumer	Improvement(s)	Figures
	waste materials; they run workshops, pop-up shops and exhibitions	them as a material for design workshops by consumer	(€3,450 for 15,000 key cards) b. Cost saving in disposal charges
IKEA is a chain store that design and sell ready-to-assemble furniture, appliances and home accessories	One Fine Day is a start-up business providing boutique, eco-sensitive camping for guests at a range of different carefully selected sites	IKEA's damaged, unsaleable and/or end-of-line stock product is supplied to One Fine Day; for instance, IKEA had 12 rugs/mats weighing up to 70 kg which were sent to the consumer to be used as comfortable, contemporary and eco-friendly grounding for the tents in their 'glamping' start-up business	a. Cost saving of purchasing 12 new rugs/mats b. Cost saving in disposal charges c. Diversion of 70 kg of unwanted from landfill/recycling

The SMILE program, however, discontinued on 31 December 2018, according to the company's website announcement.

4.5 Conclusions

The review presented some successful and unsuccessful examples of online platforms for exchanging different waste streams. In particular, the experience of Australia in running such platforms shows that the challenges encountered by these platform owners probably can impact on their sustainable operation over time. Furthermore, the insight gained from other countries highlights the need for extensive planning to run an online marketplace by experts in different fields such as supply chain management, logistics, construction industry, regulatory agencies and the like. Furthermore, it can be inferred that technologies that underpin these marketplaces play a key role in the effective exchange of waste materials across different sectors. A list of challenges provided by the MarketplaceHub is a good starting point for obtaining an understanding about the influential issues and aid in planning for finding solutions to overcome these issues.

5. An Economic Evaluation of C&D Marketplace

5.1 Introduction

This section of the report aims to cast light on the performance of a marketplace in the management of C&D waste in Australia. The fourth objective of this research is to conduct a feasibility study on creating a marketplace to connect organisations and industries across jurisdictions for trading waste. Particularly, the section presents comparative results of different waste management options using data derived from real-world case studies. The case scenarios include consideration of various waste management options. The comparison will help provide economic information to conduct a feasibility analysis for developing a marketplace to trade C&D waste. A hypothetical case study in a Melbourne inner-city suburb was considered to compare: 1) landfilling in metropolitan areas; 2) landfilling in regional areas; and 3) recycling. Waste disposal to a landfill is used as the base of comparison.

5.2 Methodology

The economic evaluation modelling in this research builds upon a framework that is developed and applied by Tran[222] (2017). To simplify the economic evaluation, several assumptions on the conditions of the study case scenarios are made. The assumptions are based on consultations with experts and previous literature in the C&D waste management context. These assumptions are listed below:

1. The costs of traffic control management are not considered
2. The levy charged for each volume of the waste is based on the state announced levy rate
3. The skip bins only contain C&D waste of 50 per cent of bins nominal capacity
4. Google Maps is used to estimate distances from the waste generation origin, construction site, to various waste landfill and recycling centres
5. The revenue lost from not selling recycled/repurposed materials is defined as the cost of waste materials
6. In this research, the aggregated information represents average values of cost and tonnage for waste materials. This method is better suited to the study scenarios as there is a lack of necessary information about certain waste materials

A case scenario is developed to capture how various the management of C&D waste in Australia economically perform. Table 37 presents a summary of the characteristics of these scenarios:

Table 37. Characteristics of the case study

Project	Characteristics of the project	Waste management strategy
Building a residential complex in Melbourne, Vic	Building a 12-story residential high-rise complex in the inner city of Melbourne	Waste produced from demolition and construction phases in this project are to be sent to a vicinity landfill, recycling facility and a further away regional landfill

5.3 Results

5.3.1 Landfilling

Landfilling is the worst option for the management of C&D waste. The scenario of the construction of a high-rise residential building in the inner city of Melbourne (suburb: South Yarra) was analysed to evaluate the economic aspects of this management option. The potential composition of C&D waste materials that were generated in the pre-construction and construction phases is tabulated in Table Table 38.

[222] Tran, V. 2017. Evaluating the Economics of Construction and Demolition Waste Minimisation and Zero Waste in the New Zealand Construction Industry. PhD Thesis. Auckland University of Technology.

Table 38. Waste generated during demolition and construction

Material	Quantity
Pre-construction/demolition	
Asbestos contaminated debris/waste	205,000 kg
Brick	3,000 kg
Clean fill	20,000 kg
Concrete rubble	2,000,000 kg
Tile	350 kg
Non-ferrous metal	6, 000 kg
Steel	120,000 kg
Construction	
Gib plasterboard sheet	45,000 kg
Timber	224, 000 kg
Plaster	1,500 kg
Brick	1,000 kg
Tile	900 kg
Steel	2,710 kg
Cardboard	1, 130 kg
Hardfill (mix of a few masonry materials)	20, 000 kg
General	100,000 kg
Total weight	2, 499,460 Kg ~ 2,500 t

In this scenario, the waste generated in the project is sent and disposed of in the nearest landfill, Altona North Landfill, that accepts C&D waste materials. Figure 23 depicts the travel distance and time for transferring the waste from the construction site to the studied landfill.

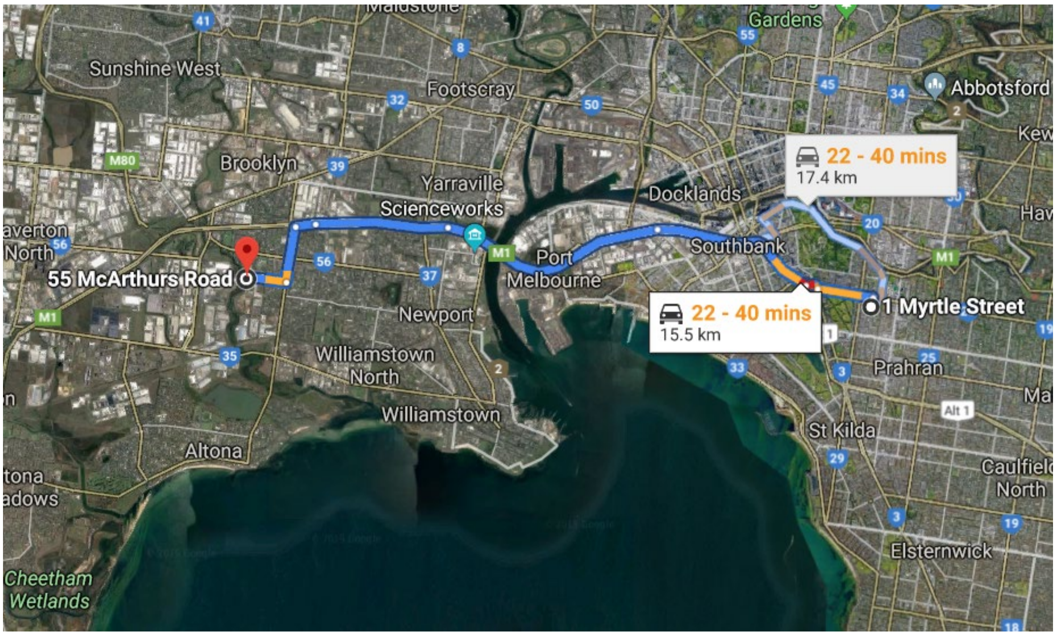

Figure 23. The 'origin- to-destination' travel distance/time of the study C&D waste load.
Source: Google map (2019)

Furthermore, the figures presented in Table 39 outline the base cost rates that are used in the calculations for economic modelling of C&D waste landfilling. The cost structure represents three cost clusters, namely waste collection, waste transport, landfill charges.

Table 39. Base rates used to estimate waste management costs

Description	Index	Amount	Unit
Charge-out rate per machinery (incl. labour)	Cr	150	$/h
Average fuel capacity of the machine		450	L
Haulage cost per trip	H	12.5	$
Diesel fuel (based on 25 L/h)	F	1.5	$/h
Loading capacity	C	20	tonne/skip
Loading factor	lf	1.5	N/A
Landfill levy rate in metropolitan Victoria	LL	64.5	$/tonne
Landfill levy rate in regional Victoria	LL	56.5	$/tonne
The number of machines	Ma	N/A	N/A
The unit cost of collecting waste	Uc	19	$/tonne
Total haulage cost per trip	H	371	$/tonne
The unit cost of waste sorting at a landfill	Us	49	$/tonne
The total time that is taken to sort out the waste load	T	1	Hour
Distance from a construction site to a landfill/recycling facility	d	N/A	km

Note: The unit costs and base rates are current as of 2019 and are based on Rawlinsons (2018)[223]

Several assumptions about the conditions of the case study are made. These assumptions are based on expert consultations, previous literature and include the following:

1. The costs of traffic control management are not considered.
2. The levy charged for each volume of the waste is based on the state-announced levy rate ($65.90/tonne in July 2020).
3. The levy is only imposed on 70 per cent of waste materials, the rest is recycled
4. The skip bins only contain C&D waste at 50 per cent of bins' nominal capacity.
5 Google Maps is used to estimate distances from the waste generation origin and construction site to various waste landfill and recycling centres.
6. Landfilling requires energy at two stages: carting waste away and processing the waste at landfill, with the energy unit cost calculated at $33.75/tonne.
7. The price of recycled material is $50 on average.
8. Only 65 per cent of waste received at the recovery facility can be recycled.

5.3.2 Landfilling in metropolitan areas

In this scenario, the waste generated in the project is sent to the nearest landfill that accepts C&D waste materials – Altona North Landfill. According to the calculations above, the total cost of C&D waste generated in this case scenario is $238,450, consisting of $38,750 (cost of waste collection), $115,325 (cost of waste landfilling) and $84,375 (cost of energy used). Refer to the main report for the full calculations.

5.3.3 Landfilling in regional areas

To understand the impact of distance/location on the economic performance of C&D waste management, the waste disposal in regional areas of Victoria is modelled. The waste generated in South Yarra (Melbourne) is dumped in a waste landfill facility located in the City of Ballarat to take advantage of a lower levy rate for regional areas. The landfill facility is 137 km away from the waste origin, and the waste transfer takes about two hours to complete. The mathematical modelling estimations show that the final cost for this management method is $501,705, which consists of cost for waste collection ($316,250), cost of waste landfilling ($101,080) and cost of energy used for

[223] Rawlinsons Publishing. 2018. Construction Cost Guide.

landfilling and waste transportation ($84,375). This cost is likely to be a major deterrent to landfilling in regional Victoria despite having lower levy rates.

5.3.4 Recycling

Recycling is a preferred method over landfilling and is generally one of the more common practices in C&D waste management systems in Australia. However, due to several reasons, this is not the case for all waste materials, areas and construction industry subdivisions. Mathematical modelling is conducted to understand the economic performance of this option as follows. The total cost of this method of waste management is $474,563, which comprises $122,500 (cost of waste segregation), $38,750 (cost of waste collection), $243,750 (cost of waste recycling), $57,663 (cost of landfilling of unrecyclable waste) and $93,150 (cost of energy used) minus $81,250 (the revenue obtained from selling recycled materials). The recycling costs in comparison with landfilling in metropolitan areas were about 99 per cent more expensive, whereas they were 5.4 per cent less expensive compared with waste disposal in regional Victoria.

5.4 Conclusions

Comparison between three scenarios for the waste load generated in the case study reveals important information on the major implicit and implied factors that can influence decision making processes in the construction industry. The following are remarks for these major factors:

1. Landfilling the waste, if it is not too far, is still a more economically viable option compared to waste recycling; this case study showed that landfilling is 76.6 per cent is cheaper than recycling
2. Transportation costs are an instrumental factor in the selection of the method to manage C&D waste; they can diminish other benefits such as lower levy rates that would have been obtained in the absence of high transportation costs,
3. Higher landfill levy is a strong disincentive tool to encourage recycling activities
4. Without a healthy and sustainable market, the minimum benefits that are currently attainable will be diminished which deteriorates the imbalance between recycling and landfilling in favour of landfilling
5. A consistent method for valuation of intangible costs such as achievement of a reputation for further recycling needs to be offered by the federal government

6. Brick- Resource Circular Economy: Opportunities to Reduce Waste Across the Supply Chain

6.1 Introduction

Brick has different applications in construction elements, notably walls and pavements. According to statistics, brick waste accounts for 50-70 per cent of the construction waste produced by urban redevelopment and 30-50 per cent by building operations[224]. It is still regarded as a viable option for residential construction due to several reasons that are outlined by Think Brick Australia[225] and presented below:

1. **Energy efficiency:** Bricks are high-density materials, which means they have the ability to effectively absorb and store heat energy. Lightweight materials do not have this quality. Correct use of thermal mass can moderate internal temperature values, averaging out day and night temperature extremes, which make a massive difference to residents' comfort, heating and cooling needs and energy bills.

2. **Noise control:**[226] The heavy mass of clay brick masonry is ideal for acoustic insulation, particularly for low-frequency noise, and cavity masonry walls have the added benefit of isolating impact sounds. It possesses an inherent resistance to the passage of airborne sound, which makes it a superior performer in attenuating low-frequency, airborne noise caused by building mechanical systems, elevators, amplified music, traffic and aircraft. Although some alternative systems may perform as well as masonry for frequencies in the speech range, these lower mass systems have difficulty insulating against low-frequency noise.

3. **Durability:** As one of the oldest building materials, bricks remain strong and look better with age, like fine wine. For instance, the Great Wall of China is a brick structure that has maintained its strength for more than 2,000 years. Bricks have kept Australian homes safe and comfortable, and they protect against extreme climates of heat and cold, bushfires, floods, severe storms and droughts. Bricks require little to no maintenance, saving owners thousands on upkeep compared to its lightweight construction counterparts. Building on the coast poses no issues for bricks. Exposure-grade bricks are made to withstand high salt conditions and are the most affordable materials on the market for the job.

4. **Fire resistance:**[227] Bricks are non-combustible and do not assist the spread of fire, making them ideal for building in bushfire-prone areas. Clay bricks normally don't suffer any structural damage after a fire and can be re-used even as load-bearing walls. Bricks are made in fire in kilns (over an oven-heated enclosure used for processing materials like bricks that require burning, firing and drying) at temperatures of up to 1,200 °C (a standard kitchen oven operates up to about 250 °C). Bricks alone do not fireproof a building but are not like timber and plastic, which are flammable, and glass that shatters in the heat. Building in brick ensures a strong foundation for protecting your investment.

5. **Structural capabilities:** Brick has continued to be a popular building material choice due to strong structural capabilities and intricate detailing. For any project, there are bricks to suit any building style. There are now more than 800 brick colours to choose from and many different finishes, from sleek, glossy blacks and metallics to rough-hewn rustic bricks with a handcrafted appearance.

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[224] Li SD. The feasibility of producing sintering building materials products using construction waste. Journal of Brick & Tile(in Chinese), 2005. 12, 36-38.
[225] Think Brick Australia> Brick Facts Thinkbrick.com.au. 2019. THINK BRICK > Brick Facts. [online] https://bit.ly/3efEuUa
[226] Think Brick Australia. 2014. Design Manual 11: Design of Clay Masonry for Sound Insulation.
[227] Think Brick Australia. 2014. Design Manual 5: Design of Clay Masonry Walls for Fire resistance.

6.2 Clay brick industry overview

Bricks are produced in several ways in terms of type, size and the material used; the variation is largely associated with the origin and time of the production. In Australia, in 2011, between 85 and 90 per cent of new dwellings are built with external brick walls and concrete flooring. However, this pattern has changed over the last few years, and the clay brick manufacturing industry (CBMI) is most affected. According to the latest IBISWorld industry report[228], the main key economic drivers, demand and supply industries, are tabulated in Table 40. The clay brick is extensively demanded by industries related to construction. The industries supplying to CBMI are categorised into three major groups of facilities and waste, transport and raw materials. An appropriately developed supply (demand) chain can maximise waste generation in these industries.

Table 40. The key drivers and the major industries dealing with clay brick (demand and supply)

Key Economic Drivers	Demand Industries	Supply industries
Dwelling commencements	House construction	Electricity, gas, water and waste services
Demand from house construction	Multi-unit apartment and townhouse construction	Road freight transport
Demand from hardware wholesaling	Bricklaying services	Rock, limestone and clay mining
Demand from multi-unit apartment and townhouse construction	Landscaping services	
Demand from C&I building construction	Commercial and industrial building construction	
	Institutional building construction	
	Hardware wholesaling	

Source: IBISWorld 2019

The IBISWorld 2019[228] report estimated that the CBMI generated $870.3 million in 2018-19, which is a 7.4 per cent decline compared to the previous financial year. This is not the only industry performance indicator that has seen a decline; others include individual added value (-8.2[229] per cent), the number of establishments (-5.1 per cent), number of enterprises (-5.7 per cent), employment (-7.2 per cent), export (-4.5 per cent) and domestic demand (-7.4 per cent). Figure 24 depicts the 6-year economic performance of CBMI with a sharp decline from 2015-16.

[228] Youl, T. 2018. IBISWorld Industry Report C2021. Clay Brick Manufacturing in Australia.

[229] The market value of goods and services produced by the industry minus the cost of goods and services used in production. IVA is also described as the industry's contribution to GDP, or profit plus wages and depreciation.

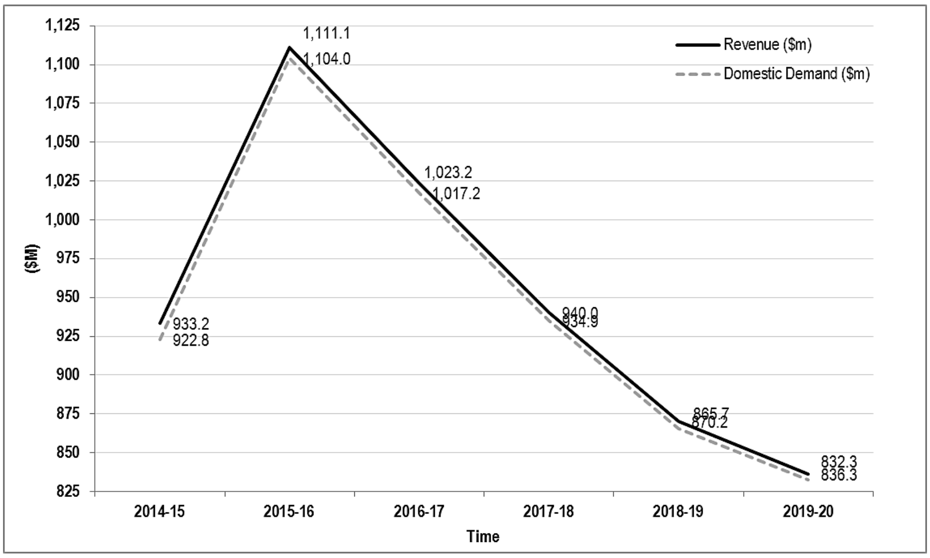

Figure 24. Statistics on CBMI (revenue and domestic demand) in Australia between 2014-15 and 2019–20
Source: IBISWorld 2019

The main reason for the decline in the CBMI economic performance is reported to be the fluctuations occurring in dwelling commencements, which heavily influences the industry's performance.[228] However, demand growth from the C&I building market provided some support to the industry's expansion. Another reason for such a decline relates to a change in the pattern of housing with specific preferred masonry materials. Australians have moved away from traditional single-unit housing, which tends to have a large brick component, towards multi-unit apartments. Generally, multi-unit dwellings use alternative cladding and structural materials to brick (for example, concrete and steel), as they provide easy-to-install and more cost-effective materials in high-rise buildings. Moreover, bricks are currently under pressure from alternative products (for example, polyurethane cladding) in single-unit dwellings because of a shift from double brick to single brick installation. Technically, in Australia, only new detached houses can use clay bricks as the dominant form of exterior wall cladding. This reflects the limited scope for the CBMI in the share of the residential housing market; notably, demand from house construction has declined versus multi-unit dwellings over the past five years.

The Australian CBMI has increasingly exported to nearby countries such as New Zealand, targeting rising construction activities. However, the corresponding revenue continues to underperform. Similarly, the import has increased but remains low relative to industry revenue. The rise in imports has largely been due to major industry firms such as Brickworks finding it cheaper to import bricks from overseas countries such as Spain rather than from factories in Western Australia.

6.2.1 Major producers in Australia

Industry firms manufacture clay pavers and bricks (excluding refractory bricks). The high transport costs and heavy nature of the product have generally resulted in manufacturers largely keeping to their own geographical market. Employment in 2019 was 1,492 people. The three main suppliers of bricks in Australia with the highest market shares are Brickworks Ltd (52.6 per cent), CSR Limited (21.7 per cent), Boral Limited (7.9 per cent) followed by BGC Pty Ltd (3-4 per cent). The following graph depicts the distribution of clay brick manufacturers across Australia.

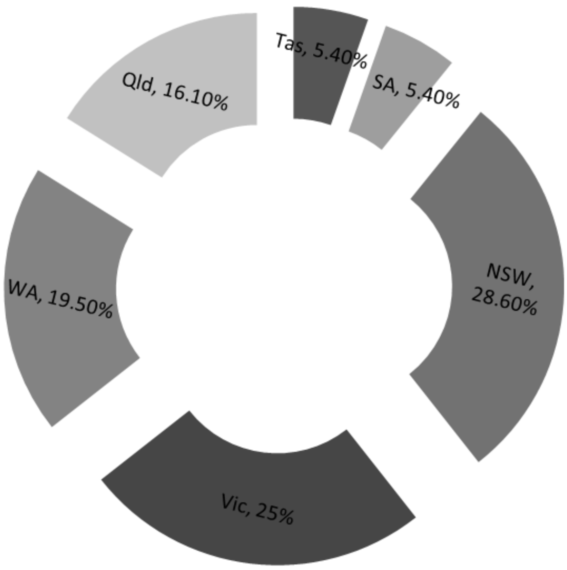

Figure 25. Location of (clay) brick manufacturers in Australia
Source: IBISWorld 2019

In response to market situations, these operators have restructured their operations over the past five years, closing inefficient plants, upgrading the existing facilities and introducing less labour-intensive production technologies. It is reported that this shift has improved efficiency and substantially reduced manufacturing (overhead) costs (for example, wages and depreciation). This, along with increased demand in two major capital cities (Sydney and Melbourne), has contributed to the industry profit over the past five years. The new technologies particularly focus on new products (brick fascia embedded on concrete or PVC panels) in the pursuit of improvements in the competitiveness and attractiveness of clay bricks compared to cheaper alternatives. Table 41 provides information on the financial performance of the major brick producers in Australia.

Table 41. The financial profile of the major brick producers in Australia.

Company name	Scope	No. of employees	Market cap
Brickworks Ltd	A public company that is ranked number 540 out of the top 2000 companies in Australia. The company generates the majority of its income from the Non-Metallic Mineral Product Manufacturing in Australia industry	1,483	AUD $2.5 bn
CSR Limited	A public company that is ranked number 198 out of the top 2000 companies in Australia. The company generates the majority of its income from the Non-Metallic Mineral Product Manufacturing in Australia industry.	2,960	AUD $1.66 bn
Boral Limited	A public company that is ranked number 79 out of the top 2000 companies in Australia. The company generates the majority of its income from the Non-Metallic Mineral Product Manufacturing in Australia industry	11, 916	AUD $6 bn
BGC Pty Ltd	An Australian private company, deriving revenue from construction services, manufacture of building products, mining, transport services, and property investment and management	3,272	AUD $1.64 bn

Source: IBISWorld 2019

6.2.2 Demand determinants

Residential construction activity largely drives demand for the industry's products. This includes both new construction, and repairs and alterations. Low-interest rates and population growth have caused dwelling commencements to rise over the past five years, supporting the demand for bricks. Increasing demand from non-residential construction, such as C&I buildings, has also positively influenced industry growth.

However, brick substitution trends have adversely affected industry demand. The use of bricks for house construction has declined over the past two decades, as builders' preferences have shifted to alternate structural and cladding materials (such as cement sheets and timber). In most cases, these alternate products are cheaper and easier to use relative to bricks. Changing consumer tastes, with preferences increasingly favouring multiple forms of exterior cladding on single dwellings, have also negatively affected demand.

Despite preferences shifting towards non-brick building materials over the long term, a fundamental demand remains for clay brick products. Bricks are bought for their unique structural qualities, such as thermal lag and durability, and their aesthetic appeal. As such, housing fashion trends also affect industry demand. Industry players have expanded their ranges of face bricks in response to growing consumer demand for brick finishes. This includes a trend towards using bricks in housing interiors for purposes such as feature walls.

Over the past five years, trends favouring the construction of medium- to high-density housing have constrained demand. Multi-unit dwellings have steadily increased as a proportion of new dwelling commencements over the past five years. Apartments and townhouses tend to be less brick-intensive than traditional houses. This is due to alternate materials, such as concrete panels and steel framing, being more practical to use and less labour-intensive, especially on high-rise apartment buildings. Export demand has little effect on the demand for clay bricks manufactured in Australia, due to the high cost of transporting bricks overseas. Figure 26 shows the main demands for Australia clay brick.

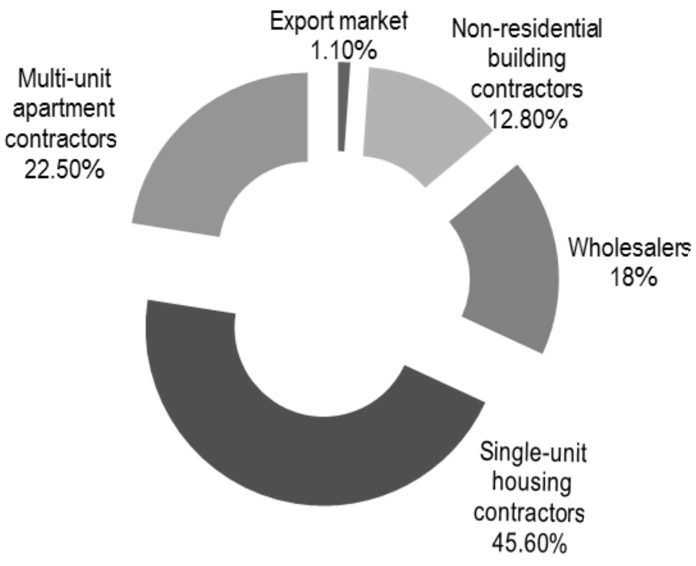

Figure 26. Main types of construction with the largest consumption of brick
Source: IBISWorld 2019

Home renovation activity also affects demand for the industry's products. Over the past five years, renovation activity has increased, as homeowners have benefited from low-interest rates to borrow funds to pay for renovations. Additionally, significant housing prices have led to consumers renovating their homes rather than buying a new property. Outdoor living spaces are one of the main areas of home alterations and upgrades, due to their increasing popularity among individuals. This has increased demand for clay pavers. Table 42 summarises the main reasons why CBMI is successful.

Table 42. Key success factors applicable in the CBMI

Key success factors	Description
Having a diverse range of clients	Manufacturers that offer a range of brick and paver products that cater to diverse customer markets can better maintain a stable revenue stream.
Ability to expand and curtail operations rapidly in line with market demand	Firms must achieve profitability at low volumes of brick capacity utilisation to survive dramatic cyclical downturns in the construction sector.
Access to high-quality inputs	Manufacturers must maintain access to good-quality reserves of appropriately located clay to produce high-quality clay bricks, which provides a competitive edge.
Economies of scale	Companies that can produce large volumes of high-quality clay bricks from large and efficient production sites generally have lower costs and can boost profitability.
Ability to compete on tender	Manufacturers that can secure competitive long-term contracts with large building contractors (the primary users of clay bricks) are better able to ensure a continuous flow of revenue.

Source: IBISWorld 2019

6.2.3 Raw materials

Clay is one of the most abundant natural mineral materials on Earth. For brick manufacturing, clay must possess some specific properties and characteristics. Such clays must have plasticity, which allows them to be shaped or moulded when mixed with water; they must have sufficient wet and air-dried strength to maintain their shape after forming. Also, when subjected to appropriate temperatures, the clay particles must fuse together[230]. There are three major clays that are used in brick construction, as follows:

Surface- This clay may be the upthrusts of older deposits or of more recent sedimentary formations. As the name implies, it is found near the surface of the earth.
Shales- This is clay that has been subjected to high pressures until it has nearly hardened into slate.
Fire- This clay is usually mined at deeper levels than other clays and has refractory qualities.

Surface and fire clays have a different physical structure from shales but are similar in chemical composition. All three types of clay are composed of silica and alumina with varying amounts of metallic oxides. Metallic oxides act as fluxes promoting fusion of the particles at lower temperatures. Metallic oxides (particularly those of iron, magnesium and calcium) influence the colour of the fired brick. The manufacturer minimises variations in chemical composition and physical properties by mixing clays from different sources and different locations in the pit. Chemical composition varies within the pit and varying manufacturing processes compensate for the differences. As a result, brick from the same manufacturer will have slightly different properties in subsequent production runs. Further, brick from different manufacturers that have the same appearance may differ in other properties.

6.3 Products overview

In 2018-19, the three main clay brick products in Australia are face bricks (65.5 per cent), common bricks (22.11 per cent) and clay pavers (12.4 per cent)[228] Figure 27 shows these forms of clay brick which are typically produced in the Australian CBMI.

[230] The Brick Industry Association. 2006. Technical notes on brick construction. 1-2.

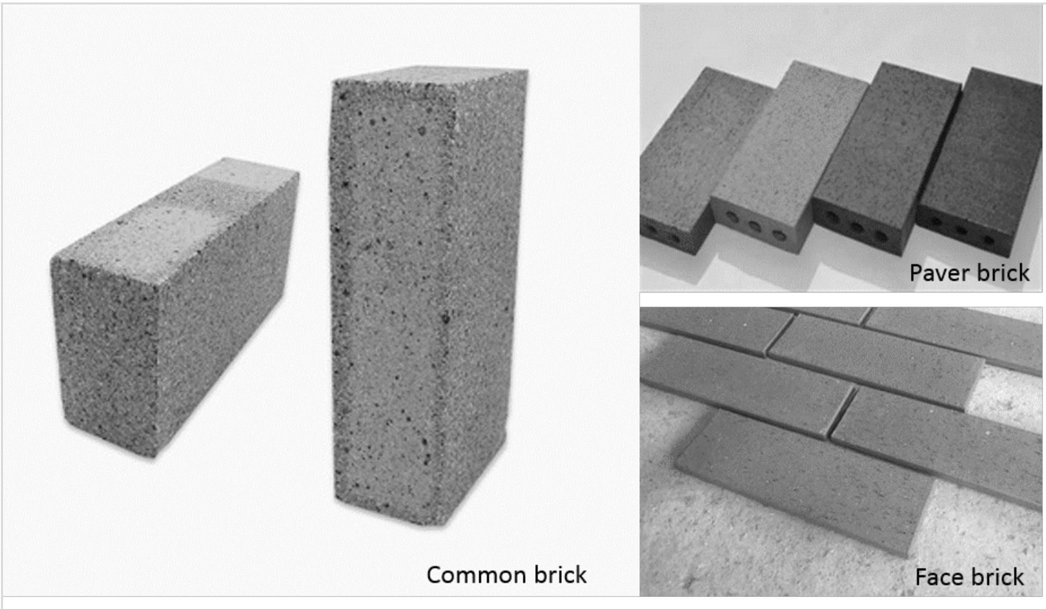

Figure 27. The main three forms of brick used in the Australian construction industry
Source: www.Alibaba.com

The following sections describe the properties of the three main bricks produced in Australia. The information on the material properties is extracted from the IBISWorld 2019 Industry report on clay manufacturing in Australia.

Face bricks-Face bricks are generally more aesthetically appealing than common bricks, as they have a smooth and accurate finish and uniform colours (Figure 27). These qualities make face bricks popular with both residential and commercial construction. Face bricks have increased as a share of revenue over the past five years, due to rising demand from residential construction. As a result, manufacturers have produced increasing quantities of face bricks, which attract higher prices and profit margins. For example, Brickworks, the industry's largest manufacturer, has increased its production of face and boutique bricks at the expense of other product categories. The aesthetic appeal and low maintenance costs of face bricks differentiate them from other cladding products such as timber. Face bricks are also able to better withstand the effects of wind, rain, and frost.

Common bricks-Common bricks generally fail to meet consumer standards for appearance (Figure 27) but they are satisfactory as non-face bricks due to their hardness and structural support qualities. Common bricks are usually hidden from view and used for internal walls and rear walls that are typically not exposed. As a result, these bricks are generally used in detached houses, which are more brick intensive. This product segment has declined as a share of revenue over the past five years, due to subdued demand from detached housing and greater activity from less brick-intensive multi-unit residential housing.

Clay pavers- Clay pavers account for a relatively small proportion of industry revenue (12.4 per cent) compared with other product segments. Pavers are generally used to form even floor surfaces for outdoor areas, such as driveways, patios, walkways and roads. Similar to bricks, pavers are manufactured in a variety of colours and textures. Clay pavers have increased as a share of industry revenue over the past five years, due to the rising popularity of outdoor living areas. This trend has increased demand for exterior paving installed in new and existing residential properties.

6.4 Manufacturing process

Although the basic principles of manufacture are fairly uniform, individual manufacturing plants tailor their production to fit their particular raw materials and operation. Essentially, bricks are produced by mixing ground clay with water, forming the clay into the desired shape, and drying and firing. The manufacturing process has six general phases (Figure 28):

1) Mining and storage of raw materials
2) Preparing raw materials
3) Forming the brick
4) Drying
5) Firing and cooling and
6) De-hacking and storing finished products

The information regarding brick manufacturing is taken from a technical note published by the US's Brick Industry Association. The following sections describe the six phases in brick manufacturing mentioned above, illustrated in Figure 28.

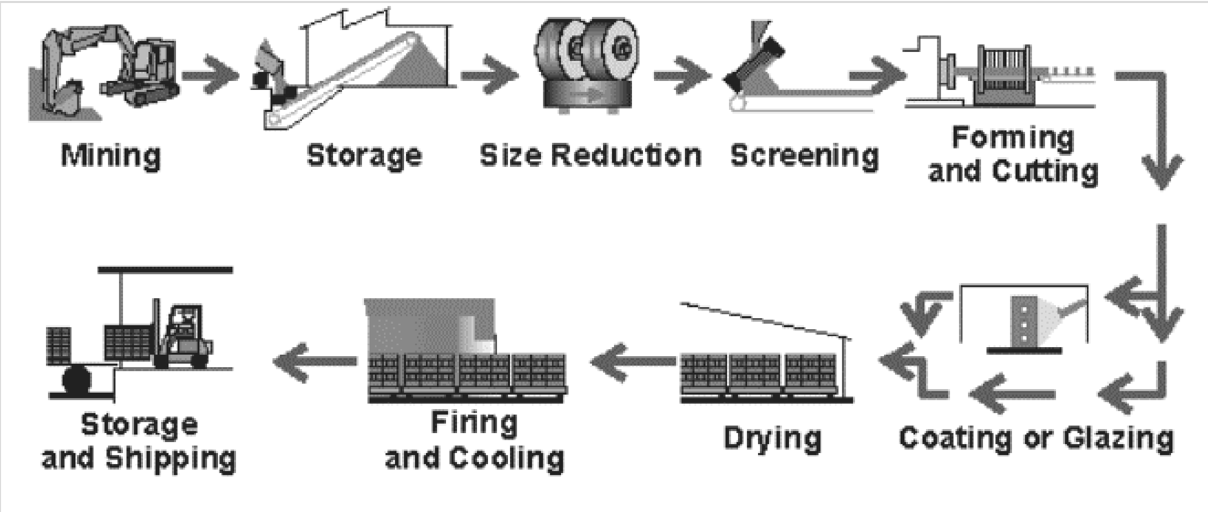

Figure 28. The typical process for brick manufacturing
Source: The US's Brick Industry Association (2006)[231]

Mining and Storage- Surface clays, shales and some fire clays are mined in open pits with power equipment. Then the clay or shale mixtures are transported to plant storage areas. Continuous brick production, regardless of weather conditions, is ensured by storing sufficient quantities of raw materials required for many days of plant operation. Normally, several storage areas (one for each source) are used to facilitate blending of the clays. Blending produces more uniform raw materials, helps control colour and allows raw material control for manufacturing a certain brick body.

Preparation- To break up large clay lumps and stones, the material is processed through size-reduction machines before mixing the raw material. Usually, the material is processed through inclined vibrating screens to control particle size.

Forming- Tempering, the first step in the forming process, produces a homogeneous, plastic clay mass. Usually, this is achieved by adding water to the clay in a pug mill, a mixing chamber with one or more revolving shafts with blade extensions. After pugging, the plastic clay mass is ready for forming.

There are three principal processes for forming brick: stiff-mud, soft-mud and dry-press.

[231] The Brick Industry Association. 2006. Technical notes on brick construction.

1) **Stiff-mud process:** In the stiff-mud or extrusion process, water in the range of 10 per cent to 15 per cent is mixed into the clay to produce plasticity. After pugging, the tempered clay goes through a de-airing chamber that maintains a vacuum of 38 cm to 73 cm of mercury. De-airing removes air holes and bubbles, giving the clay increased workability and plasticity, resulting in greater strength. The clay is then extruded through a die to produce a column of clay. As the clay column leaves the die, textures or surface coatings may be applied. An automatic cutter then slices through the clay column to create the individual brick. Cutter spacings and die sizes must be carefully calculated to compensate for normal shrinkage that occurs during drying and firing.
2) **Soft-mud process:** The soft-mud or moulded process is particularly suitable for clays containing too much water to be extruded by the stiff-mud process. Clays are mixed to contain 20 per cent to 30 per cent water, and then formed into brick in moulds. To prevent clay from sticking, the moulds are lubricated with either sand or water to produce 'sand-struck' or 'water-struck' brick. Brick may be produced in this manner by machine or by hand.
3) **Dry-press process:** This process is particularly suited to clays of very low plasticity. Clay is mixed with a minimal amount of water (up to 10 per cent), and then pressed into steel moulds under pressures from 500 to 1,500 psi (3.4 to 10.3 MPa) by hydraulic or compressed air rams. .

Drying- Wet brick from melding or cutting machines contain 7 to 30 per cent moisture, depending upon the forming method. Before the firing process begins, most of this water is evaporated in dryer chambers at temperatures ranging from about 38 ºC to 204 ºC. The extent of drying time, which varies with different clays, usually is between 24 to 48 hours. Although heat may be generated specifically for dryer chambers, it usually is supplied from the exhaust heat of kilns to maximise thermal efficiency. In all cases, heat and humidity must be carefully regulated to avoid cracking in the brick.

Hacking- Hacking is the process of loading a kiln car or kiln with brick. The number of bricks on the kiln car is determined by kiln size. The bricks are typically placed by robots or mechanical means. The setting pattern has some influence on appearance. Brick placed face-to-face will have a more uniform colour than bricks that are cross-set or placed face-to-back.

Firing- Bricks are fired between 10 and 40 hours, depending upon kiln type and other variables. There are several types of kilns used by manufacturers. The most common type is a tunnel kiln, followed by periodic kilns. Fuel may be natural gas, coal, sawdust or methane gas from landfills or a combination of these fuels. In a tunnel kiln, bricks are loaded onto kiln cars, which pass through various temperature zones as they travel through the tunnel. The heat conditions in each zone are carefully controlled and the kiln is continuously operated. A periodic kiln is one that is loaded, fired, allowed to cool and unloaded, after which the same steps are repeated. Dried bricks are set in periodic kilns according to a prescribed pattern that permits circulation of hot kiln gases. Firing may be divided into five general stages:

1) Final drying (evaporating free water);
2) Dehydration;
3) Oxidation;
4) Vitrification; and
5) Flashing or reduction firing.

All except flashing are associated with rising temperatures in the kiln. Although the actual temperatures will differ with clay or shale, final drying takes place at temperatures values of up to about 200 ºC, dehydration from about 150 ºC to 980 ºC, oxidation from 540 ºC to 980 ºC and vitrification from 870 ºC to 1,315 ºC. Clay, unlike metal, softens slowly and melts or vitrifies gradually when subjected to rising temperatures. Vitrification allows the clay to become a hard, solid mass with relatively low absorption. Melting takes place in three stages:

1)Incipient fusion, when the clay particles become sufficiently soft to stick together in a mass when cooled;
2) Vitrification, when extensive fluxing occurs and the mass becomes tight, solid and non-absorbent; and
3) Viscous fusion, when the clay mass breaks down and becomes molten, leading to a deformed shape.

The key to the firing process is to control the temperature in the kiln so that incipient fusion and partial vitrification occur but viscous fusion is avoided. The rate of temperature change must be carefully controlled and is dependent on the raw materials, as well as the size and coring of the brick being produced. Kilns are normally equipped with temperature sensors to control firing temperatures in the various stages. Near the end, the brick may be 'flashed" to produce colour variations.

Cooling- After the temperature has peaked and is maintained for a prescribed time, the cooling process begins. Cooling is an important stage in brick manufacturing because the rate of cooling has a direct effect on colour.

De-hacking- De-hacking is the process of unloading a kiln or kiln car after the bricks have cooled, a job often performed by robots. Brick are sorted, graded and packaged. Then they are placed in a storage yard or loaded onto rail cars or trucks for delivery. The majority of brick today is packaged in self-contained, strapped cubes, which can be broken down into individual strapped packages for ease of handling on the construction site. The packages and cubes are configured to provide openings for handling by forklifts.

6.5 Regulations, policies and guidelines

Bricks are subject to two Australian Standards, AS/NZS 4455[232] and AS/NZS 3700[233]. These two standards outline the key characteristics of a brick. Currently, there is no EPR scheme in place in Australia for brick waste, and manufacturers are not involved in such schemes. However, Brickworks Building Products declares that they run an initiative in which post-production waste is collected and crushed for return. The GBCA and ISCA, two current environmental rating tools, are deemed to have an impact on better management of C&D waste in Australia[234]. These two tools provide credits for applying the best possible waste management options in construction projects. Discrepancies in regulations impact the brick waste is treated. Inconsistent regulations among Australian jurisdictions make it difficult to manage brick waste among the states and territories.

Furthermore, there are policies implemented by some jurisdictions that advocate the use of a waste management option that is more environmentally preferred. For instance, in Vic, the waste management policy indicates that '*the Authority may prohibit certain wastes from being disposed to landfill if there is a higher waste management option practicably available or the waste poses an unacceptable risk to the environment*"[235].

Another issue with the current policies is the unreasonable requirements that rule out the usage of recycled brick waste in the new or renovation construction projects. Sometimes it is difficult to meet these requirements, which act as pushback for those who are involved in brick waste recovery activities. These policies should be motivated in the favour of usage of more brick waste.

[232] BD-026 (Masonry Units, Pavers, Flags and Segmental Retaining Wall Units). 2008. Masonry units, pavers, flags and segmental retaining wall units - Masonry units.
[233] BD-004 (Masonry Structures). 2018. Masonry Structures.
[234] Shooshtarian, S. T, Maqsood, PeterSP Wong1, M, Khalfan, R. Yang. Green Construction And Construction And Demolition Waste Management In Australia. 43rd AUBEA Conference: Built to Thrive: Creating Buildings and Cities That Support Individual Well-Being and Community Prosperit. November 2-4. Noova. Australia.
[235] Victorian Government Gazette. 2004.

6.6 Brick waste generation

6.6.1 How much brick waste is generated

Previous studies have shown that brick and concrete waste can account for 75 per cent of C&D waste from a construction site[236,237]. In Singapore, a study[238] found that the waste average percentage of brick is about 13 per cent of the amount purchased. In Australia, limited studies have investigated the constitution of waste generated at C&D sites. For instance, in WA,[239] it was found that bricks accounted for the main loose waste onsite (by weight) in this state. In NSW, the comparative analysis of four dwellings showed the potential of brick and concrete recovery[240] during building removal (Figure 29).

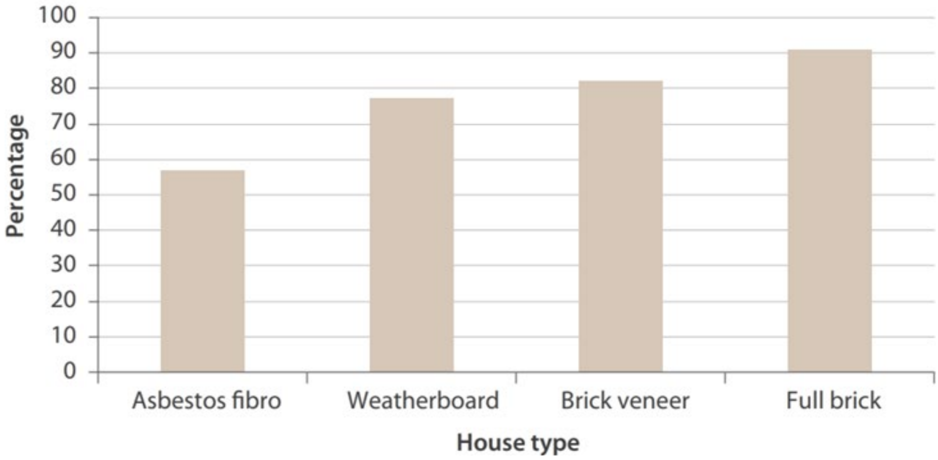

Figure 29. Percentage of bricks and concrete in house removal activities

Source: Office of Environment and Heritage (2010)[19]

Table 43 summarises the waste data reports on the national and jurisdictional brick waste in various waste streams in 2016-17[241]. As can be seen in the table, there is limited data about generation and management methods of brick waste. According to data, the period reported 1,872,467 t of brick waste was recycled. The share of the C&D sector in this waste recovery is estimated to be 60.3 per cent, the largest source of feedstock for brick waste recovery. Among the jurisdictions, almost 95 per cent of brick waste recycling took place in NSW and Vic combined in 2016-2017.

[236] Crowther, P. 2000. Building Deconstruction in Australia, Kibert, Charles J., Chini, Abdol, R., eds., 'Overview of Deconstruction in Selected Countries' CIB Report No. 252, 18-19.

[237] Formoso, C.T., Soibelman, L., De Cesare, C. and E.L. Isatto, 2002. Material waste in building industry: main causes and prevention. *Journal of Construction Engineering and Management*, 128(4), 316-325.

[238] Kang Y. Wastage in bricks. Dissertation, National University of Singapore, unpublished.

[239] Forsythe, P, Máté, K. 2007. Assessing brick waste on domestic construction sites for future avoidance. In the 41st Annual Conference of the Architectural Science Association ANZAScA.

[240] Office of Environment and Heritage. 2010. House deconstruction fact sheet: Bricks and concrete removal.

[241] Department of Environment and Energy. 2018. P863 National waste data and reporting cycle 2017-19. https://bit.ly/3gspuVA

Table 43. Brick waste data in various jurisdictions in 2016-17

	Waste generation				Waste landfill				Waste recycling			
State	**MSW**	**C&I**	**C&D**	**Total**	**MSW**	**C&I**	**C&D**	**Total**	**MSW**	**C&I**	**C&D**	**Total**
ACT	-	-	-	-	-	-	-	-	-	-	-	10,638
NSW									12,907	90,600	1,087,881	1,191,388
NT	-	-	-	-	-	-	-	-	-	-	-	-
Qld	-	-	-	-	-	-	-	-	-	-	-	41,908
SA	-	189	11,498	11,687	-	-	189	11,498	840	840	40,320	42,000
Tas	-	-	-	-	-	-	-	-	-	-	-	-
Vic	-	-	-	-	-	-	-	-	-	2,000	0	584,157
WA	-	-	-	-	-	-	-	-	0	713	1,663	2,376
Total												1,872,467

6.7 Brick waste management

6.7.1 Waste during manufacturing

Brick manufacturing is one of the most efficient uses of materials to produce a product. Brick plants are typically located close to raw material sources. Processed clay and shale removed in the forming process before firing are returned to the production stream. Bricks not meeting standards after firing are culled from the process and ground for use as grog in manufacturing brick or crushed for use as landscaping material. There is virtually no waste of raw materials in making brick.

Brick manufacturing uses readily available raw materials, including some waste products. The primary ingredient, clay, has been termed an 'abundant resource" by many authorities including the American Institute of Architects[242], confirming that depletion of clay is not a concern. However, this is not the case in some countries and may not last forever. Therefore, some brick manufacturers have started taking advantage of nonhazardous waste in brick production. Examples include using bottom- and fly-ash from coal-fired generators, using other ceramic materials as grog, using lubricants derived from processing organic materials in the forming of brick and using sawdust as a burnout material. While natural gas is the most frequently used energy source for brick manufacturing, many manufacturers are using waste products, such as methane gas from landfills and sawdust, for brick firing. There are opportunities to reduce the impact of waste during brick manufacturing; some studies have demonstrated this possibility using various waste materials. Table 44 presents a selection of these studies and their findings.

Table 44. The application of other C&D wastes in the production of brick

Waste material	Summary of study	Reference
Marble powder	The results showed that the marble dust additive had a positive effect on the physical, chemical and mechanical strength of the produced industrial brick	Bilgin et al. (2012)
Fly ash (substitute for clay)	The results showed that bricks with a high-volume ratio of fly ash are of high compressive strength, low water absorption, no cracking due to lime, no frost and high resistance to frost-melting.	Lingling et al. (2005)
Waste glass powder and limestone powder waste	The results indicated that the samples containing waste glass powder and limestone powder waste combinations provide better results for the potential of producing economical new brick materials.	Turgut (2008)
Waste glass	Waste glass addition enhances the physical and mechanical properties of fired clay brick	Phonphuak et al. (2016)
Spent shea waste	This research has provided compelling evidence that could create a new-found route for the synergistic eco-friendly re-use of spent shea waste to enhance clay brick construction aside from being a potential mainstream disposal option	Adazabra et al. (2017)
Steel slag	Bricks with a steel slag addition of less than 10 per cent and a firing temperature values above 1050°C would fit CNS3319 third-class brick for builders	Shih et al. (2004)
Textile sludge (substitute for clay) and waste glass	The recycling of textile sludge for brick production, when combined with waste glass additions, may be promising in both product quality and environmental aspects	Rahman et al. (2015)

Note: While there are multiple pieces of literature demonstrating the successful use of waste materials from various waste streams (i.e. MSW and C&I)[243] this table only presents the literature investigating the use of the C&D waste stream.

[242] American Institute of Architects, Environmental Resource Guide, The American Institute of Architects, Canada, 1998.

[243] Raut, S.P., Ralegaonkar, R.V. and Mandavgane, S.A., 2011. Development of sustainable construction material using industrial and agricultural solid waste: A review of waste-create bricks. *Construction and Building Materials*, 25(10), 4037-4042.

A comprehensive review of the waste (all waste streams) materials used in brick production has already been conducted,[244,245,246] wherein more than 20 various materials applied were identified with satisfactory results for clay brick production. There is a wide array of indications for the successful application of various waste materials in brick production in the relevant studies; the major indications include compressive strength, flexural strength, unit weight, water absorption and uptake, abrasion resistance, freezing–thawing (F–T) resistance, heavy metal leaching rate, drying shrinkage, density and thermal conductivity. The main standards that are used as a benchmark for testing the applicability of using various waste material in brick production include EN Standard EN13892-3,[247] ASTM C 779,[248] BS6073,[249] ROC CNS 1127,[250] and CNS 3319.[251] Notwithstanding, the prerequisite for their use is that they must be not only technically suitable, but also environmentally friendly.[252]

In Australia, Brickworks Building Products® asserts that their member companies are constantly striving to eliminate production waste. In 2012, this company declared that all production waste is returned to the mix. For example, the new Austral Bricks® plant in Vic has markedly reduced the instance of malformed or off-specification green (unfired) bricks. Any such units are automatically recycled into the clay mix rather than going to landfill.[253] The company also plans to investigate products that produce excessive waste, and look for ways in which these can be reduced. One efficient waste minimisation practice that takes place during the manufacturing phase is to produce half-bricks that are sometimes necessary for certain constructions. It is reported that up to 75 per cent of brick waste occurs when labourers attempt to cut bricks into half[239]. A very popular management style that can assist the construction material manufacturing industry with reducing waste is the lean and parallel-line manufacturing model[254].

6.7.2 Waste reduction opportunities during design, planning and contract

Brick design involves designing goods to last longer and to be easily repaired, upgraded or used differently in future cycles, and actively managing negative externalities such as the release of toxic substances. (Ekanayake and Ofori, 2000) reported that a substantial amount of C&D waste is closely attributed to design errors. The authors graded design changes as the most significant contributors to waste generation when construction works are in progress and the lack of information on the drawings. The other design-related waste causes that were identified in this study were the complexity of detailing, selection of low-quality materials and lack of familiarity with alternative products. Waste can also occur during the design stage due to errors in contract clauses or incomplete contract documents[255,256].

Notably, it is widely known that design variations and changes can result in a meaningful quantity of design-generated waste. These variations often change the type or quantity of the building materials.

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[244] Zhang, L., 2013. Production of bricks from waste materials–A review. Construction and Building Materials, 47, pp.643-655.

[245] Murmu, A.L. and Patel, A., 2018. Towards sustainable bricks production: An overview. *Construction and Building Materials*, 165, 112-125.

[246] Al-Fakih, A., Mohammed, B.S., Liew, M.S. and Nikbakht, E., 2018. Incorporation of waste materials in the manufacture of masonry bricks: an update review. *Journal of Building Engineering*. 21, 37-54.

[247] EN13892-3 .2004. Methods of test for screed materials. Determination of wear resistance-Bohme.

[248] ASTM C 779 .2005. Standard test method for abrasion resistance of horizontal concrete surfaces. American Society for Testing and Materials, Philadelphia, PA.

[249] BS 6073 (1981) Part 1: Precast concrete masonry units, Part 1. Specification for precast concrete masonry units. British Standards Institution.

[250] CNS Catalog. 2017. Beurue of Standards, Meteorology and Inspection. China. ISSN: 1561-8668.

[251] Ibid.

[252] Alonso-Santurde, R., Coz, A., Viguri, J.R. and Andrés, A., 2012. Recycling of foundry by-products in the ceramic industry: Green and core sand in clay bricks. Construction and Building Materials, 27(1), 97-106.

[253] Build for Living. 2012. Building a platform of commitment and responsibility.

[254] Shah, R. and Ward, P.T., 2003. Lean manufacturing: context, practice bundles, and performance. Journal of operations management, 21(2), 129-149.

[255] Craven, D.J, Okraglik, H.M. & Eilenberg, I.M. 1994. Construction waste and a new design methodology. Proc. of the 1st Conference of CIB TG 16 on Sustainable Construction, ed. C.J. Kibert, Tampa: Florida, 89–98.

[256] Bossink, B.A.G. & Brouwers, H.J.H. 1996 Construction waste: quantification and source evaluation. *Journal of Construction Engineering and Management*, 122(1), 55–60.

On the same note, the standardisation of design is found to be a solution to variation in construction. Standardisation can improve buildability and reduce the number of off-cuts[257].

Design for deconstruction also is another design strategy to reduce waste at C&D sites. In the case of brick, one Australian study[29] found that waste from set-out can design not to bond. Brick on edge was used instead of stretcher bond when trying to create a level first course on an uneven footing.

There has been a trend among modern architects in reusing old bricks in innovative designs. Further encouragement of this trend can lead to an increased uptake of old bricks in new construction projects. For instance, James Dalecki of Dalecki Designs[258] enumerated the benefits of using old bricks. He stated that the benefits of using natural building materials such as clay bricks are not only related to their incredibly long life but also the beautiful way they age. He also mentioned that, depending on the style of building, an old brick can either be used to blend in with other materials or, alternatively, can contrast to create a beautiful modern building. Furthermore, Dalecki argued "*Clay products require no finish (paint or render) to maintain their colour or appearance... this makes them a great product to reuse as it means they can easily be removed from their first application and reused without any treatments required (other than a possible clean)... A beautiful heritage brick can serve as a key design feature in contrast to a modern design...They can be used for feature paving, internal floors, ceilings, built-in furniture, steps or even seating, the options are truly endless*"[265].

In another case reported by the Edge Environment Pty Ltd[76] on six luxury eco-friendly buildings in NSW, the use of recycled materials including 40t of bricks was encouraged and inspired by the client's commitment to ecological sustainability. The goal was to create interesting buildings that would attract people and create a place with a unique character. Michael Hennessey, the owner of the resort where these buildings were built, described his principal driver as *'Mother Nature and my daughter'.*

Another strategy that impacts waste minimisation during the design phase is related to the social responsibility of designers in the promotion of activities leading to waste minimisation. This can include bringing the associated financial benefits to the attention of the client[259]. The flow of information and dissemination of best practice to reduce design waste will require investment and publicity in technology and education to reshape societal attitudes to waste disposal. This will involve partnerships with the national government, local authorities, industry, the media and community organisations.

Waste can also occur during the design stage due to errors in contract clauses or incomplete contract documents[260,261]. The stage at which contractual agreement is made presents an opportunity to minimise C&D waste[262]. Stakeholders can reduce waste by incorporating waste minimisation activities in specifically-oriented contract tender clauses. To eventuate this, some studies[263] suggest using contractual clauses to discipline poor waste management. Others, such as Greenwood[264], state that a fully integrated waste minimisation system at the contractual stage is necessary to identify and communicate the responsibilities for waste minimisation between all project stakeholders. There is

[257] Dainty, A.R.J. & Brooke, R.J., 2004.Towards improved construction waste minimisation: improved supply chain integration. Structural Survey, 22(1), 20-29.

[258] Dalecki, J. 2017. Reuse & Recycle Materials - Brickworks Building Products. [online] Brickworks Building Products. https://bit.ly/3edV6vv

[259] Osmani, M., A. D. F. Price & J. Glass.2007. Potential for construction waste minimisation through design. *WIT Transactions on Ecology and the Environment*, 84, 575-584.

[260] Craven, D.J, Okraglik, H.M. & Eilenberg, I.M., Construction waste and a new design methodology. Proc. of the 1st Conference of CIB TG 16 on Sustainable Construction, ed. C.J. Kibert, Tampa: Florida, 89–98, 1994.

[261] Bossink, B.A.G. & Brouwers, H.J.H., Construction waste: quantification and source evaluation. *Journal of Construction Engineering and Management*, 122(1), 55–60, 1996.

[262] CriBE, Waste Minimisation Through Counselling Building Project Teams & Collecting of Building Project Teams and Collecting Waste Arising. Welsh School of Architecture: Cardiff University, 1999.

[263] Dainty, A.R.J. & Brooke, R.J., Towards improved construction waste minimisation: improved supply chain integration. *Structural Survey*, 22(1), 20-29 , 2004.

[264] Greenwood, R., Construction Waste Minimisation –Good Practice Guide, CriBE: Cardiff, 2003.

evidence that even the type of contract can influence the way that waste is generated. For instance, in Australia[239], it was found that "fix only" subcontracts rarely create motivation for bricklayers to re-use off-cuts. Subcontract payment to bricklayers for labour only and based on the completed in-situ brick count does not provide a payment system that encourages low wastage.

Two of the strategies to reduce material consumption are through components' life extension or design against overconsumption[265]. The major barrier to design against overconsumption is the cost; if the cost of a used and adapted product is similar to the new one, the latter is preferred[266].

Bricklayers are important people in the battle of reducing the waste if they are not disincentivised to do so. In Australia, the bricklayers are contracted based on the number of bricks arrived onsite and are incentivised to create waste[267]. If they use half bricks, they get paid for a whole, and their pay is not deducted by the number of bricks left over. Contracting model with plastering subcontractors perhaps is the way to control this issue and reduce waste. If the model was 'supply and lay" there would not be a brick left over onsite, and any spare would be carried to the next job.

6.7.3 Reducing waste during the procurement

Correct estimation of brick needed for a construction activity can save a huge quantity of unwanted materials that might have otherwise been mixed with waste going to landfill or illegally stockpiled. Inaccurate quantity take-off and/or over-ordering ultimately create extra waste. However, on large jobs, the risk of over-ordering tends to be reduced because deliveries are made progressively throughout the job, and only the last order needs accurate take-off and ordering. Conversely, it can be a significant contributor in small jobs if the bricks are only supplied in large order increments and only a small amount of the last order increment is required. Incremental ordering problems will potentially worsen if the brickwork is made up of small amounts of different brick types—as may be required in blended brickwork[239]. An example of over-ordering is when 1,500 bricks must be ordered, for a job requiring 1,100 bricks, which typically results in 27 per cent waste[35].

Just-in-time delivery of materials to a construction site should be planned to avoid damage taking place due to insufficient space for proper storage and adverse weather conditions[268]. In this case, in close collaboration with suppliers more flexible 'last pack" sizes, i.e. a 'fractional" pallet instead of a full pallet can be arranged to minimise the waste because of over-ordering. These last packs can be offered at slightly higher prices to motivate suppliers to provide such packaging. Application of another procurement method that is called 'Supply & Lay" can significantly result in the reduction of brick waste and leftover. In this model, it is assumed that there would be no leftover, and the minimum waste is generated.

6.7.4 Reducing waste during transportation and delivery

Waste incurred through transportation can be reduced if the transportation companies typically contracted by brick manufacturers exercise good work practices. A lack of hard strap protectors at corners and edges of brick stacks and hand unloading can increase waste. Forsythe and Máté (2007) reported that an uneven landing pad for stacks could cause damage to bricks. In another study in Hong Kong, interviews with senior project managers, and experienced architects and engineers revealed that damage during transportation due to the unpacked supply is one of the two main reasons for brick wastage (Tam et al., 2006). Tam and Hao (2014) suggested that waste arising out of transportation and delivery could be reduced or eliminated by replacing site bricklaying with drywall panel systems.

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[265] Oguchi, M., Tasaki, T., Moriguchi, Y. 2010. Decomposition analysis of waste generation from stocks in a dynamic system: Factors in the generation of waste consumer durables. *Journal of Industrial Ecology*. 14, 627–640.

[266] Hirschl, B., Konrad, W., and G. Scholl, 2003. New concepts in product use for sustainable consumption. *Journal of Cleaner Production*. 11, 873–881.

[267] Barrett, C. 2019. BGC (Australia) Pty Ltd: Group Mnager Energy and Environment. Personal communications.

[268]BRE Group. 2014. The true Cost of Waste. Accessed September 5 2019. https://bit.ly/3tAxTdd

6.7.5 Reducing waste during construction

The second major brick waste generation occurs at the construction site and mostly during construction activities (Poon et al., 2004). Researchers observed that brick waste could be reduced at all stages of the construction process (Poon et al., 2004). Damaged bricks due to over-stacking in the storage area and poor products of layering are all possible causes of wastes. A field study in Australia reported that the main source of waste brick comes from inaccurate brick cutting, which is primarily done by chopping at bricks with a trowel (Forsythe & Máté, 2007). The study estimated that poor workmanship could generate up to 75% of brick waste at a construction waste.

In Australia, a field study[37] found that the main source of waste brick comes from inaccurate brick cutting, which is primarily done by chopping at bricks with a trowel. The researchers estimated that around 75 per cent of brick waste generated because of the improper operation of brick cutting. Table 45 identifies the main reasons why a brick turns into waste at a construction site.

Table 45. The causes of waste during construction

Cause of waste	Description
Cut bricks (i.e. off-cuts and breakages are rarely reused).	• Bricklayers often use a trowel instead of a bolster to cut bricks in half; this practice is used because it is faster but it may cause multiple bricks to shatter before getting the desired half-brick • Bricks that are brittle or do not cut cleanly will increase the problem • Some subcontractors are resistant to using a brick saw, as they find it slow, changes their normal work processes, requires them to get off scaffolding, the equipment is expensive to purchase and maintain and it creates the need for an extra labourer to operate the saw • Cutting increases with larger-than-normal amounts of sills, window reveals, raking cutting, offset walls or closing bond at the ends of blade walls • Poor offcuts are not often suitable in face walls
Handling and stacking breakages	• Bricks delivered on inclined surfaces cause leaves in the brick stack to fall and break • Muddy areas make handling more difficult and create a risk of dirt contamination of bottom bricks • The more restacking and barrowing, the higher the expected breakages
Use of bricks for scaffolding and other unintended uses	• Takes place mainly due to poor site control
Bricks contaminated by dirt	• The bottom layer of the stack can be affected, but the bricks stacked on pallets are less likely to be affected

Brick waste construction inefficiencies include handling and stacking breakages, use of bricks for scaffolding and other unintended uses, and bricks contaminated by dirt. Training of those who are directly and indirectly dealing with the brick at the construction site should be an integral part of any waste management plan. Such training courses can target labourers who are working at different stages of construction and maintenance and have a pivotal role in the reduction of brick waste generated. In Australia, there are various education providers that offer a specific course on the brick material in the construction industry. For instance, PointsBuild offers two online courses 'TBA Foundations: Brick Standards' and 'TBA Foundations: Defining a Brick' to educate bricklayers and others involved in construction activities about the various technicalities of bricks in construction with the view to reduce damages to the material during and after construction. In recent years, the emergence of brick-laying robotic systems has presented an opportunity to increase the industry productivity by reducing construction completion time, providing financial benefits, minimising work safety incidents, and reducing waste during construction (Giftthaler et al., 2017). In 2018, Fastbrick Robotics, a construction company based in Perth (Australia), reported its achievement in completing a three-bedroom, two bathroom house in less than three days thanks to a robotic arm from a 3D model (Hall, 2018).

Another important strategy to assist with reducing waste during construction is to estimate the quantity of waste to be generated at a construction site (Llatas, 2011). Accurate estimation can aid in efficient prevention and management from the very beginning of a construction project. Nonetheless, prior research studies indicated that one of the main hindrances to a valid estimation of C&D waste is the lack of data, including poor documentation of waste generation rates and composition. In the past, some efforts made to model the quantity of waste generated at a construction site (Wu et al., 2014) and particularly building information modelling (BIM)-based modelling in recent years (Cheng and Ma, 2013).

Proper storage of bricks at the site can also contribute to reducing waste generated during construction activities. If the construction site has enough space, bricks arriving at the site can be adequately stored away from the main traffic flow onsite (BRE Group, 2019). Application of effective construction methodologies also contributes to less waste generation. Among various methodologies, prefabrication seems to be a viable option. By definition, prefabrication is a manufacturing process that takes place in a specialised factory where different materials are brought together to form a construction component of the final installation procedure (Minunno et al., 2018). Brickwork can be prefabricated off, or onsite in panels or box units lifted into position and bolted to a building frame in a similar manner to precast concrete (Minunno et al., 2018). Panels that are moved into place onsite using cranes create a reduction in overall site waste. Furthermore, brick orders are placed and cancelled as required directly through the manufacturers allowing resources to be monitored and waste to be recognised and controlled. Some examples of buildings with prefabricated bricks are shown in Figure 30.

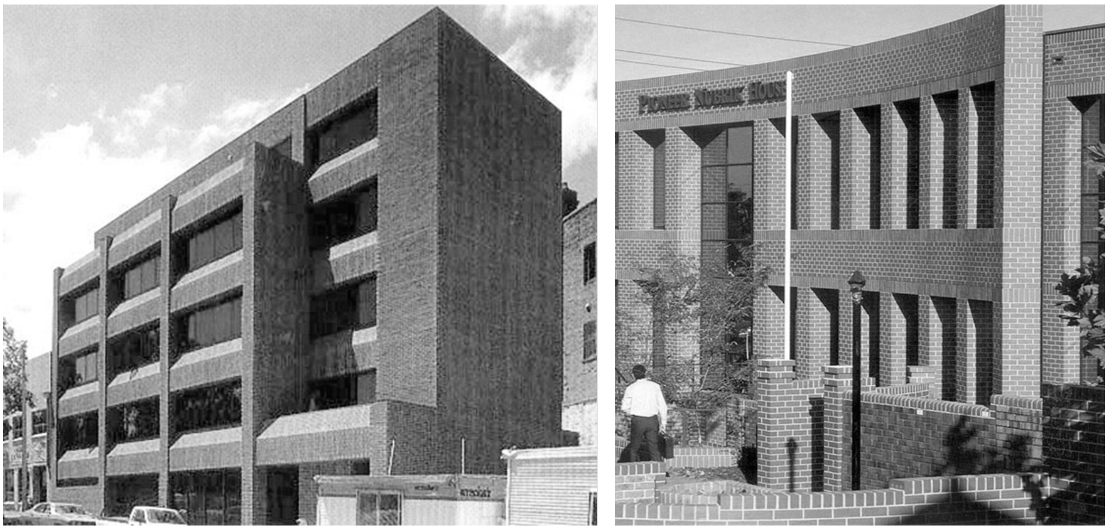


Figure 30. Examples of prefabricated brickwork in Australia
Left: Anderson House (1980) in the Melbourne suburb of Carlton (The brick panels are a single leaf, reinforced vertically and horizontally at about 600 mm centres, and contribute to the fire protection of the structural steel framing). Right: Pioneer Nubrik House in Adelaide (1990), Most of the brickwork was laid on site, but the brick soffits were prefabricated by the bricklayer in a building next to the site.
Source: Clay Brick and Paver Institute, University of Sydney.

There are several advantages of brickwork prefabrications, some of which are listed below[269]:

- work is protected from changeable weather conditions.
- design features that may be too costly or labour intensive on-site can be carried out in the factory.
- more control can be exercised over materials used and construction work carried out to ensure superior quality.

[269] Fisher, K. 1992. Prefabricated brickwork panel system. Redland Brick, September 1992.

- project time is shortened due to speedy erection of wall panels leading to earlier occupancy of the building.
- no need for storage on-site as panels can be delivered 'just in time'.
- need for scaffolding is reduced dramatically.
- waste reduction

The reduction in waste, including brick waste using prefabrication technologies, has been documented in various contexts. Table 46 summarises the evidence of brick waste reduction using prefabrication reported by various studies.

Table 46. Studies providing evidence for waste minimisation through prefabrication

Reference	Context and data collection method	Result description
Zhou et al. (2014)	China, simulation	Brick waste occurring during bricklaying tends to be minimised
Begum et al. (2010)	Malaysia, interview and on-site monitoring	This study confirms that a huge amount of material wastage can be reduced by the adoption of prefabrication; the total brick waste generated is much higher in the conventional project (i.e., 0.04 t 100 m^{-2} compared to the prefabricated/IBS project of 0.63 tones 100 m^{-2}); this study also revealed that the rates of re-used and recycled waste materials are relatively higher in projects that adopt prefabrication – based on the total waste generated at each site, it is observed that 94% of waste generated at the Industrialised Building System site is re-used and recycled, compared to only 73% at the conventional project site
Jaillon et al. (2009)	China, case study	The reduction percentage of brick waste through prefabrication is 56.1% reduction in brick waste

Despite the proven benefits of prefabrication in reducing C&D waste, this construction technology is only successful when builders and clients can enjoy cost savings. In one study on the use of prefabrication, the interviewees suggested that cost was the key factor[270]. Another study found that the resistance to adopting prefabricated techniques was often seen in companies that had not carried out detailed studies on the potential economic savings achievable through waste reduction, specific to their activities and processes[271]. There are three other enablers that encourage the use of prefabrication as outlined by some investigators[272,273]:

(1) Environmental issues: When more stringent environmental control and regulations are forthcoming, prefabrication is one of the ways to facilitate long-term waste minimisation and reduction;
(2) Construction costs: Introducing more productive and lean construction methods can reduce the construction cost-effectively and reduce the burden incurred due to high initial investment (Shen & Tam, 2002);
(3) Government incentives: Granting relaxation to the gross floor areas for projects employing prefabrication elements, e.g., discounting the area occupied by facade units (Hong Kong Government – Environmental Protection Department 2006), will encourage the use of prefabrication. Moreover, tighter control on workmanship, allowable tolerances, homogeneity and allowable rework will favour the adoption of prefabrication.

[270] Tam, V.W. and Hao, J.J., 2014. Prefabrication as a mean of minimizing construction waste on site. *International Journal of Construction Management*, *14*(2), 113-121.
[271] Cox, A.G. and Piroozfar, P., 2011, April. Prefabrication as a source for co-creation: An investigation into potentials for large-scale prefabrication in the UK. In Proceedings of the 6th Nordic Conference on Construction Economics and Organisation, Copenhagen, Denmark, 13-15.
[272] Ho OST. 2001. Construction waste management – a contractor's perspective. The Hong Kong Institute of Builders.
[273] Poon CS, Yu TW, Ng LH. 2001. On-site sorting of construction and demolition waste in Hong Kong. *Resources, Conservation and Recycling*. 32(2) 32157– 32172.

6.7.6 Reducing waste during demolition

Brick waste during demolition is generally sourced from residential or pavement demolition. In one study in China, it was found that demolition of residential buildings generates more brick waste than it does in commercial buildings (Zhao and Rotter, 2008). However, this waste almost always comes in a mix with other C&D waste. The resource recovery market strongly prefers separation at the source for masonry materials. Such a practice leads to more straightforward, cheaper and more effective recovery. This is also favourably considered in pricing mechanisms such as gate fees, which are lower for source-separated loads (Sustainability Victoria, 2014). In most cases that waste loads are mixed, the conventional practice is to separate waste materials by labours and some mechanical equipment such as excavators and front-end loaders. There are also instances of the utilisation of fixed equipment and automated sorting systems being employed to segregate materials (Hyder, 2011). Deconstruction, as opposed to demolition, is a building removal technique that aims to dismantle buildings with the goal of maximising the reuse potential of its components. The benefits of deconstruction include generation of revenue from the sale of salvaged materials, reduced disposal and transports costs, lower cost of building materials for the community, lower excavation for new materials and conserving landfill space. However, the time required to deonstruct is found to hinder the adaptation of this method (Crowther, 2000).

Selective deconstruction is the advance extension of deconstruction wherein some materials are targeted for reusing and recycling. Selective deconstruction project planning involves the scheduling for dismantling targeted building components, the definition and duration of work tasks, the choice of technology, the estimation of the required resources and the identification of any interactions among the different work tasks (Sanchez et al., 2019). Full demolition requires less time than deconstruction. Time taken includes the manpower (total man-hour) and active plant costs. The NSW Office of Environment and Heritage (2010) has published an information booklet wherein deconstruction and demolition were compared time-wise. The NSW Office of Environment and Heritage has published a factsheet[274] wherein deconstruction and demolition were compared time-wise (Figure 31).

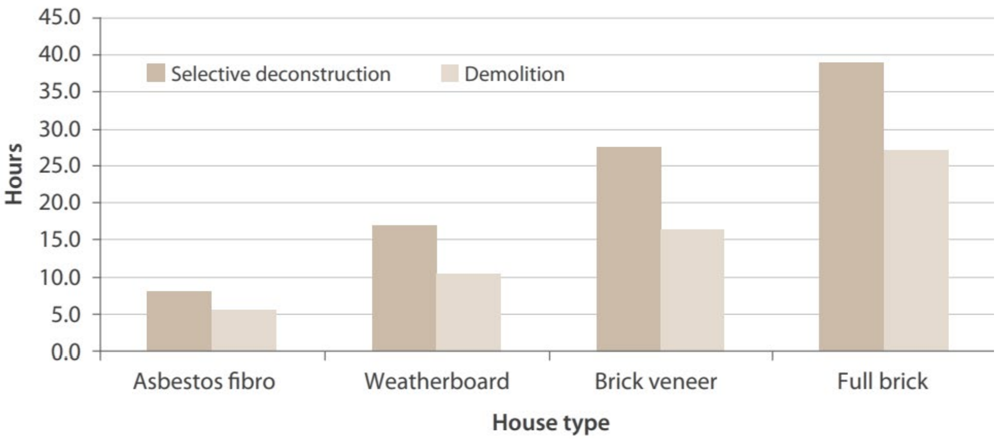
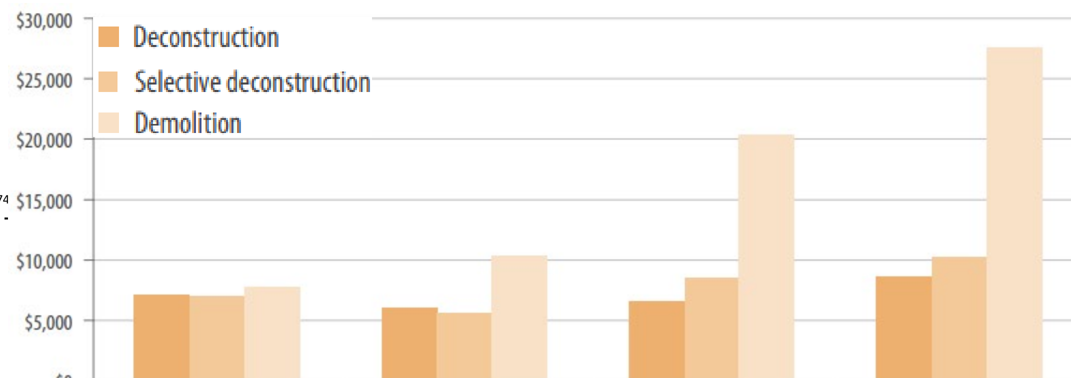


Figure 31. Time comparison for brick and concrete removal
Source: EPA NSW, House deconstruction fact sheet (2010).

The cost analysis associated with three building-removal techniques in NSW revealed that deconstruction is cheaper than demolition, by anywhere between 55% (Asbestos fibro) and 294% (full brick)[72].



[274] -

Figure 32. Cost comparison between three methods of building removal

6.7.7 Reducing waste through reusing

The demolished brick or the brick that is damaged during transport, construction or renovation can be reused in construction projects without recycling. From an environmental perspective, reusing old bricks creates environmental benefits such as saving 0.5 kgCO2-e that is eliminated by not manufacturing one block of a clary brick (Gamlemursten, 2019). There are initiatives to encourage the application of old bricks in new builds. Think Brick Australia is running a Brick Cleaning Course (Thinkbrick, 2019), a nationwide training course on brick cleaning, in partnership with TABMA Training. Brick cleaners can achieve accreditation by completing this course. The course covers basics of brickwork, working with contemporary bricks, planning and preparing a worksite, identifying brick stains, prevention of brickwork stains, techniques not to damage brickwork, effective cleaning of brick stains, clean up and safe storage of equipment and chemicals, and using environmentally-friendly cleaning solutions.

A new EU -funded project is called REBRICK[275] and has demonstrated that an old brick is not 'just a brick". This project pursues resourceful demolition of waste through automated cleaning of clay bricks so that they can be reused. This project, which is coordinated by a Danish SME, Gamle Mursten, in the past year has developed a technology to exploit the reusing potential of old bricks. This technology involves the automated sorting of demolition wastes that separates and cleans old bricks using vibrational rasping. The main REBRICKS objectives are as follows:

a) develop and modify the current brick cleaning technology to fulfil regional requirements
b) explore the market possibilities for reused bricks in Europe
c) market the use of reused bricks to key stakeholders in Europe

[275] Gamlemursten.eu. 2019. REBRICK: Rebrick. [online] Available at: http://www.gamlemursten.eu/ [Accessed 19 Aug. 2019].

Figure 33. REBRICK project operation and some examples of building with re-used (cleaned) bricks
Source: www.en.gamlemursten.dk

Furthermore, the re-use of brick may take place in the form of brick waste recycling for further use in a brick production line. In Turkey, two researchers, Demir and Orhan (2003)[276] studied the use of brick waste as an additive to raw materials for brick production. They reported that up to 30% mixture of fine brick waste additives could be successfully used in new brick production. Usage of waste material in the raw mixture minimises the physical damage that may occur during brick production. The reuse of waste-brick material in brick production provides an economic contribution and helps protect the environment by less virgin resource use, and saving in water and greenhouse gas emissions associated with clay excavation, transport, and landfilling.

6.7.8 Waste recovery (recycling and upcycling)

Brick waste can be processed and further used in the construction industry (recycling) or in another industry (upcycling). Brick waste is highly recyclable due to their inert nature and physical reprocessing requirements, with less need for chemical processes in comparison to other materials[277]. Brick recycling practice has a long history; the earliest evidence relates to the use of crushed brick with Portland cement in Germany in 1860 for the manufacturing of concrete products[278]. However, the first significant use of crushed brick as aggregates in new concrete has been recorded for reconstruction after World War II[279]. In Denmark, only 2 per cent of concrete and bricks generated are landfilled, with the remainder reused and recycled[280]. Large commercial projects lend themselves to recycling more so than small residential projects as there are significant economies of scale in collection, separation, and marketing of recovered materials[281]. Waste bricks are also applied as powder materials in some countries.

The demolished bricks are burned into slime burnt ash in Japan and are commonly crushed to form filling materials in Hong Kong (Tam and Tam, 2006). Waste brick can also replace raw materials used in a mixture for production of other construction materials. For instance, pozzolans that are derived from wastes, when used as a partial cement substitute, typically improve the resistance of mortar.

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276 Demir, I. & Orhan, M. 2003. Reuse of waste bricks in the production line. *Building and Environment*, 38, 1451-1455.
277 Sustainability Victoria.2014. Factsheet: Market summary – recycled brick, stone and concrete.
278 Devenny, A. & Khalaf, F. 1999. Use of crushed brick as coarse aggregate in concrete. *Masonry International*, 12, 81-84.
279 London, E. and F.N. Spoon.1992. Recycling of Demolished Concrete and Masonry, in: T.C. Hansen (Ed.), RILEM.
280 Residua .1999.Construction and Demolition Waste", Information Sheet in Warmer Bulletin, Issue 67, July 1999.
281 SA EPA. 2001. Barriers and Opportunities for Re-use and Recycling of Clean Fill and Building and Demolition Waste. NOLAN-ITU Pty Ltd. https://bit.ly/3n3Pkk7

Table 47 presents a selection of studies wherein the successful application of brick waste in the production of masonry materials is documented.

Table 47. Summary of studies investigating the applications of recycled brick waste

Application	Summary of findings	Reference
Replacement of cement in mortar	A substitution of cement by 10% of waste brick increased mechanical strengths of mortar; the results of the investigation confirmed the potential use of this waste material to produce pozzolanic cement	Naceri and Hamina (2009)
Pozzolanic materials	Experimental results revealed that waste brick has potential as a pozzolanic material in the partial replacement of cement or concrete to sulphate attack	Lin et al. (2010)
Mineral filler in asphalt concrete mixture	Results show that the mixtures prepared with recycled brick powder have better mechanical properties than the mixtures with limestone filler; thus, it is promising to use recycled brick powder as a mineral filler in asphalt mixture	Chen et al. (2011)
The brick powder as cementitious material replacing Portland cement	Results show the mortars containing brick powder show good performance	Corinaldesi et al. (2002)
The brick powder (dust) as a stabiliser	Results obtained showed that partial substitution of the dust with pulverised fuel ash resulted in stronger material compared to using it on its own; the blended stabilisers achieved better performance	Kinuthia and Nidzam (2011)
Crushed brick waste as a pavement subbase material	Results indicated that only recycled crushed brick with a moisture ratio of around 65% is a viable material for usage in pavement sub-base applications; the geotechnical testing results indicate that crushed brick may have to be blended with other durable recycled aggregates to improve its durability and to enhance its performance in pavement sub-base applications	Arulrajah et al. (2011)
Crushed brick as a coarse aggregate in concrete	Results demonstrated the durability of crushed bricks as a natural aggregate replacement at 25% and 50% and recommended to use the bricks in unreinforced concrete	Adamson et al. (2015)

There are limited and scattered data available showing how much brick waste is recycled or upcycled in Australia. In WA, a report[282] showed that 10.86t brick was recycled in 2005-06. In Vic, in 2012, the quantity of brick that was recycled was reported to be 390kt (median)[283]. According to the latest statistics, in 2016-17, 1,872,467 t of brick waste was recycled in Australia[241]. The share of the C&D sector in this waste recovery is estimated to be 60.3 per cent, the largest source of feedstock for brick waste recovery activities. Among the jurisdictions, almost 95 per cent of brick waste recycling took place in NSW and Vic combined in 2016-17. However, several states and territories did not report their brick waste management activities (Table 43).

A study[284] conducted in Australia found that a common solution to the brick waste problem is to crush the waste and to use the final product as a landscaping aggregate or low-grade road base. Brick recycling techniques are not complicated;[285] the bricks are crushed, either as mixed loads or in source-separated streams. In Australia, one study conducted a comparative analysis of the economic

[282] Cardno. 2008. Detailed investigation into existing and potential markets for recycled construction and demolition materials. Job No. V7038. https://bit.ly/3arjfxt

[283] Sustainability Victoria.2014. Factsheet: Market summary – recycled brick, stone and concrete.

[284] Forsythe, P. and Máté, K., 2007. Assessing brick waste on domestic construction sites for future avoidance. In 41st Annual Conference of the Architectural Science Association ANZAScA.

[285] Edge Environment Pty Ltd . 2012. Construction and Demolition Waste Guide-Recycling and Re-use Across the Supply Chain.

performance of two brick waste management scenarios in Melbourne[286] to reveal the suitability of recycling versus landfilling. The study found that the costs associated with recycling bricks were comparatively cheaper than those in landfill disposal. Clearly, the cost savings of recycling far outweighed landfill disposal and virgin gravel production. In terms of operational costs, this study reported that, for 1,000 t of brick waste, the total costs are $92,356 and $29,419 in the case of landfilling and recycling, respectively. The same results were found in a study conducted in NSW wherein demolition is more expensive than selective and full deconstruction due to reduced costs associated with transport and landfill levy. Some of the local councils provide vouchers through the rates notices to encourage the community to get their waste, including some C&D waste materials, recovered at the nominated recycling facilities.

Case study 1 – Australian experience: Midland Brick (WA): In June 2006, Midland Brick announced a brick recycling initiative aimed at reducing the amount of material being sent to landfill. Midland Brick, in association with Pindan, formed a partnership that would see all waste bricks from a number of Pindan construction sites returned to Midland Brick for recycling. Midland Brick has also set up recycling centres at several their yards throughout the metropolitan area (Cannington, Jandakot, Joondalup, Osborne Park and Middle Swan) that can be used by the general public for brick disposal. Commercial loads can be disposed at the Middle Swan yard. Plastic strapping from the brick and paver packs can also be recycled. At present, approximately 7,000 t of brick have been recycled. This is on top of roughly 80,000 t of defective product made at the Middle Swan and Cannington sites being re-introduced into the process. Midland Brick also has a partnership with Capital Demolition in Balcatta that recycles waste bricks from its recycling operations. Midland Brick has indicated that they are looking to increase the amount of waste brick material being recovered over the next few years; however, there is a maximum proportion the firing process can accept while maintaining product specification.

Case study 2 - Australian experience: SA construction companies: Responses from 12 SA based construction companies, involved in the recycling construction materials to a survey showed that about 78 per cent of brick waste was recycled[287]. Brick was found to be among the four top waste materials that were recycled; the other three materials included concrete, soil/sand and metal. Figure 34 shows the variation of materials recycled by these 12 companies.

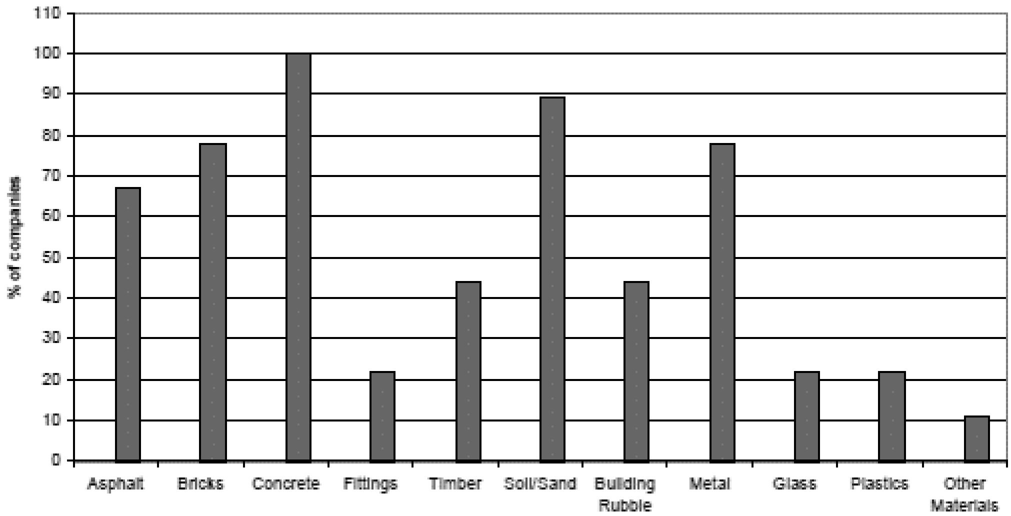

Figure 34. Materials recycled by SA construction companies surveyed
Source: EPA SA (2001)[287]

[286] Damptey, E.O. 2011. Optimising the Use of Recycled C&D Waste Material in Civil Construction Projects. PhD thesis. Faculty of Engineering and Industrial Sciences. Swinburne University, Melbourne. Australia.
[287] SA EPA. 2001. Barriers and Opportunities for Re-use and Recycling of Clean Fill and Building and Demolition Waste. NOLAN-ITU Pty Ltd. https://bit.ly/3txTjYJ

6.7.9 Illegal dumping and stockpiling

Illegal dumping and stockpiling is a prevalent incidence with respect to clay brick. Indeed, illegal dumping is a lucrative and extremely difficult practice to stop. There are service providers that are called 'cowboy operators'[288] in the waste recovery industry that offer services for skip bins, disposal, sorting or recycling at below-market rates, undercutting the cost of legitimate and licensed businesses. The waste is stockpiled or dumped on rented properties or public land in the outer suburbs or regional areas. It is the public sector's duty to address the illegal dumping of materials and to strengthen controls over licensed sites. The following is a case study on the illegal dumping of brick waste in Australia.

Case Study 1- Hughes Demolition in north-west of Melbourne (Vic)- Recently, a large demolition company, operating in a north-western suburb of Melbourne, was charged for the illegal dumping of a large quantity of C&D waste, most of which were bricks (Figure 35), on land that was not licensed to accept it. EPA ordered the company to fund the removal of about 2800 cubic metres of C&D waste from a property in Prima Court, Tullamarine[289]. In visiting this dumping site, Peter Kerr, the metropolitan EPA manager, indicated that illegal dumping of C&D materials costs Vict more than $30 million a year in clean-up costs, stating also: '*That is particularly disappointing, given that much of it can be processed for productive reuse in building and construction"*.

Figure 35. A clean-up worker amid waste illegally dumped at a field in Prima Court, Tullamarine, by demolition company Monark Industries, trading as Hughes Demolition
Source: Carolyn (2019)[289]

6.7.10 Landfilling the waste

On a world-scale, the world annual production of clay bricks, which is approximately 6.25 × 108 tonnes, about 7 × 106 tonnes of brick goes to landfills each year (Adamson et al., 2015). In some countries, due to different factors, including unavailability of land, the cost of landfilling has increased so substantially that recycling is considered to be more cost-effective. One study in the US showed that recycling one ton of brick costs about $21 per tonne while landfilling one tonne of the same amount would cost approximately $136/tonne (Lennon, 2005). In Australia, the lack of updated and accurate data about current activities in the field of brick waste management has made it difficult to plan for the maximum usage of the value of brick material. The only data for landfilling extracted for the study period of 2016-17 showed that, in South Australia, of 40,320 tonnes brick waste generated 11,498 tonnes was landfilled (Table 43).

[288] Mannix,L., Vedelago C. and C. Houston. 2017. The tipping point: Illegal dumping swamps the waste industry. [online] The Age. https://bit.ly/2RN9eEu
[289]Carolyn W.C. 2017. Companies fined for illegal dumping of waste after EPA swoop. [online] The Age newspaper. https://bit.ly/3n2dxHn

6.8 Brick waste market, barriers and strategies

There is a good market for cleaned second-hand bricks for reuse, particularly red bricks[290]. However, there are several market barriers for waste-derived materials that are outlined in Objective 3 (Identifying the economic factors and drivers that govern the disposal and reduction/reuse/recycling of C&D waste). Specific to clay brick, Sustainability Victoria has identified the specific market barriers for brick waste, including labour costs, changes in building technology and low demand[291]. Table 48 provides a summary of strategies identified to overcome barriers in the development of the market for brick waste.

Table 48. Strategies to remove barriers to market development for brick waste

Reference	Strategies to remove barriers to market development for brick waste
Sustainability Victoria	Improved separation on-site to sort brick waste from other C&D waste; developing educational materials for designers and builders about material choice and waste management; and increased promotion of the use of recycled brick waste in pavement construction.
Department of Environment and Conservation / Cardno[292]	Market instruments that could be used to remove barriers include education and communication, procurement policies, landfill levy increases, potential landfill bans on mixed materials, increase enforcement at inert landfills and compulsory waste management plans for the industry before undertaking C&D activities
Edge Environment Pty Ltd[76]	Increased supply—if the supply of reclaimed materials from demolition could be increased, the continuity of supply would improve and the opportunity for incorporating materials into designs would be greater. Increased knowledge—as tradesmen gain experience working with reclaimed materials, knowledge in the industry increases, new methods of construction can be tried and tested, and time savings can be achieved; there is a shortage of tradespeople who are able to work with the inconsistencies of reclaimed and recycled materials; training is required.
Eunice Ofeibea Damptey[293]	To effectively maintain demand for recycled RC and brick materials, the introduction of higher landfill fees, taxes on virgin products, and subsidies for recycled products such as RC and bricks, is required.

6.8.1 Integrated supply chain

According to Sustainability Victoria,[294] costs associated with transport are major factors in determining whether the material will be recycled or landfilled. Similarly, the generally low value of end product (per cubic metre or by tonnage) means that the relative distance similarly impacts transportation of products to end-users that the recycled product must be transported versus a substitute product. As such, the location of facilities for reprocessing is of particular importance, as it is the determinant of the total haulage distance from collection to recycled product end-user. Currently, there are companies across Australia that specialise in the removal and collection of brick waste generated from demolition, construction or renovation projects. The following table summarises some of these companies management practice. These companies operate in different jurisdictions, and the business information has been extracted through direct contact with their sale and technical teams.

[290] SA EPA. 2001. Barriers and Opportunities for Re-use and Recycling of Clean Fill and Building and Demolition Waste. NOLAN-ITU Pty Ltd. https://bit.ly/3n3Pkk7

[291] Sustainability Victoria. 2014. Factsheet: Market summary – recycled brick, stone and concrete.

[292] Cardno. 2008. Detailed investigation into existing and potential markets for recycled construction and demolition materials

[293] Damptey, E.O. 2011. Optimising the Use of Recycled C&D Waste Material in Civil Construction Projects. PhD thesis. Faculty of Engineering and Industrial Sciences. Swinburne University, Melbourne. Australia.

[294] Ibid.

Table 49. Supply chain characteristics of the waste collector

Business name	State	Pricing mechanism	Others
1300 Rubbish Recycle	Multiple	\$ 250 per m^3 in Sydney and Melbourne \$ 220 per m^3 in Adelaide and Brisbane	Waste is transported to transfer stations
Bingo Industries	NSW and Vic	Disposal: NSW: \$40/t + \$600 per week for skip bin Vic: \$ 40/t landfill + \$420 per week for skip bin	Waste is transferred to landfill or recycling facilities

Note: the prices tabulated above are current as of November 2019.

6.8.2 Brick lifecycle models

There are various models that are outlined to provide insight into the brick's material life cycle. In this section two models are explored.

REBRICK model: The first lifecycle model is put forward by REBRICK project, which provides information on brick waste management from the point that brick turns into waste until it becomes a construction material. This model depicts four stages with the relevant stakeholders that can contribute to building a strong integrated supply chain. The Gamle Mursten, the Danish company that created this model, believe that this model is a platform where the value that is created and shared across many stakeholders and markets.

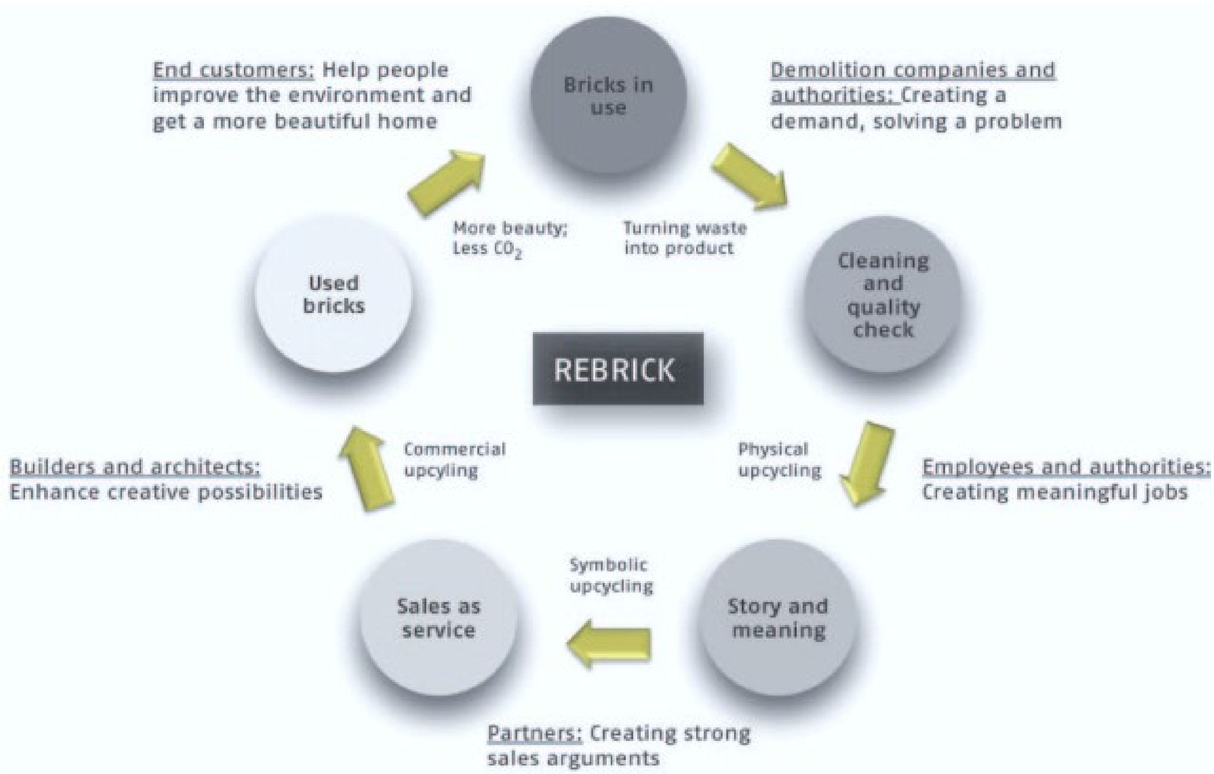

Figure 36. The REBRICK project value system.
Source: Gamle Mursten company (http://www.gamlemursten.eu/)

Brick LoWMor: According to the opportunities identified for waste minimisation and sustainable practices to redirect waste from landfill, an integrated supply chain life cycle model is developed. In this model, there are 11 points wherein brick waste can be efficiently managed. Figure 37 depicts these opportunities and the relationships among them.

Figure 37. The integrated supply chain lifecycle model for brick waste

The following table shows the role of the main players in the management of brick waste corresponding to the developed integrated supply chain. The key stakeholders identified below are believed to have a major contribution to the effective management of brick waste. Their contribution could be translated into waste minimisation or reduced waste landfilling, directly or indirectly.

Table 50. The role of various stakeholders in the effective management of brick waste

No.	Stage	Stakeholder(s)	Contributions
1	Design	Designers, construction firms, clients	• Reuse an existing building instead of a new one; • Design a new building to facilitate its re-use in the future • Consider precast brick walls in the designs • Consider building standardisation to improve buildability and reduce the number of offcuts
2	Manufacturer	Manufacturers, recyclers, suppliers	• Develop an agreement where a contractor 'sells back" the re-cycled waste from the original material supplier • Participate in the EPR and PS schemes
3	Procurement and contract	Construction firms, quantity surveyors, government	• Construction firms should order bricks more accurately using the best take-off practice. • Supplier to provide more flexible 'last pack" sizes i.e. a 'fractional" pallet instead of a full pallet • Alter the public contracts (purchasing) for brick waste based

			materials usage in public projects • Consider 'supply & lay" procurement model to eliminate brick leftover and minimise brick waste
4	Transportation & delivery	Construction firms, transporters, recycling companies	• Just-in-time delivery of materials to a construction to avoid damage taking place due to insufficient space for proper storage and adverse weather conditions • Do due diligence and exercise standard work practices • Use hard strap protectors at corners and edges of brick stacks and reduce hand unloading
5	Construction	Construction firms, sub-contractors, waste collectors, recyclers	• Ensure the bottom layers of bricks remain usable by preventing soil contamination • Store bricks in a stable flat area to avoid breakages from fall overs • Determine a means for cutting bricks into half more accurately so that both halves can be used and breakages avoided • Take unwanted bricks back to brickyard for crushing and re-use in brick production it can be also complemented by offering the customer leftover (full) bricks. • Include a clean-up payment in the scope of the bricklayer's subcontract to assist recycling and to discourage wasteful site practices.
6	Demolition	Demolition contractors, waste collectors, recyclers	• Consider selective de-construction to maximise the reuse potential of its components.
7	Reuse	Construction firms, state and territory governments, EPAs and other equivalent organisations, waste collectors	• Facilitate market development • Adjust specifications in favour of more usage of brick waste-based materials in new constructions project
8	Recycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Take brick leftovers away to use as aggregate or landscaping cover • Facilitate market development • Fund the development of waste recovery infrastructure • Adjust specifications in the favour of more usage of brick waste-based materials in new constructions project
9	Upcycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Facilitate market development • Adjust specifications in favour of more usage of brick waste-based materials in new construction projects • Facilitate the market development • Fund the development of waste recovery infrastructure
10	Stopping illegal dumping and stockpiling	State and territory governments, EPAs and other equivalent organisations	• Reinforce activities that stop illegal dumping and stockpiling • Set stricter regulations with a higher rate of penalty fees to discourage illegal dumping and stockpiling • Strengthen controls over licensed landfill sites
11	Landfill	State and territory governments, EPAs and other equivalent organisations	• Design appropriate landfill levy schemes to discourage brick waste landfilling

6.9 Relevant industry associations

In addition to the key players identified above, industry associations and training foundations are reported to have a meaningful impact on sustainable brick waste management. In this section, the relevant industry associations that specifically work towards the better management of brick and the waste associated with brick are identified. These associations are to collaborate with the public sector towards recognising opportunities for the further reduction, re-use and recycling of brick waste in Australia. Table 51 summarises the main industry associations with a focus on clay brick in Australia.

Table 51. Industry associations relevant to the management of brick waste

Associations	Scope	Vision	Website
Think Brick Australia	National	It represents Australia's clay and pave manufacturers	https://www.thinkbrick.com.au/
National Brick Layers Association (NBLA)	National	The National Bricklayers Association was set up to make the building industry better for both employees and employers, by dealing with issues that affect the industry	https://www.nationalbricklayersassociation.com.au/
Australian Brick & Blocklaying Training Foundation (ABBTF) Ltd	National	ABBTF aims to ensure there is an adequate and competent bricklaying and blocklaying workforce to support the market and also to improve the standing of bricklayers and blocklayers within the industry	https://www.becomeabricklayer.com.au/
Masonry Contractors Australia (MCA)	NSW & ACT	MCA is dedicated to improving the quality, reliability and integrity of the masonry (brick and block-laying) industry	https://masonrycontractors.com.au/

6.10 Recommendations

- Consider building standardisation to improve buildability and reduce the number of offcuts
- Design appropriate landfill levy schemes to discourage brick waste landfilling
- Strengthen controls over licensed landfill sites
- Ensure the bottom layers of bricks remain usable by preventing soil contamination
- Store bricks in a stable flat area to avoid breakages from fall overs
- Determine a means for cutting bricks into half more accurately so that both halves can be used and breakages avoided
- Supplier to provide more flexible 'last pack" sizes, i.e. a 'fractional" pallet instead of a full pallet
- Take unwanted bricks back to brickyard for crushing and re-use in brick production it can be also complemented by offering the customer leftover (full) bricks
- Include a clean-up payment in the scope of the bricklayer's subcontract to assist recycling and to discourage wasteful site practices
- Develop an agreement where a contractor 'sells back" the re-cycled waste from the original material supplier
- Take brick left-overs away to use as aggregate or landscaping cover
- Consider 'supply & lay" procurement model to eliminate brick leftover and minimise brick waste

7. Concrete- Resource Circular Economy: Opportunities to Reduce Waste Across the Supply Chain

7.1 Introduction

Concrete has been used for construction since ancient times. The oldest concrete discovered dates from around 7,000 BC. It was made in 1985, when a concrete floor was uncovered during the construction of a road at Yiftah El, in Galilee, Israel. The floor consisted of lime concrete, made from burning limestone to produce quicklime which, when mixed with water and stone, hardened to form concrete[295].

Currently, concrete is the world's most widely used architectural medium, owing to its incredible versatility. In 2009, it was reported that the annual global concrete consumption rate is approaching 25 Gt[296]. Concrete is a composite material composed of fine and coarse aggregate bonded together with a fluid cement (cement paste) that hardens over time. As a building material, it has a unique ability to be shaped and sculpted into anything from roads and footpaths to art sculptures, residential homes and skyscrapers. It is a relatively cheap material and has a relatively long life, with few maintenance requirements. Concrete is strong in compression and before it hardens is a highly pliable substance that can easily be shaped. It is also fire resistant. The main advantages of concrete as a construction material are provided in Table 52.

Table 52. The main features of concrete as a construction material

Feature	Description
Vibration	For common spans, the relatively high mass of concrete floors leads to natural damping and low vibration; for more-stringent criteria, such as for laboratories or hospital operating theatres, the additional cost to meet vibration criteria is small compared to lightweight construction
Weather protection	High-quality concrete, properly compacted and cured, effectively detailed and (in some cases) coated, can contribute to a durable weather-proof building envelope
Fire resistance	Concrete does not burn and does not emit any toxic fumes when subjected to fire; it will not produce smoke or drip molten particles – for these reasons, in the majority of applications, concrete can be described as 'fireproof' Concrete structures generally do not require fire protection if appropriately designed because of their inherent fire resistance; this removes the time, cost, additional materials and labour required to provide separate fire protection measures
Acoustic performance	Concrete offers a good barrier to airborne toxins due to its thick mass; it improves the sound insulation of a room in walls and floor; impact sound can be controlled with appropriate floor and ceiling finishes Concrete can effectively act as a buffer between outdoor noise and the indoor environment, road noise and residential areas via a sound barrier, and adjoining apartments or other spaces
Reflectivity	Concrete minimises the effects that produce urban heat islands; light-coloured concrete pavements and roofs absorb less heat and reflect more solar radiation than dark-coloured materials, such as asphalt, reducing air-conditioning demands in the summer
Construction costs	Concrete structures, especially those using post-tensioned floors and/or precast concrete, are the most economical structural solution for multi-storey buildings
Whole-of-life value	Concrete's range of inherent benefits including thermal mass, fire resistance and durability means that concrete buildings tend to have lower operating costs and lower maintenance requirements
Construction duration	Construction of concrete-framed buildings requires only short lead-in times; with modern formwork systems, floor-to-floor construction periods can be reduced
Durability[297]	When a structure is built with concrete, it is built to last – concrete is a building material that gains strength over time Concrete's 100-year service life conserves resources by reducing the need for reconstruction; concrete is durable – it resists weathering, erosion and natural disasters, and needs few repairs and little maintenance, adding up to a solid investment

[295] Brown, Gordon E., Analysis and History of Cement, Gordon E. Brown Associates, Keswick, Ontario, 1996.
[296] IEA, WBCSD. Cement Technology Roadmap 2009 – Carbon emissions reductions up to 2050. Paris, France: International Energy Agency [IEA], World Business Council for Sustainable Development [WBCSD].
[297] Concrete Sask. 2016. Why is concrete better? https://bit.ly/3n0xM8q

Waste management	Concrete can be produced in the quantities needed for each project, reducing waste; concrete waste can be recycled into aggregate for use in new pavements or as backfill or road base

Source: Adapted from Cement Concrete & Aggregates Australia (2010)[298]

7.2 Types of concrete

This section provides information about various types of concrete that are currently used in the construction industry. These types are classified based on the constituents, their mix ratio and other properties such as strength, weight, density, porosity and time of setting. Furthermore, the main applications of these concrete types are provided in Table 53. In total, 24 main concrete types that have the most frequent usage in Australia, and other developing nations are identified. The information tabulated in Table 53 is primarily sourced from The Constructor (2017)[299].

[298]Cement Concrete & Aggregates Australia. 2010. Sustainable Concrete Buildings. https://bit.ly/2QHhTYh
[299]The Constructor. 2017. 23 Types of Concrete Used in Construction and their Applications. https://bit.ly/2QgBT4m

Table 53. Various types of concrete and their applications

Type	Characteristics	Main application
Normal strength concrete	The concrete that is obtained by mixing the basic ingredients – cement, water and aggregate will give normal strength concrete	Used in concrete mixing
Ordinary concrete	The plain concrete will have no reinforcement in it; the main constituents are the cement, aggregates and water	Pavements, kerbs and the buildings, especially in areas where there is less demand for high tensile strength
Reinforced concrete	A concrete to which reinforcement is introduced to bear the tensile strength; the steel reinforcement used in the concrete can be in the form of rods, bars or in the form of meshes Recently, steel fibres are also being developed as reinforcement	Slab, wall, beam, column, foundation, and frame construction
Prestressed concrete	This is a special technique in which the bars or the tendons used in the concrete are stressed before the actual service load application	Bridges, heavy loaded structures, and roof with longer spans
Precast concrete	The precast concrete units are made and cast in the factory as per the specifications and brought to the site at the time of assembly	Structural components such as; wall panels, beams, columns, floors, staircases, pipes, tunnels
Light-weight concrete	It has a density less than 1,920 kg/m^3; will be categorised as lightweight concrete and is made of lightweight aggregates such as pumice, perlites and scoria	Floor slabs, window panels and roofs
High-density concrete	Made up of heavyweight aggregates such as crushed rocks and Baryte, this kind of concrete has densities between 3,000 and 4,000 kg/m^3; the heavyweight aggregate will help the structure to resist all possible types of radiation	Atomic power plants and for similar projects
Air entrained concrete	A concrete into which air is intentionally entrained through foams or gas (i.e. foaming agents: resins, fatty acids and alcohols) for an amount of 3% to 6% of the concrete; these air pockets relieve internal pressure on the concrete by providing tiny chambers for water to expand into when it freezes	Parking structures, bridge decks, highway pavements, curbs, and sidewalks in cold regions. Also, in structures that are exposed to moisture, freeze-thaw cycles and de-icing chemicals
Ready mix concrete	A type of concrete that is mixed and bathed in a central mixing plant; the method of mixing will also be specified and it is developed for specialist application	Bridges, wells, piles, support walls, tunnel, covered trenches, retainment, bulkheads, tiles, columns, and girders
Polymer concrete	In this type of concrete a polymer material is used to bind aggregates instead of cement; using polymer helps with the reduction of volume of voids in the aggregates; there are three categories that come under this type of concrete: polymer impregnated concrete, polymer cement concrete, and partially impregnated Epoxy is the largest category of this concrete due to its increasing use in construction and its superior properties of high-impact strength, high vibration resistance, and good bonding with concrete and metal surfaces	Engineering structures including aircrafts, helicopters, offshore platforms, and others. Also used in biomedical devices and civil structures
High-strength concrete	This concrete is yielded through the reduction in the water-cement ratio even lower than 0:35. – this ratio gives the concrete a strength greater than 40Mpa	High-rise structures such as columns (especially on lower floors where the loads will be greatest), shear walls, and foundation. It is also used in bridge applications such as highway bridges.

Type	Characteristics	Main application
High-performance concrete	This type of concrete is made according to a particular standard, but it is not limited to strength; some examples of standards include strength gain in early age, easy placement of the concrete, permeability and density factors, long life and durability and environmental concerns	Long-span bridges, high-rise buildings or structures, highway pavement[300]
Self- consolidated concrete	This concrete, which is also known as flowing concrete, is compacted by its own weight and is regarded as self-consolidated concrete	Road and bridge projects
Shotcrete concrete	This type of concrete is shot into the frame or the prepared structural formwork with the help of a nozzle; as the shooting is carried out in higher air pressure, the placing and the compaction process will occur at the same time	Concrete repairs or placement on bridges, dams, pools, and on other applications where forming is costly, or material handling and installation is difficult
Pervious concrete	A type of concrete that is designed to allow the water to pass through it; these types of concrete will have 15% to 20% voids of the volume of the concrete when they are designed	Pavements and driveways where stormwater issues persist
Vacuum concrete	In this type of concrete, the material with water content more than the required quantity is poured into the formwork; the excess water is then removed with the help of a vacuum pump without waiting for the concrete to undergo setting; as a result, the concrete structure will be ready to use earlier when compared with normal construction techniques	Industrial floor sheds such as cold storages, hydropower plants, bridges ports and harbours, cooling towers
Pumped concrete	This concrete is fluid in nature to be easily conveyed through a pipe; it has enough fine material as well as water to fill the voids; the more the finer material is used, the greater the control achieved over the mix	High rise buildings and large mega construction projects
Stamped concrete	It is an architectural concrete where realistic patterns similar to natural stones, granites and tiles can be obtained by placing an impression of professional stamping pads; this stamping is carried out on the concrete when it is in its plastic condition	Parking lots, pavements, walkways
Limecrete	In this concrete, cement is replaced by lime – unlike cement-based concrete, this type of concrete has many environmental and health benefits; these products are renewable and easily cleaned	Floors, domes as well as vaults
Asphalt concrete	It is a composite material – a mixture of aggregates and asphalt; this kind of concrete is also known as asphalt, blacktop, tarmac, bitumen macadam or rolled asphalt	It is used to surface roads, parking lots, airports, as well as the core of embankment dams
Roller compacted concrete	This concrete is placed and compacted with the help of earthmoving equipment like heavy rollers; it has cement content in lesser amounts and filled for the necessary area; after compaction, this concrete provides high density and finally cures into a strong monolithic block	Excavation and filling needs
Rapid strength concrete	A type of concrete that acquires strength within a few hours after its manufacture	Mainly in road repair projects. Also, in the airport, building floor, dockyard, formed work, parking area, rail network, and road/bridge
Glass concrete	A type of concrete into which recycled glass is used; the recycled glass increases the aesthetic appeal of the concrete and provides long-term strength and better thermal insulation	Exterior cladding panels
Fly ash concrete	This concrete has fly ash as a substitute to fine aggregates or cement or partially both – fly ash improves workability in the fresh concrete and durability and strength in hardened concrete	Brick manufacture and pavements

Source: Adapted from The Constructor (2017)[299]

[300] Rana, N., Tiwari, A. and Srivastava, A.K., 2016. High performance concrete and its applications in the field of civil engineering construction. *International Journal of Current Engineering and Technology*, 6(3), 982-985.

7.3 Concrete applications

Due to the features outlined in Table 52, concrete has a wide range of applications in the construction industry as well as other relevant industries. Concrete is used in large quantities almost everywhere humankind has a need for infrastructure. Figure 38 exhibits some of the most common applications of concrete as a construction material in various industries.

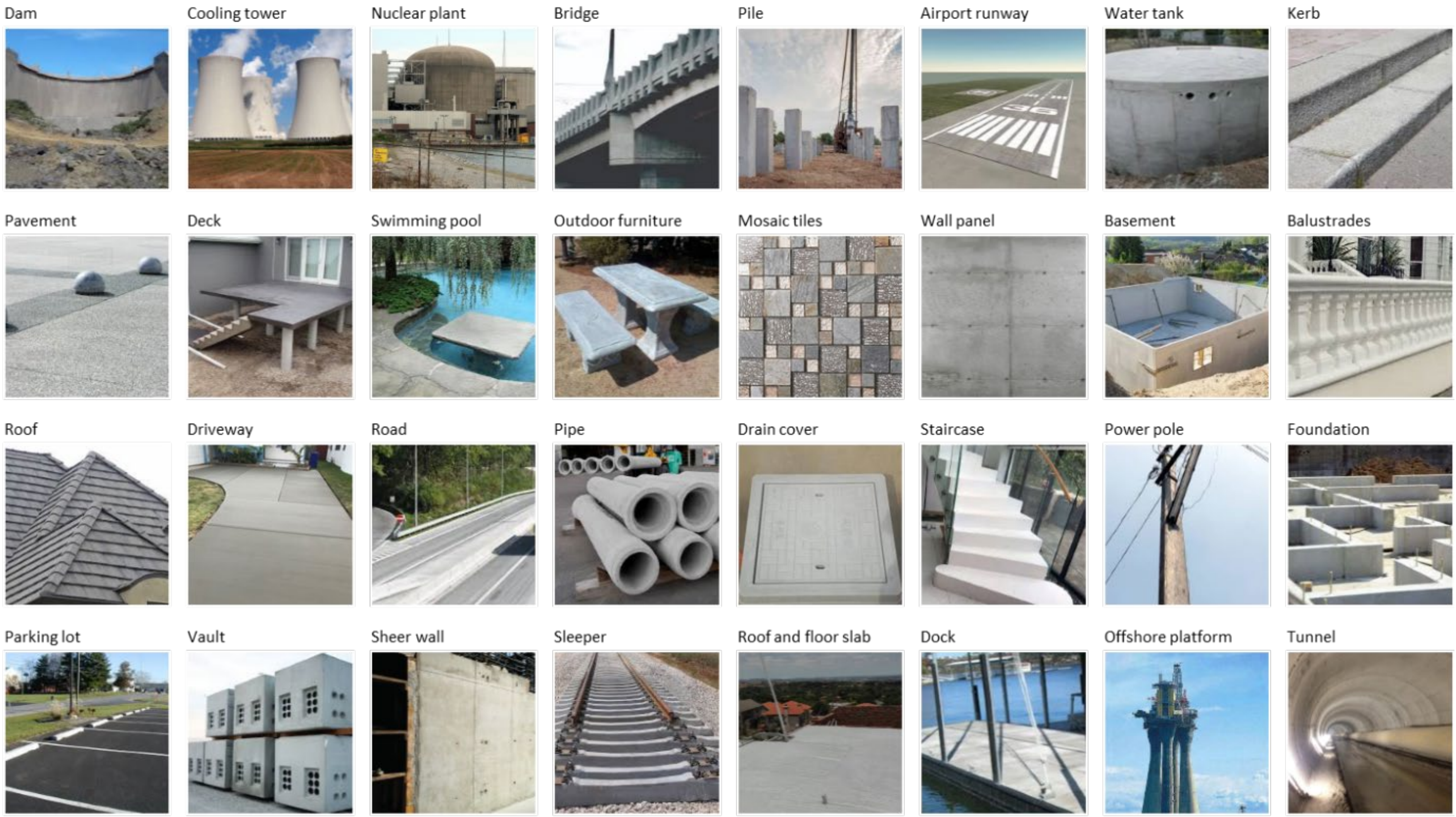

Figure 38 Different applications of concrete in the construction and relevant industries

7.4 Concrete manufacturing industry overview

As the concrete waste generation partially depends on the supply and demand for concrete products the main drivers for concrete product manufacturing (CPM) industry is analysed. The major operators in the CPM industry produce concrete products such as aerated and composite products. Downstream sectors use concrete products for a range of construction and ornamental applications. Table 54 shows the main factors impacting the demand and supply of concrete production in Australia. The information provided in this table helps researchers develop an integrated supply chain lifecycle model specific to the Australian context.

Table 54. Key drivers and the major industries dealing with concrete productions (demand and supply)

Key economic drivers	Demand industries	Supply industries
Demand from residential building construction	Mining	Cement and lime manufacturing
Demand from heavy industry and other non-building construction	Water supply	Electricity, gas, water and waste services
Demand from commercial building construction	House construction	Metal and mineral wholesaling
Capital expenditure on mining	Road and bridge construction	Rock, limestone and clay mining
Capital expenditure by the public sector	Heavy industry and other non-building construction	Cement and lime manufacturing
Demand from road and bridge construction	Commercial and industrial building construction	

Source: IBISWorld 2019[301]

7.4.1 The domestic price and current industry-current performance

The CPM industry produces a diverse range of products for use across many construction markets. Consequently, varying demand conditions across the downstream construction markets have influenced the industry's performance over the past five years. IBISWorld[301] reports that domestic demand for concrete products has increased due to strong growth in the commercial building and apartment construction markets.

IBISWorld[301] forecasts the domestic price of concrete, cement and sand to rise by 1.5 per cent in 2019-20, to 111.3 index points. Growth is anticipated to slow compared to the previous year, due to falling demand from residential building construction. However, this is expected to be mitigated by road and bridge construction, which is anticipated to have high demand due to a large array of both state and the federal government-funded infrastructure projects. Overall, from the factors listed in Table 54, it seems that five key external factors have the greatest impact on the current industry performance:

- Demand from residential building construction
- Demand from heavy industry and other non-building construction
- Actual capital expenditure on mining
- Capital expenditure by the public sector
- Demand from road and bridge construction

Demand from residential building construction

Residential building construction is the main source of demand for concrete products (i.e. concrete bricks and roof tiles, building boards and pavers). Demand from this sector has declined over 2018-

[301] IBISWorld. 2019. Concrete Product Manufacturing in Australia: IBISWorld Industry Report C2034.

19, following the completion of several major apartment developments, which poses a threat to industry revenue growth.

Demand from heavy industry and other non-building construction

The decline in demand from infrastructure construction over the past five years[301] has limited the demand for a range of concrete products (that is sleepers, tensioning posts and concrete storage tanks) used in this sector. Demand from heavy industry and other non-building construction has declined during 2018-19, which will likely reduce demand for precast concrete pipes, box culverts and other structural concrete products.

Actual capital expenditure on mining

Capital expenditure on mining development, which increases the demand for a range of heavy construction products (that is concrete pipes and box culverts, concrete beams, panels, tubes, poles and railway sleepers), has declined over the past five years and continued to decline sharply during 2018-19, constraining the pace of industry expansion. Following a surge in investment in new mine development in 2012-13, the mining industry has now moved to the production phase as most of these development projects have been completed.

Capital expenditure by the public sector

The public sector manages a large number of construction projects (that is water, sewerage, drainage, telecommunications, power and energy, and road and bridge infrastructure) across Australia. Many of these projects use concrete products and, as a result, the CPM industry is sensitive to the fluctuations in the public sector capital expenditure. Public-sector capital expenditure grew significantly in 2018-19, which may provide an opportunity for industry operators to supply more concrete products to railway, telecommunication and road projects.

Demand from road and bridge construction

Road and bridge construction impact the demand for concrete products (i.e. beams, tensioning posts, traffic barriers, precast columns and light poles). This market has grown significantly since the mid-2000s, supporting demand for industry products. Several large-scale road developments, notably NorthConnex and WestConnex in NSW and the West Gate Tunnel in Vic, drove demand from road and bridge construction to a record peak in 2017-18. Demand from road and bridge has declined marginally during 2018-19 but remained high.

7.4.2 Major markets

The residential and commercial building markets represent the principal source of demand for concrete products (Figure 39). The prime building contractors or project developers, including individual homeowners or property developers, generally fund the procurement of concrete products for building projects[301]. demonstrates the major concrete markets in Australia.

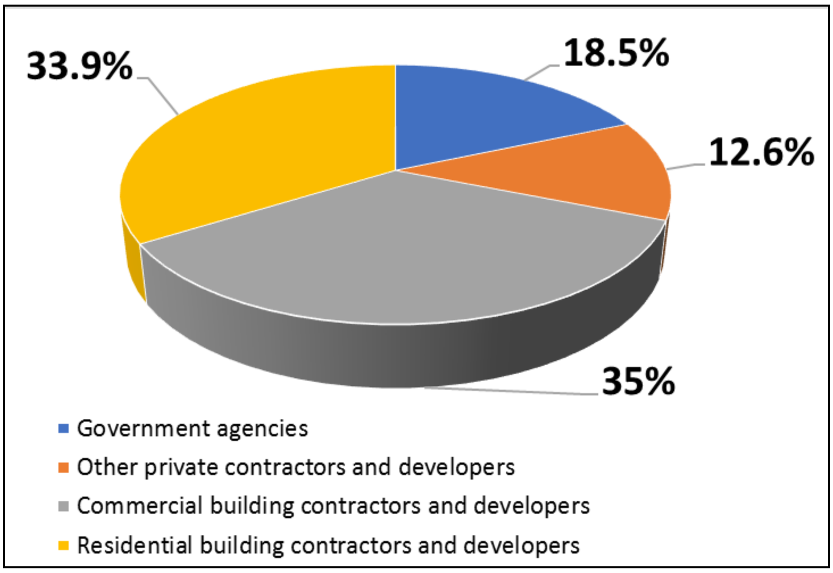

Figure 39. Major concrete markets identified in Australia
Source: IBISWorld[301]

7.4.3 Major concrete producers in Australia

The concrete market is split between two industries: the Concrete Product Manufacturing (CPM) and industry and Rady-Mixed Concrete Manufacturing (RMCM). The CPM industry produces a range of products that are key inputs in most construction markets. Products include pipes and box culverts; bricks and blocks; cement-based building boards; floor, wall and roofing tiles; and precast panels and posts. According to IBISWorld data[301], the major producers of concrete products in Australia include Fletcher Building Limited (19.1 per cent), James Hardie Industries Public Limited Company (17.7 per cent), CSR Limited (15.1 per cent), Brickworks Ltd (10.80 per cent), Holcim (Australia) Holdings Pty Ltd, Adelaide Brighton Ltd (5.1 per cent), and others (23.6 per cent). The industry also includes numerous small-scale manufacturers supplying niche markets, such as ornamental concrete products, pots and tubs. These firms typically operate in narrow regional markets and often comprise sole proprietors and partners. In 2019-20, the employment in CPM was 8, 275. The industry has a highly dispersed geographic structure as the end products are generally of high weight, low unit value, which results in prohibitively high long haul transport costs.

The RMCM industry manufactures ready-mixed concrete or mortar, dry-mix concrete and concrete slurry. These firms deliver ready-for-pouring mixed concrete and mortar to the customer in an unhardened state. In terms of employment, 8, 869 people were working in RMCM industry in 2019. RMCM is dominated by four companies namely Boral Limited (24.1 per cent), Hanson Australia (Holdings) Proprietary Limited (21.9 per cent) and Holcim (Australia) Holdings Pty Ltd (16.4 per cent) and Barro Group Pty Limited (5 per cent). The industry has a geographically dispersed structure and contains many small-scale enterprises. Table 55 shows the financial profile of the major concrete producers (CPM & RMCM) in Australia.

Table 55. Profile of the major concrete producers in Australia

Company name	Scope	No. of employees	Market cap
Fletcher Building Limited	New Zealand-based public listed company, deriving revenue from the manufacture and distribution of building products, and the provision of construction services	16,000	AUD $3.96 bn
James Hardie Industries Public Limited Company	A public company that is ranked number 120 out of the top 2000 companies in Australia. The company generates the majority of its income from the Non-Metallic Mineral Product Manufacturing in Australia industry.	4,920	AUD $4.91 bn
CSR Limited	A public company that is ranked number 198 out of the top 2000 companies in Australia. The company generates the majority of its income from the Non-Metallic Mineral Product Manufacturing in Australia industry.	2,960	AUD $1.66 bn
Brickworks Ltd	A public company that is ranked number 540 out of the top 2000 companies in Australia. The company generates the majority of its income from the Non-Metallic Mineral Product Manufacturing in Australia industry	1,483	AUD $2.5 bn
Holcim (Australia) Holdings Pty Ltd	A proprietary company that is ranked number 277 out of the top 2000 companies in Australia. The company generates the majority of its income from the Cement and Lime Manufacturing in Australia industry.	3, 193	n/a
Adelaide Brighton Ltd	a public company that is ranked number 292 out of the top 2000 companies in Australia. The company generates the majority of its income from the Non-Metallic Mineral Product Manufacturing in Australia industry	1,518	AUD $ 2.78 bn
Boral Limited	A public company that is ranked number 79 out of the top 2000 companies in Australia. The company generates the majority of its income from the Non-Metallic Mineral Product Manufacturing in Australia industry	11, 916	AUD $ 6 bn
Hanson Australia (Holdings) Proprietary Limited	A Proprietary Company that is ranked number 222 out of the top 2000 companies in Australia. The company generates the majority of its income from the Cement and Lime Manufacturing in Australia industry	4, 000	n/a
Barro Group Pty Limited	A family-owned building materials supplier that provide products and services include pre-mixed concrete businesses, quarries, builder supplies, precast concrete, cement and transport.	n/a	n/a

Source: IBISWorld data[301]

7.5 Concrete manufacturing

7.5.1 Constituents

The ingredients of concrete include a binding material (for example, cement or lime), a fine aggregate (for example, sand or other such materials), coarse aggregate (for example, gravel, crushed rocks or other alike materials) and water. Other constituents such as admixtures, pigments, fibres, polymers, and reinforcement can be incorporated to modify the properties of the plastic or hardened concrete.

7.5.2 Cement

The function of a binding material (Cement or Lime) is to bind the coarse and fine aggregate particles together. Although 'portland cement" is the most common binding material used as a binder in a mixture, much research has been done to prove that lime (especially hydraulic lime) can also be used successfully as a Binding material in common type of construction. Lime is economical as compared to cement and is also strong enough for the ordinary type of construction. In 2017-18, the Australian cement industry recorded a turnover of A$2.4 billion, employing more than 1,300 people directly and more than 5,000 indirectly—many based in regional Australia[302].

7.5.3 Water

Water is the main component of the concrete mix. Water plays an important role in the process of the chemical reaction of cement and aggregate.

7.5.4 Aggregate

The function of fine aggregates serves the purpose of filling all the open spaces in between the coarse particles. In this way, the porosity of the final mass is decreased. The maximum particle size in fine aggregates is always less than 6.35 mm. However, sand is commonly and universally used as a fine aggregate, and its grain size is around 2 mm. The function of coarse aggregates is to act as the main load-bearing component of concrete. When a good number of coarse aggregate fragments (all more than 6.35 mm in diameter) are held together by a cementing material, their behaviour towards the imposed loads is much like a very strong rock mass. Gravel and crushed stone are commonly used for this purpose.

7.6 Products overview

7.6.1 Manufacturing process

The specification, production and delivery of concrete are achieved in different ways. Production of concrete requires meticulous care at every stage. Manufacturing concrete based on Portland cement (Figure 40) includes the following stages[303]:

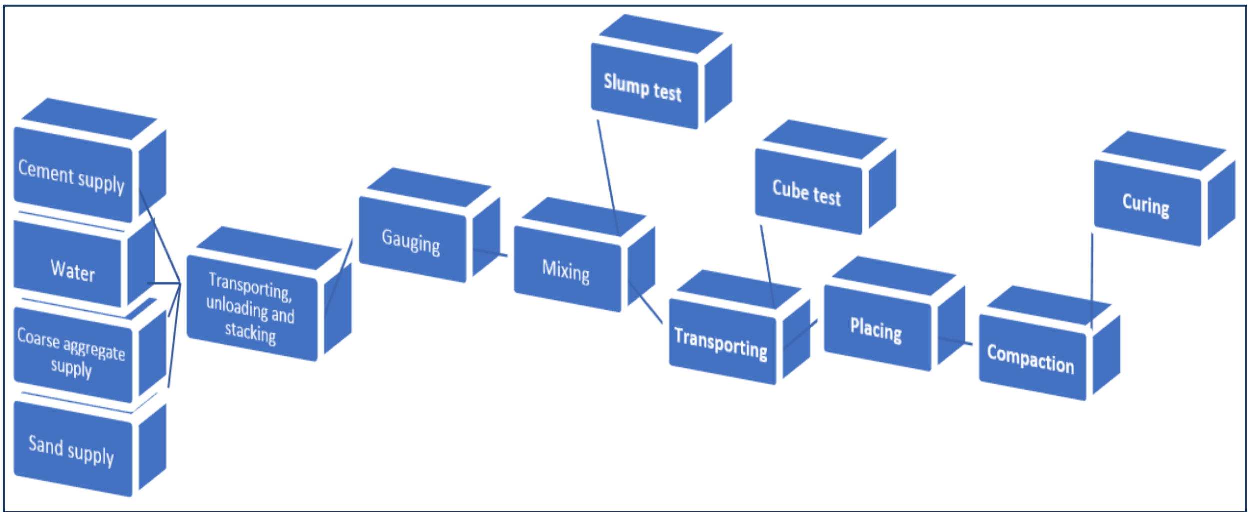

Figure 40. Schematic view of a typical concrete production process

Preparing Portland cement: The first step in making concrete is to prepare the cement. As type of cement (Portland cement) is considered superior to natural cement because it is stronger, more durable and of more consistent quality. The limestone, silica and alumina that make up Portland cement are dry ground into a very fine powder, mixed together in predetermined proportions, preheated and calcined (heated to a high temperature that will burn off impurities without fusing the ingredients). Next, the material is burned in a large rotary kiln at 1,400 °C. At this temperature, the material partially fuses into a substance known as clinker.

[302]Cement Industry Federation. 2017. Australian Cement Industry Statistics. https://bit.ly/3xi8d7N
[303] Made How platform. 2015. Volume 1. Concrete. https://bit.ly/3gohV26

The clinker is then cooled and ground to a fine powder in a tube or ball mill. A ball mill is a rotating drum filled with steel balls of different sizes (depending on the desired fineness of the cement) that crush and grind the clinker. Gypsum is added during the grinding process. The final composition consists of several compounds: tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium aluminoferrite.

Mixing: The cement is then mixed with the other ingredients: aggregates (sand, gravel or crushed stone), admixtures, fibres and water. Aggregates are pre-blended or added at the ready-mix concrete plant under normal operating conditions. The mixing operation uses rotation or stirring to coat the surface of the aggregate with cement paste and to blend the other ingredients uniformly. A variety of batch or continuous mixers are used. Fibres, if desired, can be added by a variety of methods including direct spraying, premixing, impregnating or hand laying-up. Silica fume is often used as a dispersing or densifying agent.

Transporting: Once the concrete mixture is ready, it is transported to the worksite. There are many methods of transporting concrete, including wheelbarrows, buckets, belt conveyors, special trucks (concrete agitator) and pumps. Pumping transports large quantities of concrete over large distances through pipelines using a system consisting of a hopper, a pump and the pipes. Pumps come in several types-the horizontal piston pump with semi-rotary valves and small portable pumps called squeeze pumps. A vacuum provides a continuous flow of concrete, with two rotating rollers squeezing a flexible pipe to move the concrete into the delivery pipe.

Placing and compacting: The next stage is to place and compact the concrete. These two operations are performed almost simultaneously. Placing must be done so that segregation of the various ingredients is avoided and full compaction-with all air bubbles eliminated-can be achieved. Whether chutes or buggies are used, the position is important. The rates of placing and of compaction should be equal; the latter is usually accomplished using internal or external vibrators.

Curing after placing and compacting: the concrete must be cured before it is finished to ensure that it does not dry too quickly. The moisture level influences concrete's strength during the hardening process: as the cement solidifies, the concrete shrinks. If site constraints prevent the concrete from contracting, tensile stresses will develop, weakening the concrete. To minimise this problem, concrete must be kept damp during the several days it requires to set and harden.

In addition to the process mentioned above there are new ways of concrete production such as prefabrication and in-situ cast concrete building.

7.7 Regulations, policies, and guidelines

The management of concrete waste is regulated at the state and territory level and can vary accordingly. A list of current jurisdictional C&D waste regulations and policies that apply to concrete waste is provided in Section 1. The regulations governing concrete waste management are not consistent across Australia; while some states and territories heavily regulate concrete waste, others have a more relaxed approach. Take Victoria and concrete waste as an example. The following regulations are in place:

- The Environment Protection Act 1970
- The Environment Protection (Resource Efficiency) Act 2002
- The Environment Protection (Amendment) Act 2006
- Environment Protection (Industrial Waste Resource) Regulations 2009
- Waste Management Policy (Movement of Controlled Waste Between States and Territories)

Due to the huge volume of concrete waste rubbles, health and safety issues during waste collection, particularly in demolition projects, is of importance. Furthermore, the presence of contamination can provide challenges in managing concrete waste. There is a number of policies and guidelines that provide best practice management or obligatory requirements in dealing with hazardous situations when concrete waste specifically needs to be managed.

- Occupational Health and Safety Act 2004 (Victorian Government)
- Occupational Health and Safety Regulations 2007 (Victorian Government)
- Guide to Best Practice at Resource Recovery Centres (Sustainability Victoria)
- Code of Practice for Manual Handling 2000 (Work Safe Victoria).
- The Occupational Health and Safety (Asbestos) Regulations 2003 (EPA Victoria).
- Industrial Waste Resource Guidelines Asbestos Transport and Disposal
- Recycling Construction and Demolition Material: Guidance on Complying with the Occupational Health and Safety (Asbestos) Regulations 2003 (WorkSafe Victoria) – Compliance Code: Managing asbestos in workplaces (WorkSafe Victoria).
-

Cement Concrete & Aggregates Australia (CCAA) has provided several industry guidelines that are relevant to the production and placement of concrete. The guidelines aim to assist concrete plants, truck manufacturers and drivers in operating safely, and to minimise the concrete waste during their operation. Table 56 provides a snapshot of these industry guidelines that have been published recently.

Table 56. Cement concrete & aggregates Australia industry guidelines

Guideline	Description	Date of release
Environmental Management Guideline for Concrete Batch Plants	This risk-based guideline provides guidance to operators of concrete batch plants to help them comply with their general environmental duty.	2019
Concrete Pump Delivery Guidelines	To reduce the unacceptable safety risks that may be involved in the delivery of concrete to on-site pumps, CCAA has developed a new industry guidelines document and checklist.	2019
Guidelines for Delivery of Bulk Cementitious Products to Premixed Concrete Plants	This document is intended primarily to provide a standardised approach for the pneumatic transfer of bulk cementitious powders into silos used by the premixed concrete industry.	2018
New South Wales Concrete by-product Recycling and Disposal Industry Guidelines	NSW legislation and regulations require that all operators must minimise the number of new resources used in the production process, ensure that as much material as possible is re-used or recycled and that any waste that cannot be re-used is disposed.	2014
Best Practice Guidelines For Concrete By-Product Re-Use At Concrete Batching Plants Queensland	This document provides the industry with best practice management guidelines for concrete by-product re-use management that meets legislative requirements.	2012

Source: CCAA[304]

Another set of regulations deals with the use of recycled concrete waste materials in construction projects such as roads and pavements. The standard specifications regulate and maintain the quality and provide producers as well as consumers an assurance of uniformity and consistency in quality of the recycled aggregate. For instance, in Vic, VicRoads, which is a state authority managing the road and traffic, has provided a code of practice[305] that outlines the specifications of recycled crushed concrete for application in the state road and pavement bases/subbase. In NSW, Transport for NSW (TfNSW), has set specifications for granular pavement base and subbase materials[306]. Later, the NSW EPA published a guideline entitled 'Specification for Supply of Recycled Material for Pavements,

[304]CCAA. 2019. https://bit.ly/3gpgsZx
[305]Vicroads. 2017. Code of Practice RC 500.02. Registration of Crushed Rock Mixes. https://bit.ly/3eh3Z7x
[306]RMS. 2008. Roads and Maritime Services (RMS). RT 3051 https://bit.ly/3gBDwob

Earthworks and Drainage 2010 (Greenspec)"[307], which was set to encourage local government professionals and other stakeholders within both the private and public works engineering sector such as designers, consultants, procurement managers etc. to use recycled concrete, brick and asphalt materials. Other states also have their own version of a code of practice for recycled concrete. However, similar to environmental regulations, the specifications provided in codes are not uniform[308].

Table 57. The standards and specifications guiding the use of recycled concrete

State	Title
ACT	n/a
NSW	Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage 2010 (Greenspec)
Qld	Transport and Main Roads Specifications MRTS35 Recycled Material Blends for Pavements
NT	Standard specification for roadworks
SA	The standard for the Production and Use of Waste Derived Fill Recycled Fill Materials for Transport Infrastructure - Operational Instruction 21.6 Policy Specification: Part 215 Supply of Pavement Materials
Tas	Unbound Flexible Pavement Construction
Vic	VicRoads Standard Specifications for Roadworks and Bridgeworks VicRoads Codes of Practice
WA	Main Roads Western Australia Specification 501—pavements

7.8 Concrete waste generation

Concrete waste is a large contributor to C&D waste volume worldwide. There are several sources of concrete waste and, accordingly, there are multiple concrete waste types based on the origin of generation. These may include concrete pavement waste, concrete waste from building structures and unwanted delivered concrete to construction sites. However, there is no widely accepted classification for concrete waste. The NSW EPA[309] has categorised concrete waste into four groups: concrete washings, concrete effluent, concrete delivered to a site but not used for the development and any other waste material containing concrete. Rakhimova and Rakhimov (2014) listed four types of concrete waste, namely: concrete waste, concrete waste powder, hydrated mortar concrete waste and ground concrete waste.

7.8.1 Concrete waste quantity

Previous studies have shown that brick and concrete waste can account for 75 per cent of C&D waste from a construction site[310,311]. In the US, 23.1 million t of concrete waste were produced in construction activities alone in 2015; buildings are the second-largest source of this waste after bridges and roads[312]. Furthermore, there are studies suggesting that some materials generate more waste than others[313,314,315]. These studies reported that concrete, together with mortar, bricks, steel

[307] EPA NSW. 2011. IPWEA Roads & Transport Directorate. https://bit.ly/32rE3R6
[308] Gabr, A.R., Cameron, D.A., Andrews, R. and Mitchell, P.W., 2011. Comparison of specifications for recycled concrete aggregate for pavement construction. *Journal of ASTM International*, 8(10), 1-15.
[309] NSW EPA. 2017. Concrete waste. https://bit.ly/3swpFBF
[310] Crowther, P. 2000. Building Deconstruction in Australia, Kibert, Charles J., Chini, Abdol, R., eds., "Overview of Deconstruction in Selected Countries" CIB Report No. 252, 18-19.
[311] Formoso, C.T., Soibelman, L., De Cesare, C. and E.L. Isatto, 2002. Material waste in building industry: main causes and prevention. *Journal of Construction Engineering and Management*, 128(4), 316-325.
[312] Environmental Protection Agency, 2018. Advancing Sustainable Materials Management: 2015 Fact Sheet Accessed on Sep. 6th, 2018. https://bit.ly/3dxrObU
[313] de Magalhães, R.F., Danilevicz, Â.D.M.F. and Saurin, T.A., 2017. Reducing construction waste: A study of urban infrastructure projects. *Waste Management*, 67, 265-277.
[314] Hassan, S.H., Aziz, H.A., Adlan, M.N. and Johari, I., 2015. The causes of waste generated in Malaysian housing construction sites using site observations and interviews. *International Journal of Environment and Waste Management*, 15(4), 295-308.

and ceramics/tiles are among the materials with a high rate of waste generation[313]. An analysis of wastage in five housing projects in Hong Kong showed that, among the six study materials (i.e. concrete, plastic, timber, glass, metal and paper), concrete waste was the largest contributor to C&D waste[316]. In WA, the Waste Authority reported that concrete waste was the second contributor (24 per cent) to their overall C&D waste generated in 2015-16 by weight[317]. The latest data for concrete waste was reported in 2018[318] and was prepared by Blue Environment Pty Ltd and Randel Environmental Consulting. The concrete waste data for the period 2016-17 is presented in Table 58. The individual data for the waste generation was only available for three jurisdictions: ACT, NSW and SA. An analysis of the table below shows that, among these three jurisdictions, NSW had 1,191.4 kt, from which 91.3 per cent belonged to the C&D waste stream.

[315] Song, Y., Wang, Y., Liu, F. and Zhang, Y., 2017. Development of a hybrid model to predict construction and demolition waste: China as a case study. *Waste Management*, 59, 350-361.

[316] Tam, V.W., 2011. Rate of reusable and recyclable waste in construction. *Open Waste Management Journal*, 4(1), 28-32.

[317] ASK Waste Management Consultancy Services. 2018. Recycling Activity in Western Australia 2015-16. Project No. 1603. https://bit.ly/3gqdP9Q

[318] DEE. 2018. P863 National waste data and reporting cycle 2017-19. https://bit.ly/3dyDwDu

Table 58. Concrete waste in Australian states and territories

	Waste generation				Waste landfill				Waste recycling			
State	**MSW**	**C&I**	**C&D**	**Total**	**MSW**	**C&I**	**C&D**	**Total**	**MSW**	**C&I**	**C&D**	**Total**
ACT	0	766	1,160	1,925	0	766	1,160	1,925	-	-	-	86,602
NSW	12,907	90,600	1,087,881	1,191,388	-	-	-	-	12,907	90,600	1,087,881	1,191,388
NT	-	-	-	-	-	-	-	-	-	-	-	-
Qld	-	-	-	-	-	-	-	-	-	-	-	1,476,739
SA	7,500	22,500	734,860	765,300	-	441	14,859	15,030	7,500	22,500	720,000	750,000
Tas	-	-	-	-	-	-	-	-	-	-	-	-
Vic	-	-	-	-	-	-	-	-	30,000	5,909	2,227,056	2,262,965
WA									2,291	1,900	235,271	239,462
Total	20,407	113,866	182,3901	1,958,613					52,698	120,909	4,270,208	6,007,156

Source: DEE, 2016-17

7.9 Waste management

7.9.1 Waste reduction during manufacturing

As a batch production concrete is made as specified amounts. However, there are opportunities to reduce waste during its production process. There is a large number of studies suggesting the replacement of the traditional ingredients of concrete that are freshly extracted from nature with recycled C&D waste materials. The major ingredient that is replaced is aggregate[319]. There is a growing need for aggregates in the production of concrete and other construction materials due to the large construction projects taking place all over the world. Therefore, there is a business case for encouraging recycling facilities as well as construction material manufacturers to source a part of their need for aggregate from recycled materials. In 2014, results of an analysis[320] of the consumption of aggregates showed a huge consumption of aggregates in various regions (Figure 41).

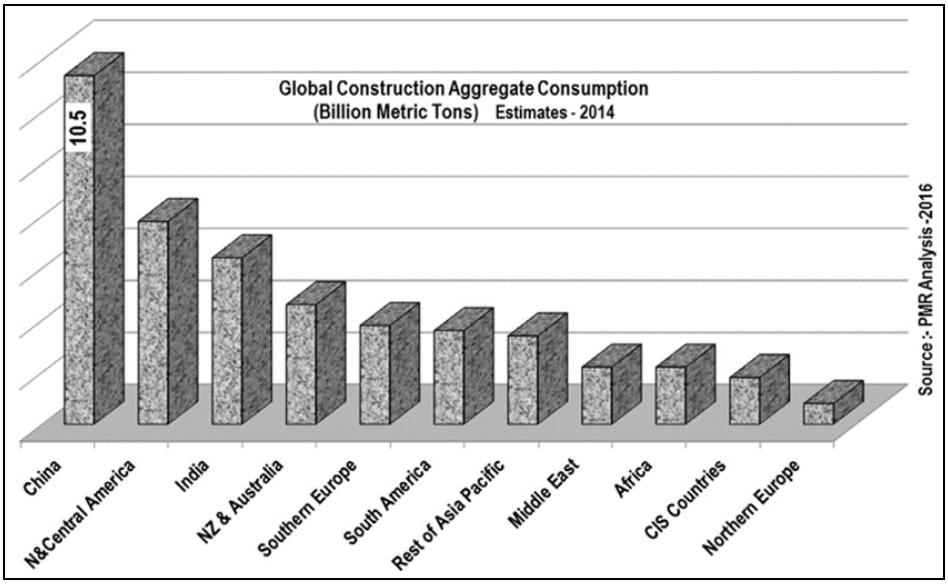

Figure 41. The worldwide consumption of recycled aggregate (2014)
Source: PMR Analysis (2016)

With some mechanical modifications, such as adding epoxy resin[321], crushed recycled concrete waste can also be used in the form of aggregate for brand new concrete if it is free of contaminants. The difference between natural aggregates and recycled concrete aggregate (RCA) include that RCA typically has higher water absorption and lower specific gravity[322]. The density of RCA is lower than the density of normal aggregates, and their porosity is also much higher than those of natural aggregates[323]. However, due to lower structural integrity, it is widely used in non-load bearing applications. A case study[324] in Australia commissioned by C&D materials recycler, the Alex Fraser Group, found that recycled crushed concrete offers superior performance, compared with its virgin counterpart, is cheaper and is better from an environmental perspective. The findings from this case study are:

[319] Tam, V.W., Soomro, M. and Evangelista, A.C.J., 2018. A review of recycled aggregate in concrete applications (2000–2017). *Construction and Building Materials*, 172, 272-292.
[320] PMR Analysis. Global Market Study on Construction Aggregate. New York, USA, 2016
[321] Shahidan, S., Azmi, M.A.M., Kupusamy, K., Zuki, S.S.M. and Ali, N., 2017. Utilizing construction and demolition (C&D) waste as recycled aggregates (RA) in concrete. *Procedia Engineering*, 174, 1028-1035.
[322] Rao, A., Jha, K.N. and Misra, S., 2007. Use of aggregates from recycled construction and demolition waste in concrete. *Resources, Conservation and Recycling*, 50(1), 71-81.
[323] Marinković, S.B., Ignjatović, I.S., Radonjanin, V.S. and Malešev, M.M., 2012. Recycled aggregate concrete for structural use–an overview of technologies, properties and applications. In Innovative Materials and Techniques in Concrete Construction (pp. 115-130). Springer, Dordrecht.
[324] Environment Protection and Heritage Council. 2010. National Waste Report. https://bit.ly/3tNtOmp

1. Crushed concrete has 65 per cent less of a carbon footprint than equivalent quarried material.
2. It is softer, resulting in less energy to crush than relative virgin rock.
3. It is 20–25 per cent less dense than crushed rock so fewer trucks are required for delivery.
4. Since cost is calculated on a weight basis, it is cheaper than crushed rock.
5. It can offer better performance in wet weather.
6. There is the reliability of supply and convenience of locations, leading to cheaper disposal of waste concrete.

Sustainability Victoria[325] reported that anecdotal evidence indicates that crushed concrete is quicker and easier to lay and to compact. It is thought that improved compaction is due to the product being made up of smoother and rounder particles, with better distribution and a larger percentage of fines and binder particles in the mix.

However, despite all the research performed in this area, recycled aggregates from waste concrete are mostly used in lower quality product applications such as backfills and road sub-base material[323]. A review study[326] on recycled concrete in structural applications compiled various methods to improve the quality of RCA based on the previous studies; these include the addition of limestone filler, additional cement, polymer additives, mineral admixture, water-reducing admixtures, two-stage and three-stage mixing approaches, and steel fibre. In addition to the aggregates, other components of concrete can be replaced with C&D waste materials such as filler, cement and freshwater. The primary C&D wastes that are found to offer benefits after being replaced are glass, brick, stone and timber. Table 59 provides a summary of some of the studies that investigate the use of recycled C&D waste in the production of concrete.

Table 59. Summary of studies investigating the use of C&D waste in the production of concrete.

Material	Summary of findings	Reference
Use of glass waste in the production of various cement-based concrete products	The findings of this investigation show encouraging results and open several outlets for recycling waste glass in the production of various concrete products including architectural cement mortars, concrete paving blocks and self-compacting concrete	Lu and Poon (2019)
Use of RCA	The evaluation of RCA in pavement construction under heavy traffic loads showed satisfactory performance.	Nassar and Soroushian (2016)
Use of recycled ceramic waste as fine and coarse aggregate for concrete production	The study proved that use of up to 50 per cent of crushed ceramics, as fine and coarse aggregates, could be used for concrete production exposed to high temperature	Canbaz (2016)
Crushed brick as a coarse aggregate in concrete	The results demonstrated the durability of crushed bricks as a natural aggregate replacement at 25 and 50 per cent and recommends to use the bricks in unreinforced concrete.	Adamson et al. (2015)
Use of granite industry waste in the production of concrete	The obtained test results were indicated that the replacement of natural sand by granite powder waste up to 15 per cent of any formulation is favourable for the concrete making without adversely affecting the strength and durability criteria	Vijayalakshmi et al. (2013)
Use of wood ash as a cement in concrete mix	Blended cement with wood ash as a partial Ordinary Portland Cement replacement material has a higher standard consistency, initial and final setting time, concrete and mortar mixtures containing wood ash increase magnitudes of water absorption in concrete mixtures. Inclusion of wood ash at low levels of cement replacement actually contributed towards the enhancement of compressive strength in concrete mixtures produced	Cheah and Ramli (2011)
Use of waste marble	The results obtained show that the mechanical properties of	Hebhoub et al.

[325] Sustainability Victoria. 2015. Market summary – recycled brick, stone and concrete. https://bit.ly/2Q7RkvL
[326] Senaratne, S., Lambrousis, G., Mirza, O., Tam, V.W. and Kang, W.H., 2017. Recycled concrete in structural applications for sustainable construction practices in Australia. *Procedia Engineering*, 180, 751-758.

Material	Summary of findings	Reference
aggregates in concrete	concrete specimens produced using the marble wastes were found to conform with the concrete production standards and the substitution of natural aggregates by waste marble aggregates up to 75 per cent of any formulation is beneficial for the concrete resistance	(2011)
Use of recycled brick waste powder as a mineral filler in asphalt concrete mixture	The results show that the mixtures prepared with recycled brick powder have better mechanical properties than the mixtures with limestone filler. Thus, it is promising to use recycled brick powder as a mineral filler in asphalt mixture.	Chen et al. (2011)
Use of ceramic waste in concrete production	Results show that concrete with 20 per cent cement replacement, although it has a minor strength loss, possess increase durability performance. Results also show that concrete mixtures with ceramic aggregates perform better than the control concrete mixtures concerning compressive strength, capillary water absorption, oxygen permeability and chloride diffusion, thus leading to more durable concrete structures.	Pacheco-Torgal and Jalali (2010)
Use of timber waste as aggregate for special lightweight concrete	The aggregate is made from a recycled small wood chunk that undertakes blast furnace deoxidization.	Tam and Tam (2006)

7.9.2 Waste reduction opportunities during design, planning and contract

Errors during the design stage, rework and unexpected changes continue to contribute to concrete waste generation in construction activities around the world[327]. The rate of occurrence of design errors in the building sector is higher as a building consists of components that are designed by different project participants and are corrected until after the construction work has started on site, which can lead to rework and construction waste[328]. Recently utilisation of the BIM offers assistance to designers to reduce concrete waste in the construction industry. By definition, BIM is a parametric component-based, three-dimensional reference structure modelling system created using file formats that allow all disciplines involved in the project life cycle to exchange their data. In the broader context, BIM is a new approach to design and construction beyond modelling[329]. BIM, at the design stage, can be beneficial in minimising waste in different ways. For instance, Won et al. (2016)[327] indicated that the use of BIM can reduce improper design, residues of raw materials and unexpected changes in building design and improve procurement, site planning and material handling in construction management. Table 60 provides some information on how BIM can benefit the construction industry in minimising the waste that might be generated at a construction site.

Table 60. Various BIM-based methods that prevent the generation of concrete waste at the design stage

Method	Case study	Results	Reference
Analysing reinforced concrete structures to reduce reinforcement waste by selecting proper lengths of rebars and considering available cut-off lengths	N/a	BIM was utilised to simulate architectural and structural design requirements and to compare results in order to make the necessary changes in the design to reduce and reuse rebar waste.	Hewage and Porwal (2011)

[327] Won, J., Cheng, J.C. and Lee, G., 2016. Quantification of construction waste prevented by BIM-based design validation: Case studies in South Korea. *Waste Management*, 49, 170-180.

[328] Gavilan, R.M., Bemold, L.E., 1994. Source evaluation of solid waste in building construction. *Journal of Construction Engineering, and Management*. 120 (3), 536-555.

[329] Crotty, R. 2012. The Impact of Building Information Modelling: Transforming Construction, Spon Press, London, UK.

Method	Case study	Results	Reference
BIM-based design validation was conducted to improve the design quality. Practitioners found 381 and 136 design errors by conducting BIM-based design validation in the first case.	Two case projects in South Korea included two residential buildings, which are reinforced concrete structures with a total floor area of about 120,000 m^2 and a sports complex with a total floor area of 9995 m^2	Concrete waste comprised the largest portion of construction waste prevented by BIM-based design validation in the two cases (98.3 per cent and 95.6 per cent)	Won et al. (2016)

7.9.3 Reducing waste during the procurement

In a study in the UK,[330] prefabrication and procurement management were identified as the most recommended methods for minimising concrete waste. Tam (2011) indicated that accurate calculation to order a quantity of concrete needs to be practised to reduce potential waste. Tam reported that the interviewed quantity surveyors for the study explained that projects cannot order concrete as the same calculation from bills of quantity without considering wastage. His observation showed that onsite practices tend to order between 5 per cent and 10 per cent additional concrete to the construction site. One of the main problems is that organisations cannot afford to not have enough concrete for onsite concreting activities; otherwise, construction will be interrupted. One possible strategy to tackle this problem is to use onsite mobile crushers that minimise the waste by crushing it as recycled aggregate for concrete production.

7.9.4 Reducing waste during transportation and delivery

Wilson and Kosmatka[331] summarised 15 methods and equipment for transporting and handling concrete. Depending on the construction site situation, some of these methods may have an advantages in reducing the likelihood of concrete waste generation over others. On any large construction site requiring multiple deliveries, a washout area needs to be designated to let the water soak into the ground and not run over the land into the stormwater system or into streams[332].

7.9.5 Reducing waste during construction

Construction technology is proven to have a fundamental impact on the generation of construction waste. The adoption of prefabrication technology in the construction industry dates back to the 1980s, when concrete was the first construction material that was prefabricated. Precast concrete was used to build a casino by François Coignet in Biarritz in 1891[333]. In 2002, a study[334] estimated a reduction of 70 per cent in concrete waste by using prefabrication. According to a set of interviews with construction practitioners, Tam (2011) suggested that the best way to reduce concrete waste is to use prefabrication instead of in situ concreting.

Another strategy to reduce waste during construction is to use structural steel. It is reported that steel causes a reduction in concrete and rebar waste. The other option is to use on-site mobile crushers. This machine can minimise the waste by crushing it to recycled aggregate for concrete production. A more sustainable approach is to educate labourers who deal with concrete products construction projects. In Australia, under the Continuing Professional Development system,

[330] Meibodi, A.B., Kew, H., Haroglu, H., 2014. Most popular methods for minimizing insitu concrete waste in the UK. New York Sci. J. 7 (12), 111-116.

[331] Wilson M.L and SH Kosmatka. 2011. Design and Control of Concrete Mixtures. Chapter 10: Batching, Mixing, Transporting, and Handling Concrete. https://bit.ly/3gnXRgp

[332] Taranaki Regional Council. 2013. Concrete washings and concrete cutting waste water. https://bit.ly/3txWbEZ

[333] Staib, G., A. Dörrhöfer, and M.J. Rosenthal, Components and Systems : Modular Construction : Design, Structure, New Technologies. 1st ed. 2008, Basel, Switzerland: Birkhäuser Verlag AG. 239.

[334] Lawton, T., Moore, P., Cox, K., Clark, J., 2002. The gammon skanska construction system. In: Proceedings of the International Conference Advances in Building Technology, Hong Kong, China, 1073–1080.

Pointsbuild[335], in partnership with the Concrete Masonry Association of Australia (CMAA) provides online training courses for construction professionals including those working with concrete materials. The following table (Table 61) shows the courses relevant to the concrete industry and which are contributing to improving concrete waste management:

Table 61. The online courses provided by Pointsbuild®[335]

Course	Objectives
CMAA Introduction to Concrete Masonry and Pavers	This course provides a background on the benefits and advantages of concrete masonry and paving and includes key industry concepts and terms to build your knowledge.
Designing Robust Concrete Structures	This learning module brings together two of Australia's leading experts in the design and understanding of robust concrete structures.
The Durability of Concrete Structures	This Concrete Institute of Australia (CIA) webinar provides an update on the work of the Institute Durability Committee and provides guidance on durability design processes and practice that satisfy requirements
Prefabricated Concrete Elements (Changes to AS 3850)	This seminar looks at the reforms made to the prefabricated concrete elements industry and at the Australian Standards documents, formally known as AS3850 Tilt-up Concrete Construction.

7.9.6 Reducing waste during demolition

If space permits, on-site mobile crushers are an excellent choice for concrete waste management through crushing the waste to aggregate that is usable in concrete production. Figure 42 shows the typical recycling process in stationary recycling plants, which are suitable as recycling centres in urban areas

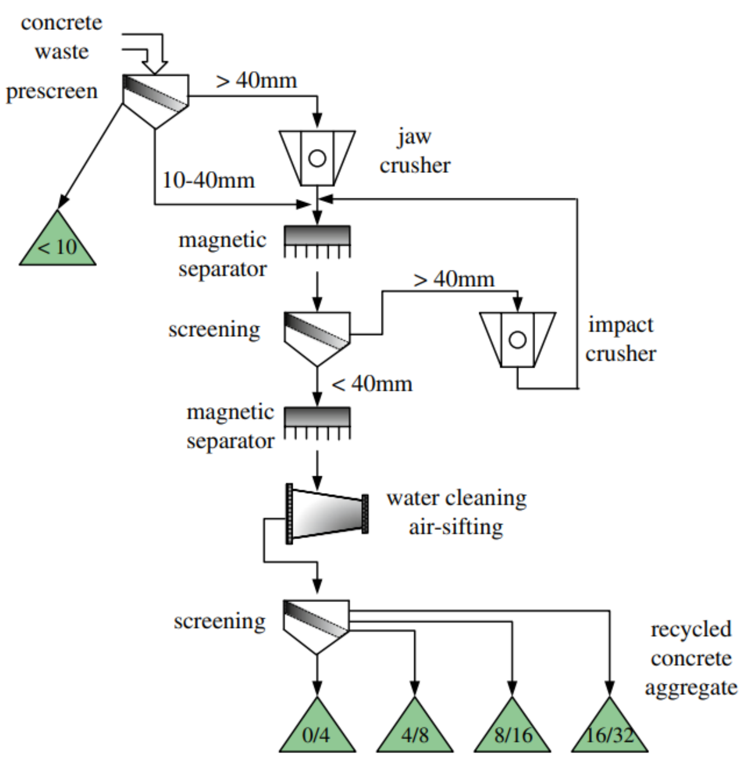

Figure 42. Concrete waste recycling process using an on-site recycle crusher
Source: Marinković et al (2012)[323]

[335] PointsBuild®. https://www.pointsbuild.com.au/

In mobile recycling plants, the processing is limited to one-stage crushing, magnetic separation and screening. When demolished concrete is crushed, a certain amount of mortar and cement paste from the original concrete remains attached to stone particles in recycled aggregate.

7.9.7 Reducing waste through reusing

Re-using concrete waste, provided it has an acceptable level of contamination, is a typical practice in the construction industry. However, there are limitations in the level of re-using concrete waste. For instance, in NSW, hardened returned concrete cannot be utilised for dams, mines, quarries or sand dredge rehabilitations as backfill for voids, or utilised in reshaping land for agricultural purposes. However, this material can be applied to road construction on private land if the following conditions are met:[336]

- The relevant waste is applied to land to the minimum extent necessary for the construction of a road.
- Consent for the development has been granted under the relevant environmental planning instrument. It is to provide access (temporary or permanent) to a development approved by a local government.
- The works undertaken are either exempt or they are a complying development. The material applied to the land must be sampled and tested, as detailed in the general exemptions, to ensure that it will pose minimal risk of harm to the environment.

One study in Hong Kong[337] showed that the actual average rate of re-usable and recycled concrete waste in five housing projects was 48 per cent. The percentage for metal, timber, glass and paper was 64 per cent, 58.5 per cent, 29.6 per cent and 83 per cent, respectively.

There are some examples of construction with significant usage of RAC including an office building with an open multi-storey garage, Vilbeler Weg, in Darmstadt (Figure 43). The complete reinforced concrete structure was constructed using RCA. Approximately 480 m^3 of RAC was used in and RCA was also applied for all in-door structural elements, as well as for the foundation slab, in a residential building, also in Darmstadt, Germany (1998, Figure 43).

Figure 43 Left: Vilbeler Weg office building in Darmstadt, Germany, (1997-98), Right: Residential building in Darmstadt, Germany (1998)
Source: BIM (2010)

Crushed concrete can be re-used in the landscape industry. It is possible to create a short planter or garden wall with broken pieces of concrete that is about the same height. A brief instruction for such

[336]CCAA. 2014. New South Wales Concrete by-product Recycling and Disposal Industry Guidelines. https://bit.ly/3mZwU40
[337] Tam, V.W., 2011. Rate of reusable and recyclable waste in construction. *Open Waste Management Journal*, 4(1), 28-32.

an application is provided by the All Around Soil and Stone blog[338]. The CCAA has provided a guideline[339] on RCA specifications that reviews the various types of aggregates and their potential for use in concrete and/or road construction materials.

7.9.8 Waste recovery (recycling and upcycling)

Recycling is a typical practice for concrete waste management, and it offers multiple benefits, including reduced costs of removing and hauling, elimination of high landfill fees and contribution to the production of lower-cost recycled aggregate products. Japan is a leading country in recycling concrete waste, with a recycling rate of 98 per cent; the recycled materials are used in concrete structural applications[340]. Also, in Denmark, only 2 per cent of concrete and bricks generated are landfilled, with the remainder reused and recycled[341]. In Australia, it is common to mix RCA with small amounts of crushed bricks and soil to obtain a recycled product considered suitable for use in pavements[342]. There are three main types of concrete waste-based aggregates RCA, recycled concrete and masonry (RCM), and reclaimed aggregate. The performance of these materials is compared to natural aggregates.

Table 62. Summary of studies investigating the applications of recycled concrete waste

	Application	Summary of findings	Reference
Upcycling	Oyster bed	In the US, a novel application for RCA was found in the construction of an artificial reef. Since the recycled material is being placed in a marine environment, concrete, particularly with high chloride content, is acceptable	Presented in Tam et al. (2018)
Upcycling	Use of autoclaved aerated concrete (AAC) as lighting material in the structure of a green roof	The results showed some similarities between the study of AAC and natural green roof characteristics; based on the results the authors indicated that the introduction of granular waste AAC within the structure of a green roof could help to reduce industrial wastes	Bisceglie et al. (2014)
Upcycling	Use of recycled concrete as a gardening mulch	The resulting concrete mulch is an aesthetically pleasing landscaping ground cover that effectively and productively disposes of post-consumer waste	Flynn (2010)
Recycling	Use of RCA as alternative granular infills in hollow segmental block systems	RCA is an alternative infill material used for segmental retaining walls; the interface shear capacity (peak) of blocks infilled with RCA is almost equal to that of those with natural aggregates, and the grade of concrete has little or no effect on the frictional performance of the RCA used in facing units	Bhuiyan et al. (2015)
Recycling	Use of RCA in structural members such as beams, columns, slabs and walls	A C40 grade concrete, with up to 100% RCA, was used for all structural members (i.e. beams, columns, slabs and walls); the good experience acquired in the construction of this building enabled alterations in the building code requirements of Singapore to allow the use of RCA in all buildings	Ho et al. (2015)

Australian jurisdictions have already started taking advantage of these materials in the construction industry. The following are examples of such applications:

[338] All Around Soil and Stone. 2018. Uses for Recycling Concrete in Landscaping. https://www.soilandstone.com/recycling-concrete-landscaping/

[339] Cement Concrete & Aggregates Australia. 2008. Use of Recycled Aggregates in Construction. https://bit.ly/3v5JqBS

[340] Tam, V.W., Tam, L. and Le, K.N., 2010. Cross-cultural comparison of concrete recycling decision-making and implementation in construction industry. *Waste Management*, 30(2), 291-297.

[341] Residua. 1999. Construction and Demolition Waste", Information Sheet in Warmer Bulletin, Issue 67, July 1999.

[342] Bakoss, S.L., Ravindrarajah, R.S., 1999. Recycled Construction and Demolition Materials for Use in Road Works and Other Local Government Activities: Scoping Report. University of Technology, Centre for Built Infrastructure Research, Sydney, 136.

Case study 1- Rehabilitation of existing pavement in a residential street (NSW): Fairfield City Council- Delgarno Road, Bonnyrigg Heights[307]. In this project, which used recycled concrete, the contractor engaged replaced 175m^2 of the failed pavement material with 150 m^2 of crushed concrete in 2002. Inspection after seven years shows that the pavement is still in excellent condition, with no defects being observed. The following table shows the conditions of the rehabilitated residential road before and seven years after reclamation using crushed concrete.

Figure 44. Road conditions before and seven years after reclamation with crushed concrete
Source: IPWEA NSW (2010) [307]

In the ACT, in 2018-19, a program called Sustainable Roads[343] was launched, whereby the roads in Canberra were rehabilitated using various waste materials including old car tyres, printer toner powder, recycled road surface, recycled road base, recycled concrete and fly ash from power generation. Recycled concrete was incorporated in road base and paths. In WA, upon successful application of crushed recycled concrete in several state projects, in 2018 a large infrastructure project[344] (Kwinana Freeway Northbound Widening) set out to maximise the use of recycled concrete. This eight-kilometre project is planned to consume 25 kt of recycled concrete as road base.

Case study 2- Samwoh Eco-Green Building (Singapore): The Samwoh Eco-Green Building was the result of a demonstration project envisaging the construction of the first structure in Singapore using concrete with up to 100 per cent RCA[345]. The objective of this project was to evaluate the feasibility of using RCA produced from C&D waste in structural concrete. This project involved two stages, including the extensive evaluation of the performance of concrete containing RCA, and construction and structural monitoring of a three-storey building containing the material. A C40 grade concrete, with up to 100 per cent RCA, was used for all structural members (that is beams, columns, slabs, and walls) of the building in the second stage of the project. In situ performance monitoring of the RCA was based on fibre-optic sensors installed to measure the columns' deformation. The good experience acquired in the construction of this building enabled alterations in the building code requirements of Singapore to allow the use of RCA in all buildings.

[343] ACT Transport Canberra and City Services. 2019. Sustainable Roads. https://bit.ly/3aIbxzp
[344] WA Main Roads. Kwinana Freeway Northbound Widening. 2019. https://bit.ly/3v64GY0
[345] Ho, N.Y., Lee, Y.P.K., Lim, W.F., Chew, K.C., Low, G.L. and Ting, S.K., 2015. Evaluation of RCA concrete for the construction of Samwoh Eco-Green Building. *Magazine of Concrete Research*, 67(12), 633-644.

Figure 45. The Samwoh Eco-Green Building, Singapore, built using RCA for building construction
Source: Samwoh(2019)[346]

Metals coming from the C&D sector are also sourced from concrete reinforced with steel. In the demolition phase, there can be a ratio of 80 per cent concrete to 20 per cent steel. Demolition companies recover and reprocess the concrete. However, a report in the context of Australia estimated that even after this processing of the steel, it generally has about 10 per cent concrete (contamination) remaining with the steel[347]. It is necessary to utilise advanced density separation techniques to grade crushed concrete fines in recycling facilities. Application of these techniques results in an increase in homogeneity of RCA and reduce the presence of foreign inclusions.

7.9.9 Illegal dumping and stockpiling

There is limited documented data about the illegal dumping of concrete waste in Australia. As noted before, while there are hefty penalties for illegal dumping and stockpiling of C&D waste in some jurisdictions (for example, NSW and Vic), in other jurisdictions there are no (or more relaxed) regulations against dumping activities. The inconsistencies are thought to be a source of inter-state waste transfer. Another issue that has created confusion or opportunity for wrongdoing by developers and the waste recovery industry is an unclear definition of waste and resource. This uncertainty could lead to a commitment of the offence of illegal dumping and stockpiling.

Case study: Darwin water park site (NT)[348] In 2019, the NT EPA lay charges against DWD Project Pty Ltd, a construction company accused of illegally dumping thousands of cubic metres of construction waste on Darwin harbour's foreshore, including some that were allegedly dumped on neighbouring government land—the proposed site of the water theme park (Figure 46). The NT EPA reported that the disposal and burial of these wastes raised the levels of the land, covered foreshore habitat and filled a large area of Darwin Harbour with wastes and contaminants. However, the director of this company indicated that the alleged pollution was, in fact, part of another program of recycling; all the debris, according to the director, is recycled concrete from building sites.

[346] SAMWOH. 2019. Innovative solutions. https://bit.ly/2QkF7ng
[347] Hyder Consulting and EnCycle Consulting & Sustainable Resource Solutions. 2011. Construction and Demolition Waste Status Report: Management of Construction and Demolition Waste in Australia.
[348] Ashton, K. 2019. ABC News: Illegal waste allegedly dumped on proposed Darwin water park site, NT EPA claims. https://ab.co/3szYPbI

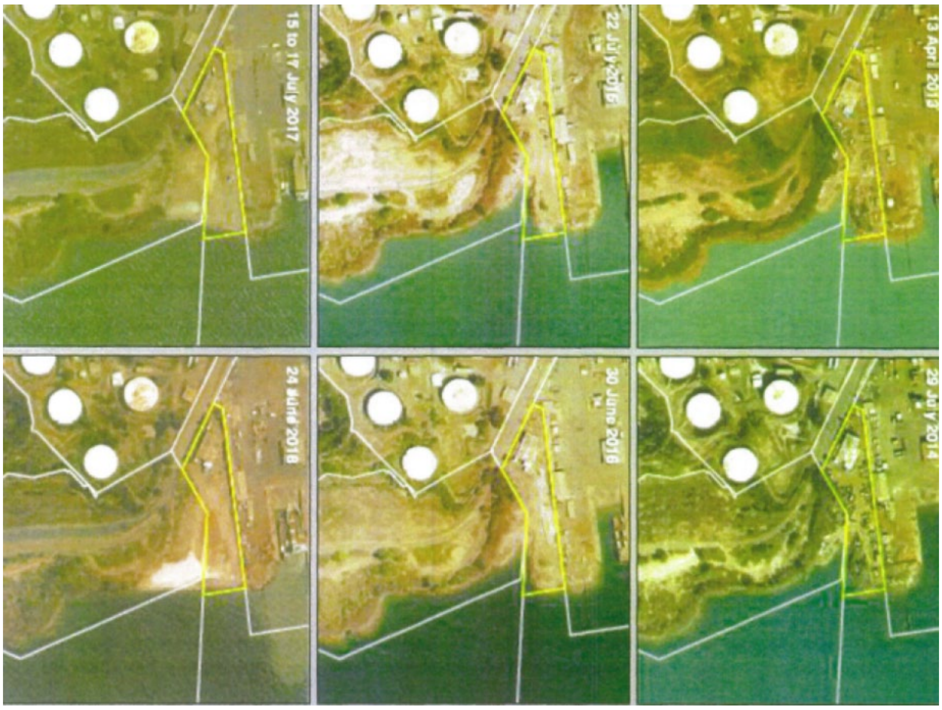

Figure 46. Satellite pictures of the Darwin water park site
Source: Ashton (2019),[348] supplied by the NT EPA.

7.9.10 Landfill the waste

There is a lack of accurate data registered for concrete waste landfilling in various Australian jurisdictions. In the financial year 2008-09, concrete waste disposal including landfilling in the three states of NSW, WA and SA was 2,063.6 kt[349]. According to the latest available data that is presented in Table 58, SA and the ACT landfilled 16.96 kt of concrete waste in 2016-17. Of this number, 94.5 per cent was from the C&D waste stream.

7.10 Concrete waste market, barriers, and strategies

Concrete makes up the greatest proportion of masonry material recycled in Australia, at around 60 per cent of all masonry material recycled[347]. Some states have conducted a market analysis for C&D waste, including concrete waste. For instance, in Vic, Sustainability Victoria[350] published the results of market analysis for recycled concrete. Based on this report[350], the markets for recycled concrete are generally mature and strong, particularly in metropolitan areas. The C&D recovery sector is dominated by private companies where basic economic principles apply; that is when there is sufficient market demand, and the product is the right price, the supply side of the equation will, to a large extent, look after itself. This analysis also estimated that the value of concrete waste recovery and the end product is at about AUD $167 m and AUD $40 m, respectively. However, the market faces several challenges that need to be addressed in the interest of sustainable operation of the market. However, anecdotal evidence shows in some parts of Australia such as WA, recycled concrete market is yet to be fully developed and as a result currently there are many stockpiles.

In 2017, a review study[351] identified the main barriers to the wider usage of recycled aggregates including recycled concrete aggregates, which include limiting standards/specifications, low-quality materials, insufficient financial incentives, customer perception, low supply and demand, and long

[349] DSEWPaC (2011) Waste and Recycling in Australia 2011, prepared by Hyder Consulting.
[350] Sustainability Victoria. 2015. Market summary–recycled brick, stone and concrete.
[351] Silva, R.V., De Brito, J. and Dhir, R.K., 2017. Availability and processing of recycled aggregates within the construction and demolition supply chain: A review. *Journal of Cleaner Production*, 143, 598-614.

distances from C&D waste recycling. Specifically, in Australia, the three factors that are having a negative impact and are regarded as a barrier are:

1. The need to separate concrete waste from other waste which is sometimes next to impossible; the price of management of contaminated concrete waste is more than five times that of clean waste.
2. Inconsistent jurisdictional standard specifications limiting an operation of a nationwide market.
3. Long distances between construction sites and C&D waste recycling facilities.

Another study[352] in the context of Australia investigated the main barriers among Australian designers, builders and engineers. The barriers identified included:

1. Builders: (a). cost related to using additives to improve RCA durability and (b). reluctance to change the resultant concrete specification.
2. Designers and architects: (a). lack of cost-saving associated with the use of RCA and (b). presence of the risk of structural failure.
3. Engineers: (a). uncertainty about the consistency of recycled concrete and (b). lack of standard specifying the specifications of RCA and (c). potential higher costs of RCA.

In keeping with the barriers mentioned above, anecdotal evidence acquired by Sustainability Victoria[350] suggests there is less likelihood that product with recycled content will be used for higher performance applications where traditional "proven" products are available. However, evidence and case studies supporting the application of recycled products is gradually emerging in the marketplace. Table 63 provides a summary of strategies identified to overcome barriers in the development of the market for concrete waste.

Table 63. Strategies to remove barriers to market development for concrete waste

Reference	Barrier	Strategy to remove the barrier(s)
Senaratne et al. (2017)	Costs associated with additives to RCA for better durability	▪ Conduct a life cycle analysis to quantify potential saving from increased durability ▪ Introduce RCA through pre-cast panels as a quality that can be closely monitored ▪ Change the industry attitudes towards sustainability-conscious material choices, as inertia towards traditional practices in construction is prevalent.
Sustainability Victoria[350]	Labour costs, changes in building technology and low demand	▪ Improve separation on-site to sort concrete waste material from other C&D waste ▪ Develop educational materials for designers and builders about material choice and waste management ▪ Increase promotion of the use of recycled concrete in pavement construction.
Cement Concrete & Aggregates Australia	Government procurement	▪ Continued research and development on further end-uses for recyclable materials ▪ Removing barriers to government procurement of recyclables can contribute to the development of end markets for materials ▪ Develop performance-based specifications for the use of recycled waste materials

7.10.1 Integrated supply chain

According to Sustainability Victoria,[353] costs associated with transport are major factors in determining whether the material will be recycled or landfilled. Similarly, the generally low value

[352] Senaratne, S., Lambrousis, G., Mirza, O., Tam, V.W. and Kang, W.H., 2017. Recycled concrete in structural applications for sustainable construction practices in Australia. Procedia engineering, 180, 751-758.

of end product (per cubic metre or by tonnage) means that the relative distance similarly impacts transportation of products to end-users that the recycled product must be transported versus a substitute product. As such, the location of facilities for reprocessing is of particular importance, as it is the determinant of the total haulage distance from collection to recycled product end-user. Currently, there are companies across Australia that specialise in the removal and collection of concrete waste generated from demolition, construction or renovation projects. Table 64 summarises two companies management practices. These companies operate in different jurisdictions, and the business information has been extracted through direct contact with their sale and technical teams.

Table 64. Supply chain characteristics of the waste collector

Business name	State	Pricing mechanism	Others
Cleanway Environmental Services	Vic	\$250 per load of 6 m skip bin that can hold 8 t of waste – the clean waste costs \$31/t If it is contaminated, the price will be \$250 for transport and \$145/t	Concrete waste will be sent to a recycling facility.
Bingo	Vic	\$420 per load of 6 t of concrete waste; the price includes drop-off, pick-up and renting a skip bin for 7 days \$125/t clean concrete waste \$150/t mixed concrete waste	The waste received at the yard will be recycled, un-recyclables will be sent to landfill

Note: the prices tabulated above are current as of November 2019.

7.10.2 Concrete lifecycle models

Figure 47 shows the supply chain of concrete waste in various applications[354]. This diagram illustrates how a concrete waste can explore various possible avenues including upcycling in road base or solid stabiliser, recycling into aggregates in preparation of ready-mixed concrete or cement, or disposal.

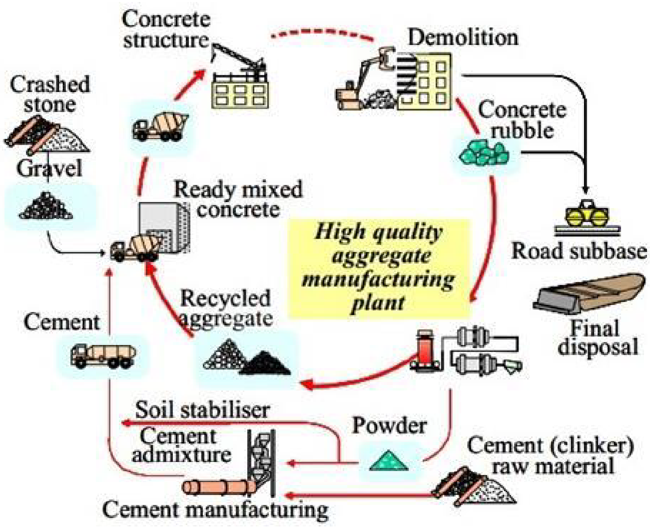

Figure 47. Supply chain or concrete waste recycling
Source: ASTM C136[354]

[354] ASTM C 136 – 95a, 2009. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregate, Annual Book of ASTM, International Standard Worldwide.

In this model, there are 11 points at which concrete waste can be efficiently managed. Figure 48 depicts these opportunities and the relationships among them.

Figure 48. The integrated supply chain lifecycle model for concrete waste

Table 65 shows the role of the main stakeholders in the management of concrete waste corresponding to the developed integrated supply chain. The stakeholders identified in Table 65 are thought to make a major contribution to the effective management of concrete waste. Their contribution could be translated into waste minimisation or reduced waste landfilling, directly or indirectly.

Table 65. The role of various stakeholders in the effective management of concrete waste

No.	Stage	Stakeholder(s)	Contributions
1	Design	Designers, construction firms, clients	• Re-use an existing building instead of a new one • Design a new building to facilitate its re-use in the future • Consider precast concrete panels in the designs • Consider building standardisation to improve buildability and reduce the number of offcuts

2	Manufacturer	Manufacturers, recyclers, suppliers	• Recycling of aggregates, sands and water at the manufacturing site • Develop an agreement where a contractor 'sells back" the re-cycled waste from the original material supplier • Participate in appropriately developed EPR and PS schemes, • Building R&D activities for finding new mixes and applications of RCA
3	Procurement and contract	Construction firms, quantity surveyors, government	• Construction firms to order concrete more accurately using the best take-off practice • Suppliers to provide more flexible 'last pack" sizes i.e. a 'fractional" pallet instead of a full pallet • Alter public contracts (purchasing) for crushed concrete usage in public projects.
4	Transportation and delivery	Construction firms, transporters, recycling companies	• Just-in-time delivery of materials to construction sites, to avoid damage taking place due to insufficient space for proper storage and adverse weather conditions • Do due diligence in handling concrete products and exercise standard working practices.
5	Construction	Construction firms, waste collectors, recyclers	• Adopt prefabrication technologies • Provide cost-efficient recycled aggregates for constructions • Separate clean concrete waste from other waste materials
6	Demolition	Demolition contractors, waste collectors, recyclers	• Consider selective de-construction to maximising the reuse potential of its components.
7	Reuse	Construction firms, state and territory governments, EPAs and other equivalent organisations, waste collectors	• Facilitate market development; • Adjust specifications in favour of more usage of concrete waste-based materials in new constructions project. • Standardise national approach to road base specification and other applications • Incentivise reusing through Green building rating schemes
8	Recycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Facilitate market development; • Fund the development of waste recovery infrastructure; • Adjust specifications in favour of more usage of concrete waste-based materials in new constructions project.
9	Upcycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Facilitate market development; • Adjust specifications in favour of more usage of concrete waste-based materials in new constructions project; • Fund the development of waste recovery infrastructure.
10	Stopping illegal dumping and stockpiling	State and territory governments, EPAs and other equivalent organisations	• Reinforce activities that stop illegal dumping and stockpiling; • Set stricter regulations with a higher rate of penalty fees to discourage illegal dumping and stockpiling; • Strengthen controls over licensed landfill sites.
11	Landfill	State and territory governments, EPAs and other equivalent organisations	• Design appropriate landfill levy schemes to discourage concrete waste landfilling.

7.11 Relevant industry associations

In addition to the stakeholders identified above, industry associations and training foundations are reported to have a meaningful impact on sustainable concrete waste management. In this section, the relevant industry associations that specifically work towards the better management of concrete and the waste associated with the concrete are identified. These associations are to collaborate with the public sector towards recognising opportunities for the further reduction, reuse and recycling of concrete waste in Australia. Table 66 summarises the main industry associations with a focus on concrete in Australia.

Table 66. Industry associations relevant to the management of concrete waste

Associations	Vision	Website
Concrete Pipe Association of Australasia (CPAA)	As the principal source of technical knowledge and education covering all aspects of pipe and related products, the aim of the CPAA is to promote and develop excellence in the steel-reinforced concrete pipe industry, ensuring that reinforced concrete pipe is the benchmark product for stormwater drainage, large diameter sewers, low pressure and irrigation pipe applications in Australasia.	www.cpaa.asn.au
Cement, Concrete & Aggregates Australia (CCAA)	The CCAA is the peak body for the heavy construction materials industry in Australia. Members include cement manufacturing and distribution facilities, concrete batching plants, hard rock quarries and sand and gravel extraction operations throughout the nation.	www.concrete.net.au
Cement Industry Federation (CIF)	The CIF is the national body representing the Australian cement industry; Its membership is made up of the three major Australian cement producers: Adelaide Brighton Ltd, Boral Cement Ltd and Cement Australia Pty Ltd.	www.cement.org.au
CMAA	The CMAA represents the concrete masonry and segmental paving manufacturers of Australia. CMAA's aim is to inspire contemporary masonry architecture and building design in all areas of the built environment: commercial, residential and landscape.	www.cmaa.com.au
CIA	The CIA is an independent, not for profit organisation made up of many members who share a common interest in staying at the forefront of concrete technology, design and construction in Australia	https://www.concreteinstitute.com.au/Home
National Precast Concrete Association Australia (NPCAA)	Since 1990, the NPCAA has grown to become the peak body for the Australian precast concrete industry; membership comprises precast manufacturers of all capabilities, across all states, as well as product and service suppliers, industry professionals, tertiary institutions and allied organisation.	www.nationalprecast.com.au
Concrete Pumping Association of Australia Inc (CPAA)	The CPAA is the national body representing the interests of the concrete pumping industry within Australia; the Association provides a strong, unified and respected voice for the concrete pumping industry across Australia while working to improve the professionalism, safety, standards and performance of the industry it represents.	http://www.cpassoc.com.au/

7.12 Recommendations

- Recognise that recycled aggregate, when produced to conform to the standard specification criteria, is a technically viable alternative that can be utilised in non-structural and structural concrete elements.
- Conduct a life cycle analysis to quantify potential saving from increase durability on RCA.

- Introduce RCA through pre-cast panels as a quality that can be closely monitored.
- Change the construction industry attitudes towards sustainability-conscious material choices, as inertia towards traditional practices in construction, is prevalent.
- Improve separation on-site to sort concrete waste material from other C&D waste.
- Utilise advanced density separation techniques to grade crushed concrete fines to increase homogeneity and reduce the presence of foreign inclusions.
- Incentivise end-markets for RCA such as minimum recycled content specifications in projects, additional green-star / ISCA rating points.
- Standardise the technical specification of applications across Australian jurisdictions so that one State does not have higher standards than another State.
- Direct some landfill levy revenue to industry R&D activities to test RCA products into practice (link manufacturers with engineers and procurement).

8. Steel- Resource Circular Economy: Opportunities to Reduce Waste Across the Supply Chain

8.1 Introduction

Steel is has been one of the morest common materials used in construction for several centuries. Early processes of steel making were made during the classical era in Ancient Iran, Ancient China, India, and Rome. Praised for its versatility, extremely high tensile strength and value, it is widely used in everything from residential construction to buildings and skyscrapers. There are is a number of different kinds of steel used for construction. Indeed, construction is one of the most important steel-using industries, accounting for more than 50% per cent of world steel demand. Steel is an alloy of iron and carbon, and sometimes other elements. Table 67 shows the main properties of steel and explains its wide application in the construction industry.

Table 67. Main properties of steel in the construction industry

Property	Description
Strength, beauty, design freedom	Steel offers architects more design freedom in colour, texture and shape. Its combination of strength, durability, beauty, precision and malleability gives architects broader parameters to explore ideas and develop fresh solutions. Steel's long-spanning ability gives rise to large open spaces, free of intermediate columns or load-bearing walls. Its capacity to bend to a certain radius, creating segmented curves or freeform combinations for façades, arches or domes sets it apart. Factory-finished to the most exacting specifications under highly controlled conditions, steel's final outcome is more predictable and repeatable, eliminating the risk of onsite variability.
Fast, efficient, resourceful	Steel can be assembled quickly and efficiently in all seasons. Components are pre-manufactured offsite with minimal onsite labour. A whole frame can be erected in a matter of days rather than weeks, with a corresponding 20% to 40% reduction in construction time relative to onsite construction, depending on a project's scale. For single dwellings, on more challenging sites, steel often allows fewer points of contact with the earth, reducing the amount of excavation required. Structural steel's lighter weight relative to other framing materials such as concrete enables a smaller, simpler foundation. These efficiencies in execution translate to considerable resource efficiencies and economic benefits including accelerated project schedules, reduced site management costs and an earlier return on investment.
Adaptable and accessible	These days, a building's function can change dramatically and rapidly. A tenant may want to make changes that increase floor loads significantly. Walls may need to be repositioned to create new interior layouts based on different needs and space usage. Steel-built structures can cater for such changes. Non-composite steel beams can be made composite with the existing floor slab, cover plates added to the beams for increased strength, beams and girders easily reinforced and supplemented with additional framing or even relocated to support changed loads. Steel framing and floor systems also allow easy access and alterations to existing electrical wiring, computer networking cables and communication systems.
Fewer columns, more open space	Steel sections provide an elegant, cost-effective method of spanning long distances. Extended steel spans can create large open-plan, column-free internal spaces, with many clients now demanding column grid spacing over 15 m. In single-storey buildings, rolled beams provide clear spans of more than 50 m. Trussed or lattice construction can extend this to 150 m. Minimising the number of columns makes it easier to subdivide and customise spaces. Steel-built buildings are often more adaptable, with greater potential for alterations to be made over time, extending the lifetime of the structure.
Endlessly recyclable	When a steel-framed building is demolished, its components can be re-used or circulated into the steel industry's closed-loop recycling system for melt-down and repurposing. Steel can be recycled endlessly without loss of properties. Nothing is wasted. Steel saves on the use of natural raw resources, since around 30% of today's new steel is already being made from recycled steel.
Added fire resistance	Extensive testing of structural steelwork and complete steel structures has provided the industry with a thorough understanding of how steel buildings respond to fire. Advanced design and analysis techniques allow precise specification of fire protection requirements of steel-framed buildings, often resulting in significant reductions in the amount of fire protection required.
Earthquake resistant	Earthquakes are unpredictable in terms of magnitude, frequency, duration and location. Steel is the material of choice for design because it is inherently ductile and flexible. It flexes under extreme loads rather than crushing or crumbling. Many of the beam-to-column connections

	in a steel building are designed principally to support gravity loads. Yet they also have a considerable capacity to resist lateral loads caused by wind and earthquakes.
Aesthetics, meet function	Steel's slender framing creates buildings with a sense of openness. Its flexibility and malleability inspire architects to pursue and achieve their aims in terms of exploring distinctive shapes and textures. These aesthetic qualities are complemented by steel's functional characteristics which include its exceptional spanning ability, dimensional stability over time, its acoustic noise dampening abilities, endless recyclability and the speed and precision with which it is manufactured and assembled onsite with minimal onsite labour.
More usable space, less material	Steel's ability to maximise space and internal width with the thinnest shell possible means thinner, smaller structural elements are achievable. Steel beam depths are around half that of timber beams, offering greater usable space, fewer materials and lower costs compared with other materials. Wall thicknesses can be thinner because steel's strength and excellent spanning capacity means there's no need to build solid, space-consuming brick walls. This can be particularly relevant for heavily constrained sites, where steel's space-saving properties can be the key to overcoming spatial challenges.
Lighter and less impact on the environment	Steel structures can be significantly lighter than concrete equivalents and require less extensive foundations, reducing the environmental impact of the build. Less and lighter materials means they are easier to move around, reducing transportation and fuel use. Steel pile foundations, if required, can be extracted and recycled or re-used at the end of a building's life, leaving no waste material onsite. Steel is also energy efficient, as heat radiates quickly from steel roofing, creating a cooler home environment in hot climate areas. In cold climates, double steel panel walls can be well insulated to better contain the heat.

8.2 Various types of steel in the construction industry

There are various products made from steel that are used in the construction industry. Each has their own unique properties and therefore specific uses in building and other construction projects. The main types include: structural, rebar, alloy, mild, stainless, tool and light gauge. Following is a description for each of these seven steel types used in construction activities which has been extracted from Tork Media LLC[355].

Structural steel is durable and strong. It can be transformed into any shape including but not limited to I Beam, L shape, T shape and Z shape. This type of steel can be constructed in no time on the construction site. High-rise buildings and skyscrapers are constructed using structural steel, but it is also used for garages and large agricultural buildings.

Rebar steel is also known as reinforcing steel. Rebar is made from different alloys and grades of steel. Stainless steel rebar is rust-resistant and used in poured concrete driveways and the construction of buildings. It is commonly used as a tension device for reinforced concrete structures. Rebar steel is made from carbon steel. It is also used as a tensioning device to reinforce other masonry structures. This type of steel is durable, resistant and stiff. Rebar is very useful because of its recyclable tendencies.

Alloy steel has had small amounts of one or more alloying elements such as manganese, silicon, nickel, copper, chromium, titanium and aluminium added to it. This mix gives out properties that aren't found in regular carbon steel. Alloy steel is usually more responsive to heat and mechanical treatments than carbon steel. Alloy steel is pretty popular because of its ease of processing, good mechanical properties and availability. Alloy steels are broken down into low alloy steels and high alloy steels.

Mild steel is also known as plain carbon steel. It is steel with carbon content up to 2.1 per cent by weight. Mild steel is also used in steel building constructions. It is durable and strong and makes for a sturdy establishment. Mild steel is also very flexible, which does not allow it to crack when bent. Due

[355] Tork Media LLC. 2019. Hard as Steel! The 7 Types of Steel to Use in Construction. https://bit.ly/3dxlxgl

to its strength, it is more suitable for buildings. This type of steel can withstand earthquakes, making it very popular in earthquake-prone areas.

Stainless steel is a steel alloy but with increased corrosion resistance compared to alloy steel. Common ingredients mixed with stainless steel include chromium, nickel or molybdenum. Stainless steel contains chromium at 10 per cent or more by weight. This extra chromium gives steel its unique corrosion-resisting properties. The chromium content allows the formation of a rough corrosion-resisting chromium oxide film on the surface. If the film is damaged mechanically or chemically, it is self-healing as long as oxygen is present. Many kitchen appliances are made from stainless steel. Food and handling processing, medical instruments, and hardware are also made from stainless steel. There are more than 60 grades of stainless steel.

Tool steel is extremely hard and usually used to form other metal products. Different tool applications include cutting applications, mould-making applications, impact applications (like hammers) and knives. Tool steel comes in various shapes including square bar, round bar and flat bar, just to name a few. Six groups of tool steel include water-hardening, shock-resistant, hot-work, special purpose, cold-work and high-speed.

Light gauge steel is known to offer a range of benefits due to its unique lightweight characteristic. Benefits include: fast construction, safe to work with, cost-efficiency, ease of handling during fabrication, highly sustainable method of construction, and energy-efficient production. Light gauge steel is used in modular construction, storage, light steel-framed buildings, and loads from walls above and resisting lateral wind loads.

8.3 Steel industry overview

The structural steel fabricating industry has derived solid demand from the key building markets over the past five years, although declining demand from the non-building and mining infrastructure markets has negatively affected the industry's performance. The constant threat of competition from low-priced imports has also limited industry revenue growth over the period. Industry revenue is expected to decline at an annualised 1.5 per cent over the five years through 2019-20 to total $6.1 billion. This performance mainly reflects the deterioration in domestic demand for structural steel products over the same period. Domestic demand has fallen faster than industry revenue, as imports have declined rapidly since 2014-15. Falling demand for structural steel components for large-scale resource developments, such as LNG processing plants in northern Australia, has driven this decline in imports.

Reduced investment in large-scale apartment developments and declines in several key infrastructure markets are expected to cause industry revenue to contract by 4.3 per cent in 2019-20. Declining demand for steel products from multi-storey office, hotel and retail store construction projects is constraining the industry's performance. However, major road construction projects, such as WestConnex in Sydney and the West Gate Tunnel project in Melbourne, continue to be a stable source of demand for fabricated structural steel products.

The industry's performance is forecast to strengthen over the next five years as an investment in residential building construction and several key infrastructure markets recovers. However, a further decline in demand from the residential building market over the short term is expected to limit demand for structural steel. Domestic demand is forecast to grow at an annualised 0.8 per cent over the next five years, to total $7.9 billion, although the industry is projected to gradually lose market share to low-cost imports. Industry revenue is anticipated to rise at an annualised 0.5 per cent over the five years through 2024-25, to total $6.3 billion. Figure 49 shows the steel industry products and services segmentation.

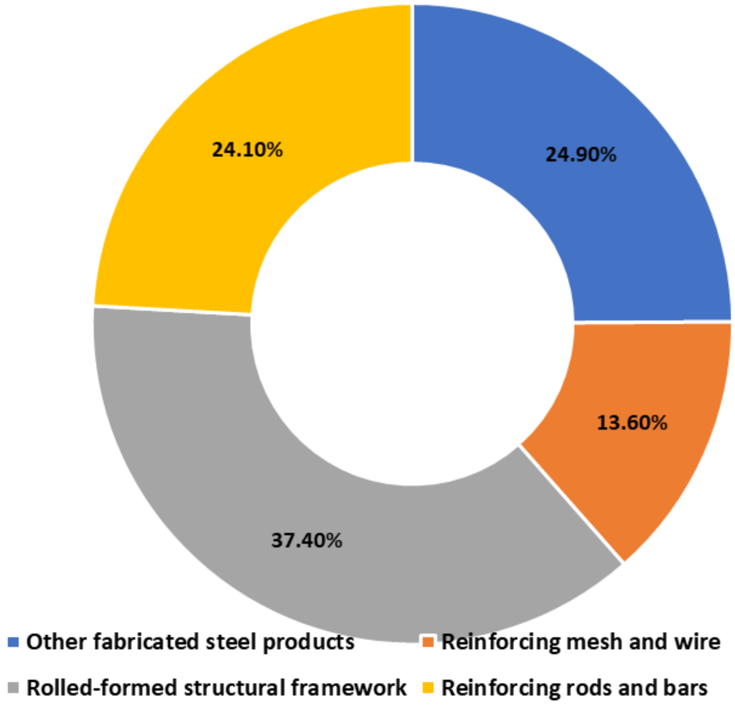

Figure 49. Steel industry products and services segmentation
Source: Kelly (2019)[356]

The key economic drivers for the steel industry are directly related to the demand from (residential and commercial) construction activities and beverage manufacturing (Table 68). Similarly, the main demand industries include those related to construction activities.

Table 68. Key drivers and the major industries in steel wholesaling (demand & supply).

Key Economic Drivers	Demand Industries	Supply industries
Demand from residential building construction	House construction in australia	Iron smelting and steel manufacturing in australia
Demand from commercial building construction	Multi-unit apartment and townhouse construction in australia	
Demand from road and bridge construction	Road and bridge construction in australia	
Domestic price of iron and steel	Heavy industry and other non-building construction in australia	
Trade-weighted index	Structural steel erection services in australia	
Demand from heavy industry and other non-building construction	Commercial and industrial building construction in australia	

Source: IBISWorld 2019[356]

8.3.1 Major producers in Australia

Industry firms manufacture structural steel components that are used in buildings and other structures. The geographic spread of the industry is marginally skewed towards Queensland and Western Australia. These states have a high concentration of infrastructure construction activity, which is a key market for fabricated steel inputs. Employment data for 2019 showed that 18,641 was working in this industry. In Australia, the major players of the steel fabrication market (2015-2020) produce 45 per cent of annual steel product[356]. The steel market is dominated by two manufacturers namely ‘ BlueScope Steel Limited (23.9 per cent)’, and ‘ Infrabuild Trading Pty Ltd (21.1 per cent)’.

[356] Kelly, A. 2019. Structural Steel Fabricating in Australia. Australia Industry (ANZSIC) Report C2221.

The reminder of the market is supplied by small to medium-sized firms which hold a small share of the market. These steel fabrication firms supply a range of products. Most firms operate in narrow state-based markets, although several medium- to large-scale businesses have operations spanning several jurisdictions and a range of products.

Table 69. The financial profile of the major steel producers in Australia.

Company name	Scope	No. of employees	Market cap
BlueScope Steel Limited	An Australian-owned public company that derives its revenue from the manufacture and distribution of steel building products.	6, 234	AUD $6.22 bn
Infrabuild Trading Pty Ltd	A foreign-owned private company, deriving revenue from the manufacturing and distribution of structural steel and related steel products	1, 156	n/a

Source: IBISWorld 2019

8.3.2 Demand determinants

The key demand determinants in this industry include demand from residential, non-residential building, heavy industry and other non-building and road and bridge construction. Followng is a description for each determinant.

Demand from residential building construction:

Investment in residential building construction, including single-unit housing, multi-unit apartments and renovations and repairs, drives sales of structural steel products. High-rise apartment developments represent a particularly important market for industry products such as reinforcing steel, girders, plates, rods, joists and scaffolding. Demand from residential building construction is expected to decline in 2019-20 due mainly to the sharp reduction in apartment construction as a result of the recent completion of major high-rise developments and oversupply conditions in some urban markets. This trend is anticipated to limit sales of structural steel building products in 2019-20.

Demand from commercial building construction:

Constructing commercial buildings, such as multi-storey office developments, large industrial buildings and shopping centres, requires high volumes of structural steel products. Increased investment in C&I building developments has directly boosted industry sales over the past five years. Demand from commercial building construction is expected to decrease during 2019-20, reflecting the winding back of investment on some major commercial building projects. However, despite the scaling back of activity in this market, continued work on major office and hotel projects is expected to support growth for some suppliers.

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Demand from heavy industry and other non-building construction:

Heavy industry and other non-building infrastructure projects require large volumes of structural steel products. Robust investment in mining infrastructure and other infrastructure developments increased demand from this market to a record peak in 2013-14, but it has sharply contracted over the past five years. Firms are continuing to wind back investment in major developments such as the LNG processing plants in northern Australia. Demand from heavy industry and other non-building construction is expected to decline further during 2019-20, which poses a significant threat to the industry's short-term performance.

Demand from road and bridge construction:
Construction firms use large quantities of steel components to construct bridges, tunnels and road pavements. Public and private investment, particularly in large-scale toll road and tunnel developments, influences demand from this construction market. Demand from road and bridge construction is expected to maintain strong growth during 2019-20, lifting activity to historically high levels with work on major road projects. This trend provides an opportunity for the supply of structural steel products, such as reinforcing mesh of welded steel and reinforcing rods.

Domestic price of iron and steel:
Steel is the industry's primary material input and therefore increases in the price of steel raise production costs. Industry operators tend to pass these increases on to consumers through higher prices, which increases industry revenue. However, rising steel input prices can erode profit margins for structural steel producers if price rises cannot be passed on in full. The domestic price of iron and steel is expected to decrease during 2019-20 due to a sharp fall in the world price of iron ore.

Trade-weighted index:
The industry is exposed to substantial import competition. Competitive pressures typically increase when the Australian dollar appreciates against its major trading partners. Industry sales tend to deteriorate as the Australian dollar appreciates, as local companies become less competitive against imports. The Australian dollar has depreciated over the past five years, providing some relief for local manufacturers. The continued decline in the trade-weighted index during 2019-20 may improve the industry's cost competitiveness in international markets.

8.3.3 Raw materials

The steel industry is dependent on a sufficient, dependable and reasonably priced supply of raw materials. Two t of raw materials are required to produce one tonne of steel. Essential raw materials needed in steelmaking include iron ore, coal, limestone and recycled steel. Following are the description of these materials that are extracted from WorldSteel Association (2019)[357]:

Iron ore: Steel is an alloy consisting mostly of iron and less than two per cent carbon. Iron ore is, therefore, essential for the production of steel, which in turn is essential in maintaining a strong industrial base. Ninety-eight per cent of mined iron ore is used to make steel. Iron is one of the most abundant metallic elements. Its oxides, or ores, make up about five per cent of the Earth's crust. The average iron content for high-grade ores is 60 per cent to 65 per cent, after taking into account other naturally occurring impurities.

The majority of iron ore is mined in Brazil, Australia, China, India, the US and Russia. Australia and Brazil together dominate the world's iron ore exports, each having about one-third of total exports. Worldwide iron ore resources are estimated to exceed 800 billion t of crude ore, containing more than 230 billion t of iron. Australia consolidated its position as the main supplier of steelmaking materials with iron ore exports growing from about 150 Mt to 800 Mt

Coal and coke: Coking coal is a key raw material in steel production. As iron occurs only as iron oxides in the Earth's crust, the ores must be converted, or 'reduced', using carbon. The primary source of this carbon is coking coal. Coke, made by carburising coking coal (that is, heating in the absence of oxygen at high temperatures) is the primary reducing agent of iron ore. Coke reduces iron ore to molten iron saturated with carbon, and is called hot metal. Around one billion tonnes of

[357] WorldSteel Association. 2019. Fact sheet: steel and raw materials. https://bit.ly/3v7P86m

metallurgical coal are used in global steel production, which accounts for around 15 per cent of total coal consumption worldwide.

Coal reserves are available in almost every country worldwide, with recoverable reserves in around 80 countries. Although the biggest reserves are in the US, China, Russia, Australia and India, coal is actively mined in more than 70 countries. About 30 per cent of coal can be saved by injecting fine coal particles into the blast furnace, a technology called pulverised coal injection (PCI). One tonne of PCI coal used for steel production displaces about 1.4 t of coking coal.

Limestone: Limestone is the most used flux. It is a sedimentary rock, usually white, and varies from hard and compact to soft and friable.

Recycled steel: Steel products naturally contribute to resource conservation through their lightweight potential, durability and recyclability. At the end of a product's life, steel's 100 per cent recyclability ensures that the resources invested in its production are not lost and can be infinitely re-used. Due to its magnetic properties, steel is easy to separate from waste streams, enabling high recovery rates and avoiding landfills. Some steel products contain up to 100 per cent recycled content. Recycled steel is a key input needed for all steelmaking process routes. Electric arc furnaces (EAFs) can be charged with up to 100 per cent of recycled steel and basic oxygen furnaces with approximately 30 per cent.

8.4 Products overview

Figure 50 displays various applications of steel in the construction industry. In this report, in total, 40 different steel products are identified.

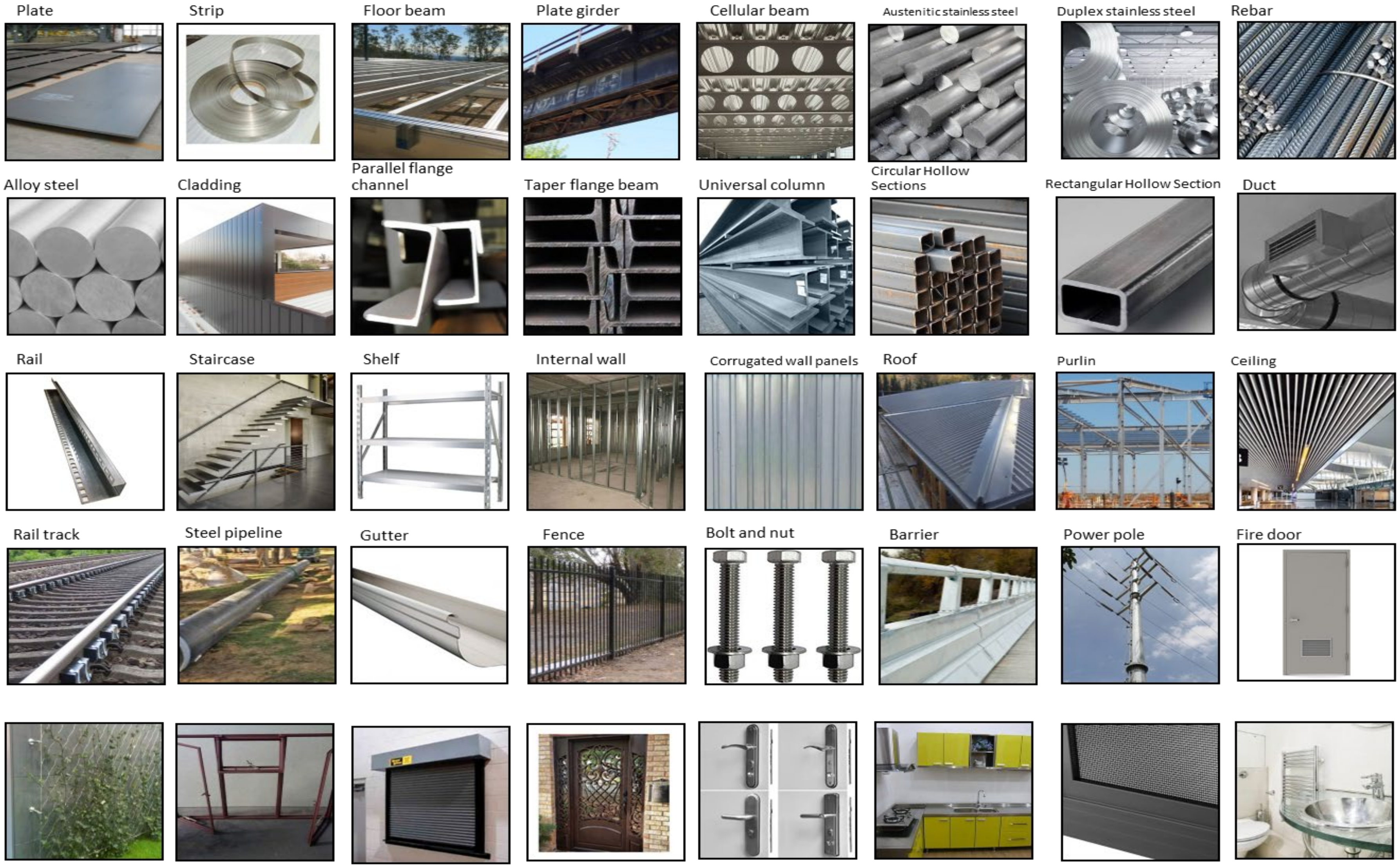

Figure 50. Various applications of Steel products in the construction industry

8.4.1 Manufacturing process

Steel is an alloy produced via two main methods: basic oxygen furance (primary) and EAF (secondary). Following is a description for each of these two common methods.[358]

Basic oxygen furnace (BOF): The most commonly applied process for steelmaking is the integrated steelmaking process via the blast furnace. In the BOF, the iron is combined with varying amounts of steel scrap (less than 30 per cent) and small amounts of flux (Figure 50). A lance is introduced in the vessel and blows 99 per cent pure oxygen, causing a temperature rise to 1,700 °C. The scrap melts, impurities are oxidised and the carbon content is reduced by 90 per cent, resulting in liquid steel.

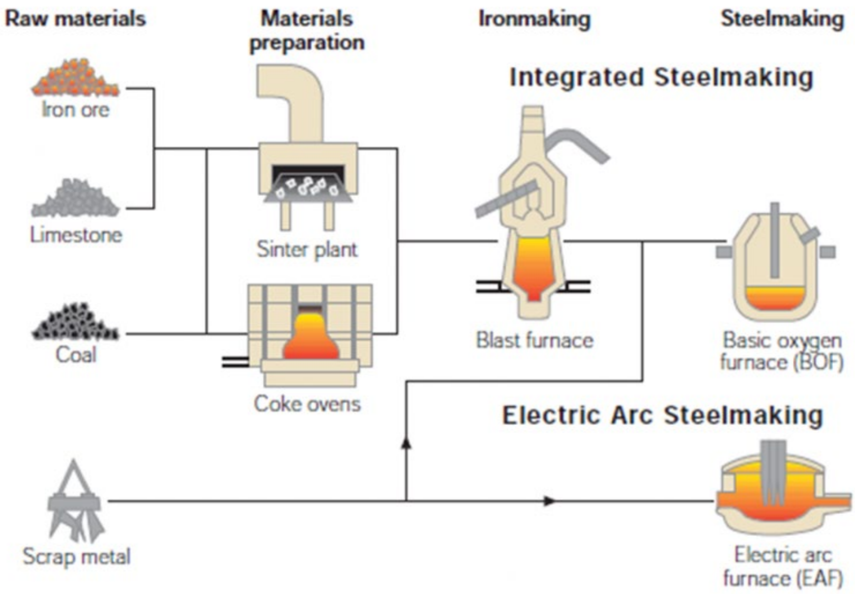

Figure 51. Typical steelmaking processes
Source: steel Construction Encyclopedia (2019)[359]

Other processes can follow – secondary steelmaking processes – where the properties of steel are determined by the addition of other elements such as boron, chromium and molybdenum, among others, ensuring the exact specification can be met. Optimal operation of the blast furnace demands the highest quality of raw materials – the carbon content of coke therefore plays a crucial role in terms of its effect in the furnace and on the hot metal quality. A blast furnace fed with high quality coke requires less coke input, results in higher quality hot metal and better productivity. Around 0.6 t (600 kg) of coke produces 1 t (1,000 kg) of steel, which means that around 770 kg of coal are used to produce 1 t of steel through this production route. BOFs currently produce about 74 per cent of the world's steel.

EAF: The EAF process, or mini-mill, does not involve ironmaking. It re-uses existing steel, avoiding the need for raw materials and their processing. The furnace is charged with steel scrap; it can also include some direct reduced iron or pig iron for chemical balance. The EAF operates on the basis of an electrical charge between two electrodes providing the heat for the process. The power is supplied through the electrodes placed in the furnace, which produce an arc of electricity through the scrap steel (around 35 million watts) and raise the temperature to 1,600 ˚C, melting the scrap. Any impurities may be removed through the use of fluxes and draining off slag through the taphole.

[358] World Coal Association. 2019. How is steel produced. https://bit.ly/3tFYLZG
[359] Steel Construction Encyclopedia.2019. Recycling and reuse. https://bit.ly/3emj9IR

EAFs do not use coal as a raw material, but many are reliant on the electricity generated by coal-fired power plants elsewhere in the grid. Around 150 kg of coal are used to produce 1 t of steel in EAFs.

8.5 Regulations, policies, and guidelines

Legislation of steel waste management occurs at the jurisdictional level. As a result, there are various policies and requirements for steel waste in Australia. However, the inconsistencies in these jurisdictions are regarded as a challenge for successful management of steel waste. Steel scrap compared to other waste materials has better conditions as the most part of it is sent to steel manufacturing for making new steel products. In order to increase the use of recycled steel, the regulatory frameworks of Australian jurisdictions should allow for market development. The Australian Steel Stewardship Forum (ASSF) has developed a sustainability certification scheme for Australian 'ResponsibleSteel' (*http://www. responsiblesteel.org/*). In 2019, ASSF published the first version of ResponsbileSteel[360], in which 12 principles for steel production in a responsible manner are outlined. Principle 9 states that this scheme certifies sites that prevent and reduce emissions and effluents that have adverse effects on communities or the environment, manage waste according to the waste management hierarchy and take account of the full life cycle impacts of waste management options. The objective of this principle is to find the most appropriate waste management option, making sure that waste is avoided or recovered where reasonably possible, and disposed of in a responsible manner.

8.6 Steel waste generation

8.6.1 Steel waste quantity

The latest steel waste data is for period 2016-17361 and presented in Table 70. The available waste data for steel is incomplete and does not represent the entire steel waste management across Australia. According to the available data in the study period, 3,822,990 t of steel waste was generated in Australia. Among the jurisdictions, the largest volume was generated in NSW (1,345,349), Vic (925,563) and Qld (703,502). Except for SA, with 3,155 t of landfilled steel waste, other jurisdictions did not report their disposal rate. From data reported in Table 70 it is not possible to determine the volume of steel waste generated in the C&D waste stream.

Table 70. Steel waste generation and fates in Australia (2016-17)

	Waste generation		Waste landfill		Waste recycling	
State	**C&D**	**Total**	**C&D**	**Total**	**C&D**	**Total**
ACT	n/a	20,308	n/a	n/a	n/a	20,308
NSW	n/a	1,345,349	n/a	n/a	458,508	1,345,349
NT	n/a	58	n/a	n/a	0	58
Qld	n/a	703,502	n/a	n/a	0	703,502
SA	2,328	275,405	2,328	3,155	27,500	272,250
Tas	n/a	39,753	n/a	n/a	0	39,753
Vic	n/a	925,563	n/a	n/a	116,920	925,563
WA	n/a	513,052	n/a	n/a	109,248	513,052
Total	2,328	3,822,990	2,328	3,155	712,176	3,819,835

Source: DEE, 2016-17 [361]
Note: The values for waste generation are the result of summing waste landfilling and recycling values.

[360] The Australian Steel Stewardship Forum.2019. ResponsbileSteel Standard Version no. 1. https://bit.ly/3aorn1V
[361] Department of Environment and Energy. 2019. National Waste Report Data. https://bit.ly/3tB8kJ1

8.7 Steel waste management

The aim of this section is to provide an insight into the sustainable management of steel waste through various opportunities that emerge throughout the steel life cycle. The section also discusses the various waste management methods that are supplemented by case studies that showcase success stories in sustainable steel waste management. Steel construction products are inherently low-waste products through all phases of the design, production, construction and deconstruction process. Designers and specifiers can be confident that, by choosing steel construction products and systems, material resources are optimised, waste is minimised and recycling is maximised[363].

8.7.1 Waste during manufacturing

Automation and technology both contribute to minimising waste during the fabrication process – and hence manufacturers should continue to invest in manufacturing processes and equipment to ensure their ongoing competitiveness. For example, a fabricator using sophisticated CNC equipment or laser cutters can maximise the number of items or forms made from a single metal sheet due to the precision accuracy of the equipment – and are therefore able to minimise the amount of waste material[362]. Advanced software can also help to maximise the usage of materials. As far as possible, leftover remnants should be retained and used wherever possible

By-products from iron and steel making, including sludges, slags and dust, are beneficially used by the construction industry in a range of products including roadstone, lightweight aggregate and as a substitute for Portland cement. During component manufacture, computer controlled, fully or semi-automated production lines ensure that wastage of steel is minimised. The typical wastage rate for fabricating structural steel products is just 4 per cent and any off-cuts, trimmings, swarfe, etc. from the production process are 100 per cent recycled into new steel (Table 70)[363].

8.7.2 Waste reduction opportunities during design, planning, and contract

To date, the focus of C&D waste reduction has been mainly on-site waste management practice. However, the best opportunities for improving materials resource efficiency in construction projects occur during the design stage[364]. Implementing these opportunities can provide significant reductions in cost, waste and carbon. There are five key principles that design teams can use during the design process to reduce waste. These principles are based on extensive consultation, research and work carried out by by UK charity Waste and Resources Action Programme (WRAP) directly with design teams[364]. They principle summarised in Table 71 together with questions the design team should address to design out waste.

Table 71. Design opportunities to reduce steel waste.

Opportunity	Description	Questions
Design for reuse and recovery	Design for reuse of material components and/or entire buildings has considerable potential to reduce the environmental burdens from construction; much of this is common sense as, with reuse, the effective life of the materials is extended and thus annualised burdens are spread over a greater number of years.	▪ On previously developed sites, can materials from the demolition of the building be re-used in the design? ▪ Can reclaimed products or components be re-used? ▪ When materials are re-used, can they be re-used at their highest value? ▪ Can any excavation materials be re-used? ▪ Can cut and fill balance be achieved? How can it be optimised to avoid removal of spoil from site?

[362] West Australian Steel Sales. 2015. How to minimise waste in sheet metal fabrication. https://bit.ly/3ascprH
[363] Steel Construction Encyclopedia. 2019. Construction and demolition waste. https://bit.ly/2QCRsDd
[364] WRAP. 2010. Designing out Waste Tool for Buildings (DoWT-B). https://bit.ly/3tu7k9H

Design for off-site construction	Off-site construction is one of a group of approaches to more efficient construction sometimes called modern methods of construction which also include prefabrication and improved supply chain management. Experience shows that the choice of off-site construction can have a significant influence on initial design considerations and therefore should be considered during the early project stages.	▪ Can the design or any part of the design be manufactured offsite? ▪ Can site activities become a process of assembly rather than construction?
Design for materials optimisation	Good practice in this context means adopting a design approach that focuses on materials resource efficiency so that less material is used in the design, i.e. lean design, and/or less waste is produced in the construction process, without compromising the design concept. Three main areas offer significant potential for waste reduction ▪ minimisation of excavation ▪ simplification and standardisation of materials and component choices ▪ dimensional coordination.	▪ Can the design, form and layout be simplified without compromising the design concept? ▪ Can the design be coordinated to avoid/minimise excess cutting and joining of materials that generate waste? ▪ Is the building designed to standard material dimensions? ▪ Can the range of materials required be standardised to encourage re-use of offcuts? ▪ Is there repetition and coordination of the design, to reduce the number of variables and allow for operational refinement (e.g. re-using formwork)?
Design for waste efficient procurement	Designers have considerable influence on the construction process itself, both through specification as well as setting contractual targets, prior to the formal appointment of a contractor/constructor. Designers need to consider how work sequences affect the generation of construction waste and work with the contractor and other specialist subcontractors to understand and minimise these. Once work sequences that cause site waste are identified and understood, they can often be 'designed out	▪ Has research been carried out to identify where onsite waste arises? ▪ Can construction methods that reduce waste be devised through liaison with the contractor and specialist subcontractors? ▪ Have specialist contractors been consulted on how to reduce waste in the supply chain? ▪ Have the project specifications been reviewed to select elements/components/materials and construction processes that reduce waste?
Design for deconstruction and flexibility	Designers need to consider how materials can be recovered effectively during the life of the building when maintenance and refurbishment is undertaken or when the building comes to the end of its life. A range of alternative construction methods are likely to be suitable for design for deconstruction and flexibility. Generally, those methods that facilitate easy disassembly at the end of the design/service life to improve the potential for reuse and/ or recyclability should be selected in preference to the more contiguous structural systems	▪ Is the design adaptable for a variety of purposes during its life span? ▪ Can building elements and components be maintained, upgraded or replaced without creating waste? ▪ Does the design incorporate re-usable/recyclable components and materials? ▪ Are the building elements/components/materials easily disassembled? ▪ Can a BIM system or building handbook be used to record which and how elements/components/materials have been designed for disassembly?

Source: WRAP (2010)[364]

8.7.3 Reducing waste during the procurement

It seems the most practical way to reduce waste during procuremtn is to select steel with a high durability to diminsh the need for re-work. Application of technologies such as BIM during the procurement phase can significantly reduce steel waste. These technologies improve quantity take-off practices and procurement documentation leading to a precise estimation of steel required for a construction project. Procurement documentation should include a full analysis of quality, price, flexibility and other conditions (for example, location, service level, etc.)(Wang and Wang, 2010).

8.7.4 Reducing waste during transportation and delivery

Steel products are delivered to the construction site pre-engineered to the correct dimensions. Consequently, there is no waste during transportation[363].

8.7.5 Reducing waste during construction

Steel products are delivered to site with minimal packaging. Packaging comprises mainly timber pallets and bearers and plastic or metal strapping. Timber packaging is generally reused by the haulage company making site deliveries, and the strapping is either recycled or reused. Off-site construction can contribute to steel waste minimisation. Technologies used for offsite manufacture and prefabrication include light gauge steel framing systems and modular and volumetric forms of construction which offer great potential for improvements to the efficiency and effectiveness of construction[363]. Furthermore, practices such as using the trimmed sections to produce additional parts, batching parts together that have similar straight edges or radii[362].

8.7.6 Reducing waste during demolition and renovation

The majority (about 90 per cent) of metals recovered from the C&D sector comes from commercial demolition sites. Of this material, up to 95 per cent is steel, and the remaining materials (about 5 per cent) are non-ferrous metals. This non-ferrous component mostly includes aluminium (1 to 2 per cent), stainless steel and copper piping or wire[365]. Ferrous metals like steel can be easily recovered from the waste stream using relatively inexpensive magnets. Increase in the metal scrap collection is traditionally following demolition activities in the construction industry (Figure 52)[366].

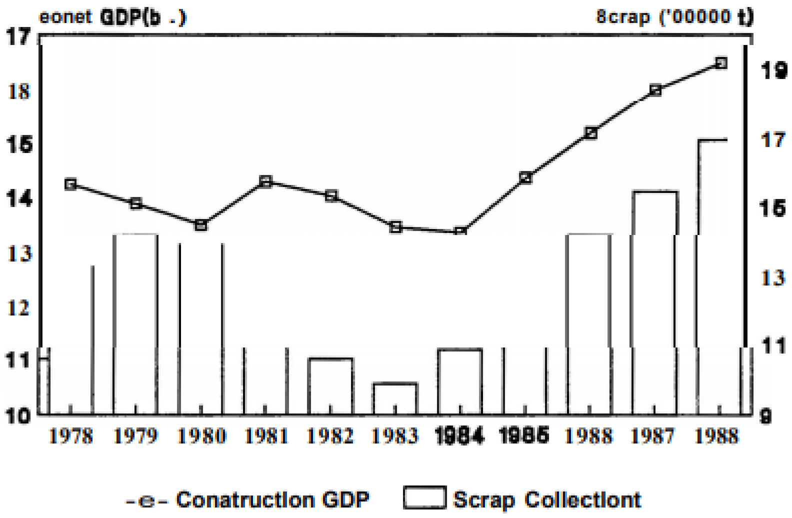

Figure 52. Construction activity level and scrap collection in Australia between 1978-98
Source: Industry Commission (1991)[366]

The simplicity of steel construction products recovery during deconstruction of a building, coupled with the economic value of scrap steel to reuse and recycle, has made steel waste an important resource in a circular economy. Furthermore, steel is one of the few magnetic metals[1] and is easy to separate from other waste mwaterials. Hyder Consulting Pty Ltd (2012)[34] reported that when demolition activities were high and prices for metals were strong, demolition companies would bring their materials for recycling to the key metal recyclers. However, when there was a downturn in both activity and metal prices, it was suggested that the demolition companies were more likely to stockpile the metals if they could and wait for improved commodity prices. The issue with demolition is that reinforced steel used in some structures is mixed with concrete. In the demolition phase, there can be a ratio of 80 per cent concrete to 20 per cent steel. Demolition companies recycle the

[365] Edge Environment Pty Ltd for the department.2012. Construction and Demolition Waste Guide - Recycling and Re-Use Across the Supply Chain. https://bit.ly/3xb6AZh
[366] Industry Commission. 1991. Working paper no. 1. An analysis of the factors affecting steel scrap collection.

concrete. But according to estimations generally, the recycled steel has about 10 per cent concrete (contamination) remaining with the steel[Error! Bookmark not defined.].

8.7.7 Reducing waste through reusing

At the end of a building's useful life, its steel frame can be easily dismantled and elements of it either re-used or recycled. The most common reuse of steel waste is steel portal frame. Steel re-use can take place in three ways: (a) In-situ re-use in which the structural frame is reused, with or without alterations, in situ, (b) Relocation reuse involves deconstruction of an existing steel frame, which is then transported and re-erected, generally in its original form, at a different location for the same or similar purpose and (c) Component reuse involves careful deconstruction of an existing structure where individual structural steel members are reclaimed and used to construct a new permanent structure[367].

Case study: Honda cental receiving building[368]: Originally erected on Honda's Swindon site in 2001, this 927m^2 steel-framed warehouse building was dismantled in 2004 and put into storage. In September 2005, the structure was re-erected, at a different location on the same Swindon site, as a new Central Receiving Area. All the main frame structural steelwork was reused including the column base plates, bracing and cold-rolled secondary steel. The dismantled steel structure was re-erected in just one week. The condition of the steelwork was assessed by the coating manufacturer Sherwin-Williams Protective & Marine Coatings, cleaned and then repainted to Honda's specification for the newly erected building.

Figure 53. Honda cental receiving building
Source: Caunton Engineering

8.7.8 Waste recovery (recycling and upcycling)

Steel is the most recycled material in the world, with about 670 Mt recycled in 2017, including pre- and post-consumer scrap. Steel is one of the few magnetic metals[357] and is easy to separate from waste streams. By sector, global steel recovery rates are estimated at least 85 per cent for construction[357]. Reusing reclaimed steel is not a new idea; in fact, the practice was more prevalent in the past but has declined over the last few decades. The main reasons being new development program constraints and tougher health and safety requirements in relation to demolition activities,

[367] Building.co.uk. 2017. CPD 6 2017: Sustainable steel buildings. https://bit.ly/3x7a27g
[368] SteelConstruction.info. 2014. Honda central receiving building. https://bit.ly/3gqCStA

in particular, working at height. Recycled steel (scrap) can be collected from excess material in steel facilities and foundries (home scrap) or downstream production processes (industrial scrap) and from discarded products (obsolete scrap). Recycling steel waste accounts for significant energy and raw material savings: more than 1,400 kg of iron ore, 740 kg of coal, and 120 kg of limestone are saved for every 1,000 kg of steel scrap made into new steel[357]. The availability of home and industrial scrap is closely related to current domestic steel production levels while the availability of obsolete scrap is closely related to levels of past steel production, average product lives and efficient recycling programs. In Australia, according to the latest data[361], which is not complete, the recycling rate of steel waste is almost 100 per cent (Table 73). In 2016-17 the amount of steel waste generated in all waste streams was 3,822,990 t. This volume for C&D waste stream was 712,176 t.

Table 72. Steel waste recycling data in Australia

Waste recycling		
State	**C&D recycling**	**Total**
ACT	n/a	20,308
NSW	458,508	1,345,349
NT	0	58
Qld	0	703,502
SA	27,500	275,405
Tas	0	39,753
Vic	116,920	925,563
WA	109,248	513,052
Total	712,176	3,822,990

While the price that recyclers pay for mixed steel scrap is highly variable, the current ballpark figure ranges between $70 (steel) and $1100 (stainless steel) per tonne. Coupled with the value of avoided landfill disposal costs, there is a strong economic incentive to recover this material stream.

8.8 Illegal dumping and stockpiling

Generally, due to the financial value of metal scrap, it is less likely that illegal dumping and stockpiling occurs in Australia. However, there are reports showing that illegal dumping activities take place due to mismanagement. Furthermore, prices of scrap metals are always very important to the scrap recycling industry. When scrap prices are in a downward trend for a long period, recycling rates decrease with the trend and scrap metal firms struggle to make a profit[369] leading to an increase in illegal dumping and stockpiling.

Case study- An abandoned warehouse in Thomaston, Melbourne[370]

A warehouse in Melbourne's outer north was supposed to be filled with scrap metal and broken glass, as overflow storage for a nearby recycling business (Figure 54). It was not until the company collapsed into insolvency six months later, that the warehouse doors were opened to reveal a potential health and environmental disaster on Melbourne's suburban fringe: pallets of steel drums and plastic tubs, stacked to the ceiling, filled with mercury, contaminated powders, leaking batteries and suspected X-ray machine parts – almost 800 containers of highly toxic material, abandoned by a company that no longer operated.

[369] Haque, T. 2019. Current scarp prices trends and analysis. The balance small businesses. https://bit.ly/3szQqVK

[370] Mannix, L., Vedelago, C. and C. Houston. 2017. The tipping point: Illegal dumping swamps the waste industry. The Age: https://bit.ly/32te37M

Figure 54. An abandoned warehouse in Thomaston (Melbourne) which was filled with t of waste including steel waste
Source: Mannix et al (2017)[370]

8.9 Waste disposal

While the disposal of stainless-steel waste to landfills is not harmful to the environment but is a waste of resources. In metropolitan markets, there is likely to be very little metal from the C&D waste stream that ends up in a landfill. Even in regional areas, where landfill fees are lower and there may be limited metal reprocessors, indications are that scrap metal is separated from other materials and put aside at local transfer stations, resource recovery facilities and landfills, ready for collection once there is a sufficient stockpile to warrant the recovery and transport costs**Error! Bookmark not defined.**.

8.10 Steel waste end-market

8.10.1 Existing and future markets for steel waste

Stainless steel has valuable metal content - chromium and nickel. Markets for recycled stainless steel are functioning without any stimulus, and the stainless-steel industry is utilising all feasibly available recycled stainless steel.

8.10.2 Integrated supply chain and steel lifecycle model

Two lifecycle models for steel waste are provided below. These include EPA Victoria's flow of steel and the steel LowMor model. EPA Victoria flow of steel model: The flow of steel in the Victorian economy is modelled in (Figure 55)[372]**.** that is based on the period 2004-05. In this period steel recycling represents 82 per cent of total metal stream recycled in Victoria. From what recycled between 70-90 per cent was used domestically and the reminder was exported[371]. The model shows how steel waste generated during C&D activities flows until it reaches landfill.

[371] EPA Victoria.2007. Impact of Landfill levy on the steel recycling sector in Victoria. 2007. https://bit.ly/32saJK7

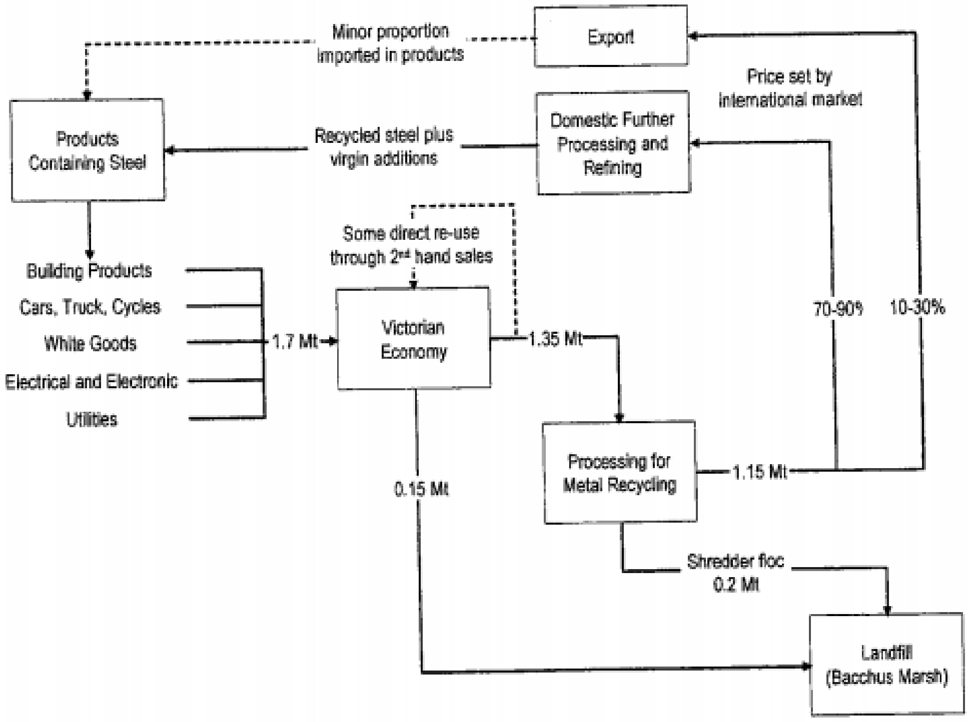

Figure 55. The flow of steel in the Victorian economy
Source: EPA Victoria (2007)[372]

Steel LoWMor model: In this model, there are 11 points wherein steel scrap can be efficiently managed. Figure 56 depicts these opportunities and the relationships between them. In Australia, the majority of steel waste is sent back to steel fabrication manufactures to be used to produce new steel products.

[372]EPA Victoria.2007. Impact of Landfill levy on the steel recycling sector in Victoria. 2007. https://bit.ly/3gtVNDB

Figure 56. The integrated supply chain lifecycle LoWMor model for steel waste

8.10.3 Bbarriers towards the establishment of a market for steel waste-based materials

There are several barriers identified that negatively impact the establishment of a market for steel waste-based materials. Table 73 summarises these barriers, extracted from various Australian reports and publications.

Table 73. The main barriers identified in the establishment of recycled steel in Australia

Source	Barrier	Explanation
EPA Victoria (2007)[373]	Landfill levy	Levy on the disposal of recycling residuals reduces the competitiveness of materials sold into the market; for every $15/t increase in the levy rate, an additional $738,000 per annum cost is incurred by the steel recycling industry in Vic
Senate Environment and Communications References Committee (2018)[49]	Market volatility	Steel recycling is largely affected by the price of virgin materials
Australian	Steel scrap	Some scrap will no longer be viable to recycle, even if it is available for free

[373] EPA Victoria.2007. Impact of Landfill levy on the steel recycling sector in Victoria. 2007. https://bit.ly/3gtVNDB

Council of Recycling (2015)[374]	is not viable	Remote/country (transport costs) • Low-grade or scrap, with high waste content (high waste disposal costs) • Complex (high processing costs) • Hazardous (processing and waste disposal costs) • Scrap at locations with high compliance costs or inefficient work practices

8.10.4 Strategies towards the establishment of a market for steel waste-based materials

Together with the responses to the barriers identified above, several strategies that can facilitate the establishment of a sustainable market for steel waste-based materials are presented in this section. The strategies are presented in Table 74.

Table 74. Strategies to remove barriers of recycled steel market development.

Barrier	Strategy
Landfill levy	Provision of a partial levy exemption for the steel recycling industry, better funding and grants to support the steel recycling industry, and the use of PS programs
Australian Council of Recycling (2015)[374]	▪ Formal support for use of recycled steel in projects across all tiers of government ▪ Offer freight subsidises to enable the delivery of recyclables to processing facilities ▪ Enforce anti-dumping regulations to protect the Australian steel industry from dumped Chinese steel ▪ Accelerate depreciation allowances for investment in recycling infrastructure and equipment

8.11 Economics of steel waste recovery in Australia

Generally, scrap metal is removed from a construction site free of charge. However, the price that recyclers pay for mixed steel scrap is highly variable[375]. In 2012, a ballpark figure of $250 per tonne was estimated for mixed steel scrap. Traditionally, steel waste recycling has not resulted from environmental or resource scarcity concerns, nor from government requirements. In fact, those large amounts have arisen mostly from the technical requirements of steel production and the commercial considerations of both steel producers and steel users[376].

Most scrap is consumed in EAFs which make billet and then roll it into products. EAFs are easy and cheap to start and stop. Cheap billet means unless scrap falls too, the best option is to turn off the EAFs and import billet instead of scrap. Scrap prices will almost certainly follow the billet price and unless the price of billet rises, the price of scrap cannot rise. It is unlikely the price of billet will increase in the foreseeable future, as iron ore prices will not rise because of new mines coming on line (rather, iron ore is forecast to become cheaper). Local Chinese steel demand has fallen; however, Chinese governments are likely to support local steel blast furnaces for both ego and political (employment) reasons – thus Chinese blast furnaces will continue to operate and flood the world with cheap billet. Table 75 shows the costs associated with C&D based steel waste management and recovery.

Table 75. Cost estimation of C&D-based steel waste management and recovery

Company	**Price**	**Pricing mechanism**
Bingo	Accepts steel waste at their recycling facility for free. If pick-up included, $350 for bin hire (12 t) in	Free, extra charge for pick-up for up to 7

[374] Australian Council of Recycling. 2015. Australian scrap market analysis https://bit.ly/3dwkdKU
[375] Hyder Consulting Pty Ltd. 2012. Construction and demolition waste status report. Management of construction and demolition waste in Australia.
[376] Industry Commission. 1991. Working paper no. 1. An analysis of the factors affecting steel scrap collection.

	NSW	days
Southern Cross Metal Recyclers	Steel waste is purchased at the range of $80 to $200/t in Vic Pressing steel $80/t (without ABN number) and $110/t (with ABN number) Heavy metal $110/t (without ABN number) and $170/t (with ABN number)	▪ The price includes drop-off only ▪ The rate variation exists based on the type of waste and having an ABN number

Source: the rates are obtained from an online quote

8.12 Relevant industry associations

In this section, the relevant industry associations that specifically work towards better management of Steel and the waste associated with steel waste are identified. These associations are to collaborate with the public sector towards recognising opportunities for further reducing, reusing and recycling steel waste in Australia. Table 76 summarises the main industry associations with a focus on steel in Australia.

Table 76. Industry associations relevant to the management of steel waste

Associations	Vision	Website
Australian Steel Association (ASA)	The ASA's primary objective is to ensure a competitive market environment in Australia for manufacturing users and converters of steel product.	https://www.steelaus.com.au/
Australian Steel Institute (ASI)	The ASI is the nation's peak body representing the entire steel supply chain from the manufacturing mills right through to end-users in building and construction, heavy engineering and manufacturing.	https://www.steel.org.au/
Australasian (iron & steel) Slag Association (ASA)	The underlying vision of the ASA is to serve as an authoritative and credible central reference point for its stakeholders on all matters relating to the iron and steel slag industry.	https://www.sa-inc.org.au
Australian Stainless Steel Development Association (ASSDA)	ASSDA is a non-profit industry group that aims to increase the consumption of stainless steel in Australia.	https://www.assda.asn.au/
The Australian Steel Manufacturing Research Hub	This ground-breaking initiative is testament to the critical importance of this industry in Australia and demonstrates the value that both industry and government place in collaborative, cross-disciplinary research.	https://scholars.uow.edu.au/display/grant113823
The Steel Reinforcement Institute of Australia (SRIA)	The SRIA is Australia's leading non-profit institute for reinforcing steel, providing the hub for knowledge, industry linkage and support.	https://www.sria.com.au/

8.13 Key stakeholders and their role in steel waste management

In this section, the role of key stakeholders in the effective market development for steel waste is provided (Table 77). The role of the stakeholders is reviewed in 11 stages with the view to reduce, recover, and divert waste from landfill.

Table 77. Role of various stakeholders in the reduction of steel waste

No.	Stage	Stakeholder(s)	Contributions
1	Design	Designers, construction firms, clients	• Design a new building to facilitate its re-use in the future • Consider building standardisation to improve buildability and reduce the number of offcuts
2	Manufacturer	Manufacturers, recyclers, suppliers	• Develop an agreement where a contractor 'sells back" the re-cycled waste from the original material supplier • Participate in the EPR and product PS
3	Procurement and contract	Construction firms, quantity surveyors, government	• Construction firms should order steel products more accurately using the best take-off practice.
4	Transportation and delivery	Construction firms, transporters, recycling companies	• Just-in-time delivery of materials to construction to avoid damage taking place due to insufficient space for proper storage and adverse weather conditions • Do due diligence and exercise standard work practices
5	Construction	Construction firms, sub-contractors, waste collectors, recyclers Universities and research centres	• Consider offsite construction
6	Demolition	Demolition contractors, waste collectors, recyclers	• Consider selective de-construction to maximise the reuse potential of its components.
7	Reuse	Construction firms, state and territory governments, EPAs and other equivalent organisations, waste collectors	• Facilitate market development • Adjust specifications in favour of greater usage of steel waste-based materials in new constructions project
8	Recycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations training courses provider	• Facilitate market development • Fund the development of waste recovery infrastructure • Adjust specifications in favour of more usage of recycled steel waste in new constructions project • The jurisdictional landfill levy regulations need to change in the favour of further steel recycling
9	Upcycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Facilitate market development • Adjust specifications in favour of more usage of steel waste-based materials in new construction projects • Fund the development of waste recovery infrastructure
10	Stopping illegal dumping and stockpiling	State and territory governments, EPAs and other equivalent organisations	• Reinforce activities that stop illegal dumping and stockpiling • Set stricter regulations with a higher rate of penalty fees to discourage illegal dumping and stockpiling • Strengthen controls over licensed landfill sites
11	Landfill	State and territory governments, EPAs and other equivalent organisations	• Design appropriate landfill levy schemes to discourage steel waste landfilling

8.14 Recommendations

Following are recommendations for maximising the opportunities to reduce steel waste in various stages of C&D activities.

1. Provide landfill levy exemptions for MRF's steel recycling.
2. Adjust specifications in favour of the greater use of steel waste-based materials in new construction projects.
3. Stabilise market volatility to ensure the sustainable use of steel waste in steel manufacturing.
4. Call on state governments to offer freight subsidises to enable the delivery of recyclables to processing facilities.

9. Glass- Resource Circular Economy: Opportunities to Reduce Waste Across the Supply Chain

9.1 Introduction

There is no exclusive definition of 'glass", a term describing a variety of inorganic materials with different mechanical and optical properties. What all glass materials have in common is a vitreous or amorphous state, originated by the relatively fast cooling and solidification of an initial molten state[377]. Glass is a hard substance that may be transparent or translucent and is brittle in nature. It is one of the oldest and most useful materials made by humans. The Phoenicians discovered it more than 5,000 years ago[378]. For 2,000 years, hand-blowing glass was the principal way of making glass bottles. In the last 100 years, mechanised glass-blowing techniques have revolutionised the production of glass containers and other glass products. Production of Clear glass, by the introduction of manganese dioxide, saw glass being used for architectural purposes. Cast glass windows began to appear in the most important buildings and villas in Rome and Pompeii. Glass is now widely used in for construction and architectural purposes in engineering. Figure 57 depicts the various applications of such purposes.

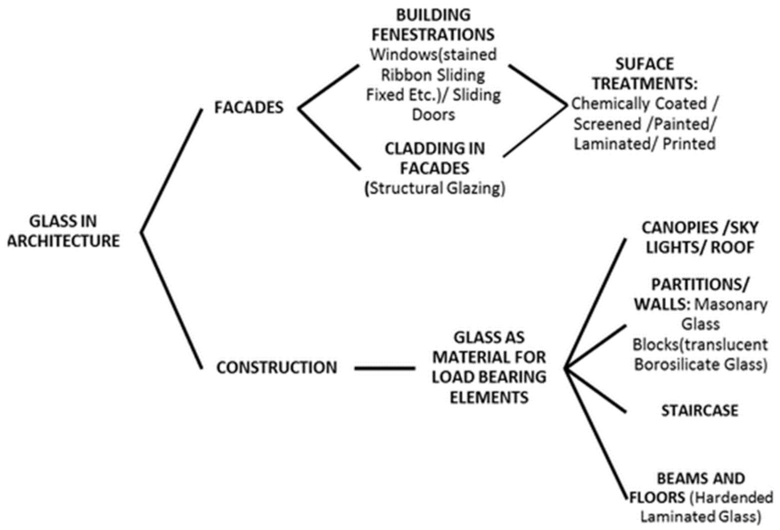

Figure 57. The application of glass in the construction and architectural sector
Source: Understand construction.com (2014)[379]

Safe, sustainable and green buildings have gained popularity worldwide in recent years. This has given a major boost to the market for construction glass. Technological advancements in the manufacturing process further bolster demand for construction glass. The main properties of glass which make it suitable in the construction industry include transparency, workability, U value, recyclability, transmittance and strength. A description of each property is provided in Table 78.

Table 78. Main properties of glass in the construction industry

Property	Description
Transparency	Transparency is the main property of glass, which allows vision of the outside world through it; the transparency of glass can be from both sides or from one side only; in one-sided transparency, glass behaves like a mirror from the other side
Workability	Glass can be moulded into any shape or it can be blown during melting, so the workability of glass is a superior property of glass
U value	U-value represents the amount of heat transferred through the glass; if a glass is said to be an insulated unit, then it will have a lower u-value

[377]Pharosproject: Background information on waste glass reclamation and recycling. https://bit.ly/3sFwJw4
[378]Waste Authority. 2015. Glass Fact Sheet. The Waste Wise School Program. https://bit.ly/2RQivvu
[379] Understand construction.2015. Glass. https://bit.ly/3dyvqKT

Recyclability	Any glass can be 100% recyclable; it can also be used as a raw material in the construction industry
Transmittance	The visible fraction of light that passes through the glass is the property of visible transmittance
Strength	Strength of glass depends on the modulus of rupture value of glass; in general, glass is a brittle material, but by adding admixtures and laminates, we can make it stronger; it is resistant to weather conditions and chemicals

9.2 Various types of glass in the construction industry

Table 79 shows the most common types of glass used in the construction industry.

Table 79. Various types of glass used in the construction industry

Glass	Description
Float glass	Float glass is made of sodium silicate and calcium silicate, so it is also called soda-lime glass. It is clear and flat, causing glare. These glasses are available from 2 mm to 20 mm thickness ranges. They have a weight range of 6 kg to 36 kg/m^2 and are used as shop fronts, in public places etc.
Shatterproof glass	Shatterproof glass is used for windows, skylights, floors etc. Some types of plastic polyvinyl butyral is added in its making process. Therefore, it does not form sharp-edged pieces when it breaks.
Laminated glass	Laminated glass is the combination of layers of normal glass, so it has more weight than normal glass. It has more thickness and is UV-proof and soundproof. These are used for aquariums, bridges etc.
Extra clean glass	Extra clean glass has two special properties: photocatalytic and hydrophilic. Because of these properties, it is stainproof and gives a beautiful appearance. Maintenance is also easy.
Chromatic glass	Chromatic glass is used in hospital intensive care units, meeting rooms etc. It can control the transparent efficiency of glass and protects the interior from daylight. Chromatic glass may be photochromic, which has light-sensitive lamination, thermos-chromatic, which has heat-sensitive lamination, or electrochromic, which has electric lamination over it.
Tinted glass	Tinted glass is nothing but coloured glass. Colour-producing ingredients are mixed into the normal glass mix to produce coloured glass, which does not affect other properties of glass.
Toughened glass	Toughened glass is strong glass that has low visibility. It is available in all thicknesses and, when it is broken, forms small granular chunks, which are dangerous. It is also called tempered glass. This type of glass is used for fire-resistant doors, mobile screen protectors etc.
Glass blocks	Glass block sor glass bricks are manufactured from two different halves and they are pressed and annealed together during the melting process of glass. They are used for architectural purposes in the construction of walls, skylights etc. They provide an aesthetic appearance when light is passed through it.
Glass wool	Glass wool is made of fibres of glass and acts as a good insulating filler. It is a fire-resistant glass.
Insulated glazed units	Insulated glazed units contain glass that is separated into two or three layers by air or vacuum. Heat is not allowed through it because of the air between the layers, meaning it acts as a good insulator. These are also called double-glazed units.

Source: The Constructor (2017)[380]

[380] The Constructor. Types of Glass and its Engineering Properties for Use in Construction. https://bit.ly/3v5UEGp

9.3 Glass industry overview

The Glass and Glass Product Manufacturing (GGPM) industry comprises firms that manufacture glass containers and flat glass products. Industry revenue is expected to increase at an annualised 2.0 per cent over the five years through 2019–2020, to reach $4.2 billion. Glass product imports are anticipated to increase at an annualised 2.8 per cent over the five years through 2019–2020, to capture 18.3 per cent of domestic demand in the current year. Exports account for an estimated 1.6 per cent of industry revenue in 2019–2020. Growth in the commercial building and apartment construction markets has underpinned demand for flat glass products over the past five years. The industry's performance has also benefited from stronger demand for glass bottles for packaging wine and spirits, along with premium non-alcoholic beverages.

In 2019–2020, weakening demand for glass products from downstream residential and commercial building markets is expected to erode domestic demand for flat glass products. Industry revenue is projected to contract by 2.8 per cent in 2019, contributing to declines in industry employment and enterprise numbers. Favourable trends in the local beer and wine production are expected to support demand for glass containers in 2019–2020.[381]

The industry's performance is forecast to continue to deteriorate over the short term. Demand for flat glass products from the apartment construction and commercial building markets will continue to contract over the two years through 2021-22, due to the completion of several large-scale office, hotel and casino projects. The industry is forecast to benefit from recovering demand from the residential building market from 2022-23 onwards, as demand rises for glass bottles used in the wine production and beer manufacturing markets. Industry revenue is forecast to increase at an annualised 0.4 per cent over the five years through 2024-25, to reach $4.3 billion.[381] This limited rise reflects subdued growth in domestic demand for glass products and industry firms continuing to lose market share to imports.

The primary activities of this industry381 include the manufacture of glass blocks, glass bottles and other glass containers, domestic glassware (kitchenware, ornamental and drinking glasses), flat glass – stained and laminated – laboratory and scientific glassware. Other manufacturing activities include mirrors, optical glass, safety glass and windscreens. The major products in this industry are glass (Figure 58).

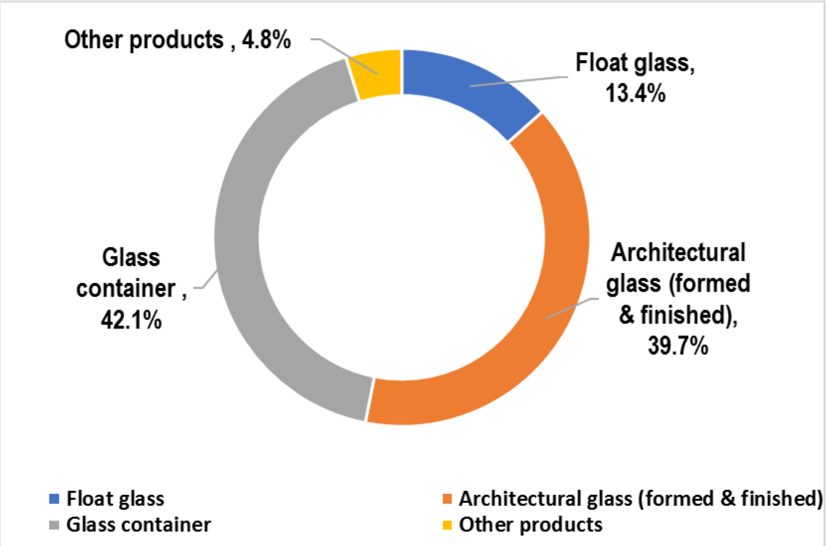

Figure 58. Major products of the GGPM industry
Source: Kelly (2019)[381]

[381] Kelly, A: IBISWorld. 2019. Glass and Glass Product Manufacturing in Australia.

The key economic drivers for the GGPM industry are directly related to the demand from (residential and commercial) construction activities and beverage manufacturing (Table 80). Similarly, the main demand industries include those related to construction, and food and beverage production and processing.

Table 80. Key drivers and the major industries that are dealing with glass wholesaling (demand and supply)

Key economic drivers	Demand industries	Supply industries
Demand from residential building construction	Fruit and vegetable processing	Corrugated paperboard Container manufacturing
Demand from non-residential building construction	Beer manufacturing	Mineral sand mining
Demand from beer manufacturing	Wine production	Printing
Demand from wine production	Aluminium door and window manufacturing	Rock, limestone and clay mining
Household consumption expenditure	Construction	
Per-capita alcohol consumption	Glazing services	

Source: IBISWorld 2019[381]

9.3.1 Major producers in Australia

In Australia, the major players of the glass production market produce 37.8 per cent of glass products annually[381]. The glass market is dominated by three companies which include Owens-Illinois Holding (Australia) Pty Ltd (22.5 per cent), Crescent Capital Partners Holdings Pty Ltd (8.6 per cent) and Orora Limited (6.7 per cent). The remainder of the market is supplied by small- to medium-sized companies that have a small percentage of the market (Figure 59).

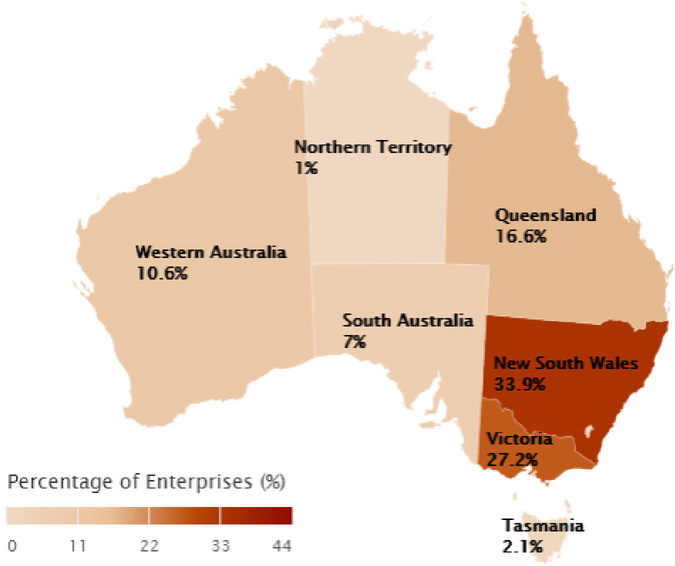

Figure 59. Bussiness concentration of glass manufacturing in Australia (2019)
Source: IBISWorld

Table 81 provides information on the financial performance of major glass producers in Australia.

Table 81. The financial profile of the major glass producers in Australia.

Company name	Scope	No. of employees	Market cap
Owens-Illinois Holding (Australia) Pty Ltd	O-I Australia is a Proprietary Company that is ranked number 517 out of the top 2000 companies in Australia. The company generates the majority of its income from the Glass and Glass Product Manufacturing in Australia industry	1,675	n/a
Crescent Capital Partners Holdings Pty Ltd	A Sydney-based private equity firm investing in middle market companies located in Australia and New Zealand	n/a	n/a
Orora Limited	Orora Limited is a locally owned publicly listed company, deriving revenue from the manufacture and supply of packaging products.	7,221	n/a

Source: IBISWorld 2019

9.3.2 Demand determinants

The dynamics of the impact of the key economic factors which are tabulated in Table 80[381] are described below:

1. **Demand from non-residential building construction**
   Increased investment in non-residential building construction has driven demand for flat glass products over the past five years. Higher demand has been derived from firms constructing commercial buildings, particularly offices and retail buildings, representing a substantial source of demand for glass wall panels, windows, glass bricks and blocks, doors, shower screens and mirrors. Demand from non-residential building construction is expected to contract in 2019–2020. However, some manufacturers may benefit from sales of flat glass products for completion work on major office and hotel developments.

2. **Demand from residential building construction**
   Trends in the downstream residential building market significantly affect demand for flat glass products, notably windows. Glass consumption is highest in the construction of large-scale apartment complexes, which are often clad in glass and have glass balconies. Demand from residential building construction has varied significantly over the past five years. Demand is expected to decline in 2019–2020, following the completion of many large-scale apartment developments. This fall represents a significant threat to the industry's performance.

3. **Demand from beer manufacturing**
   Demand for glass bottles heavily depends on demand from the local beer manufacturing sector. Local brewers use cans and bottles to package beer. Demand from beer manufacturing has fallen slightly over the past five years. However, demand is expected to increase in 2019–2020, supporting demand for glass beer bottles.

4. **Demand from wine production**

   Many industry firms supply glass containers used to bottle locally produced wine. Demand from wine production has risen over the past five years. However, the shift towards exporting bulk wine in PVC bladders has limited demand from this market. Demand from wine production is expected to expand in 2019–2020, underpinning stronger demand for glass wine bottles.

5. **Household consumption expenditure**
   Household consumption expenditure indicates households' capacity to purchase products that may contain glass. These products include glass containers used to package beverages

and food products (for example, jam), glass-based furniture products (for example, mirrors) and products used for household window repairs. Household consumption expenditure has risen steadily over the past five years and is expected to continue growing in next years.

6. **Per-capita alcohol consumption**
Alcoholic beverages represent the main market for glass bottle production. Alcohol consumption has significantly fallen since 2006-07 due to government policies and rising health consciousness. Per-capita alcohol consumption is expected to decrease slightly in 2019–2020, weakening demand for glass wine, beer and spirit bottles.

9.3.3 Raw materials

In this section, the raw materials needed for the manufacturing of float glass is described. Float glass is the main type of glass that is used in the construction industry. Float glass is a sheet of glass made by floating molten glass on a bed of molten metal, typically tin, although lead and other various low-melting-point alloys were used in the past. This method gives the sheet uniform thickness and very flat surfaces. The following are the principal constituents of float glass:

1. **Silica sand:** The main ingredient of glass which makes up 60 per cent of the composition. It has a very high melting point of over 2,000 ˚C.
2. **Sodium carbonate:** Helps glass endure a range of temperatures without melting. It basically lowers the melting point of silica down to about 1,000 ˚C and is therefore added to make the process more efficient. The sodium carbonate will, however, cause the finished glass to be water-soluble, which is not desirable in glassmaking. Sodium carbonate was originally found in the ash of certain plants –soda ash – but is now commonly produced from table salt.
3. **Limestone:** Calcium oxide, extracted from limestone, contributes to strengthen the properties of glass. This material negates the effects of the sodium carbonate, making the glass non-soluble in water. Magnesium oxide and aluminium oxide can also be used to enhance the properties of the glass.
4. **Dolomite:** Dolomite that is composed of calcium and magnesium carbonate contributes to glass resistance to melting. It also improves general resistance to natural or chemical attack or weathering.
5. **Glass cullet:** Commonly known as broken glass, this accelerates the melting of glass as it goes through the float glass process. Glass cullet is 100 per cent crushed material that is generally angular, flat and elongated in shape. The fragmented material comes in colour or colourless forms. The size varies depending on the chemical composition and method of production[382].
6. **Other additives:** These include lead, boron, lanthanum oxide, iron and colour-producing agents.

9.4 Products overview

The use of glass in the building sector has a long history, however, with new technological advances, its application has become very broad. Glass is now being used in the building industry as insulation material, structural component, external glazing material and cladding material. In infrastructural projects, the application of glass includes but is not limited to the sound barrier, tunnel, ingredients for road surface such as asphalt and insulators. Figure 60 shows multiple applications of glass products in the construction industry.

[382] GHD. 2008. Packaging Stewardship Forum, Australian Food and Grocery Council. The use of Crushed Glass as both an Aggregate Substitute in Road Base and in Asphalt in Australia Business Case. https://bit.ly/3tz05gR

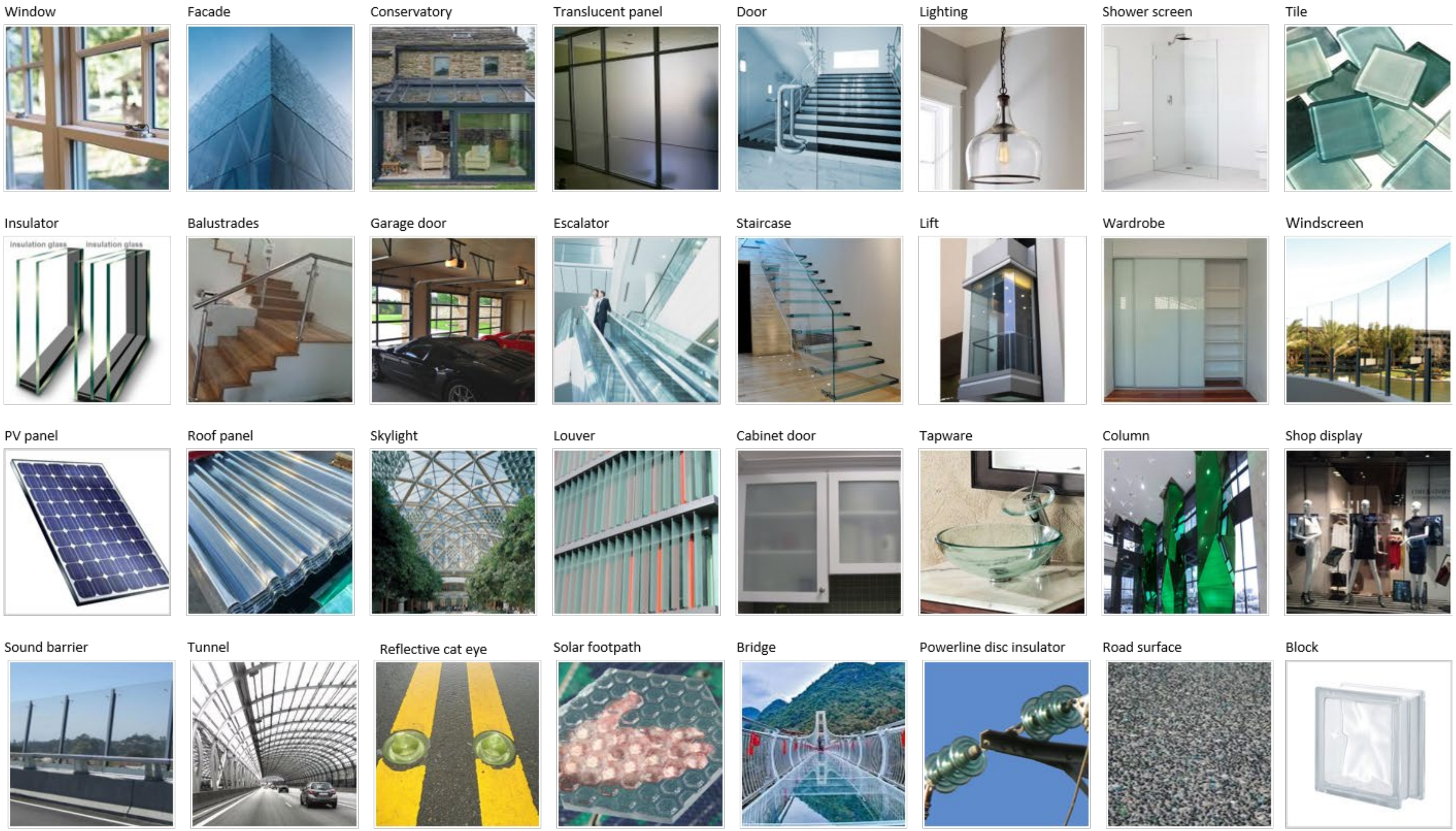

Figure 60. Various applications of glass products in the construction industry

9.5 Manufacturing process

There are various manufacturing processes for several types of glass products that are used in the construction industry. However, float glass is the most commonly used type of glass (Table 79). As a result, the production process for float glass is provided below. The process can be divided into five universal steps, as follows:

1. **Batching of raw materials:** The main components, namely soda-lime glass, silica sand (73 per cent), calcium oxide (9 per cent), soda (13 per cent) and magnesium (4 per cent) are weighed and mixed into batches to which recycled glass (cullet) is added. The use of cullet reduces the consumption of natural gas. The materials are tested and stored for later mixing under computerised control.
2. **Melting of raw materials in the furnace:** The batched raw materials pass from a mixing silo to a five-chambered furnace, where they become molten at a temperature of approximately 1,500 °C.
3. **Drawing the molten glass onto the tin bath:** The molten glass is 'floated' onto a bath of molten tin at a temperature of about 1,000 °C. It forms a ribbon with a working width of 3,210 mm, which is normally between 3 mm and 25 mm thick. The glass, which is highly viscous, and the tin, which is very fluid, do not mix and the contact surface between these two materials is perfectly flat.
4. **Cooling of the molten glass in the annealing lehr:** On leaving the bath of molten tin, the glass – now at a temperature of 600 °C – has cooled down sufficiently to pass to an annealing chamber called a lehr. The glass is now hard enough to pass over rollers and is annealed, which modifies the internal stresses, enabling it to be cut and worked in a predictable way and ensuring the flatness of the glass. As both surfaces are fire-finished, they need no grinding or polishing.
5. **Quality checks, automatic cutting and storage:** After cooling, the glass undergoes rigorous quality checks and is washed. It is then cut into sheets in sizes of up to 6,000 mm x 3,210 mm, which are in turn stacked, stored and ready for transport.

9.6 Regulations, policies, and guidelines

Legislation of glass waste management occurs at the jurisdictional level. As a result, there are various policies and requirements for glass waste in Australia. However, the inconsistencies in these jurisdictions are regarded as a challenge for the successful management of glass waste. Another set of regulations deals with the use of recycled glass waste materials in construction projects such as roads and pavements. The Standard Specifications regulate and maintain the quality and provide producers, as well as consumers, an assurance of uniformity and consistency in the quality of the recycled aggregate. For instance, in Victoria, Vicroads, which is a state authority managing the road and traffic, has provided a code of practice[383] that outlines the specifications of recycled crushed glass for application in the state road and pavement bases/subbase. In NSW, TfNSW has set specifications for granular pavement base and subbase materials[384]. Later, the EPA NSW published a guideline entitled 'Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage 2010 (Greenspec)"[385], which was set to encourage local government professionals and other stakeholders within both the private and public works engineering sector to use recycled concrete, brick and asphalt materials. Other states also have their own version of codes of practice

[383] Vicroads. 2017. Code of Practice RC 500.02. Registration of Crushed Rock Mixes. https://bit.ly/3v4ynsr
[384] RMS. 2008. ROADS AND MARITIME SERVICES (RMS) . RT 3051 https://bit.ly/3aqyqqE
[385] EPA NSW. 2011. IPWEA Roads & Transport Directorate https://bit.ly/2RQphkX

for recycled concrete. However, similar to environmental regulations, the specifications provided in the codes are not uniform[386] .

Table 82. The standards and specifications guiding the use of recycled concrete

State	Title
ACT	N/a
NSW	Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage 2010 (Greenspec)
Qld	Transport and Main Roads Specifications MRTS35 Recycled Material Blends for Pavements
NT	Standard specification for roadworks
SA	The standard for the production and use of Waste Derived Fill Recycled Fill Materials for Transport Infrastructure - Operational Instruction 21.6 Policy Specification: Part 215 Supply of Pavement Materials
Tas	Unbound Flexible Pavement Construction
Vic	VicRoads Standard Specifications for Roadworks and Bridgeworks VicRoads Codes of Practice
WA	Main roads Western Australia specification 501 – pavements

The other aspect of regulation that has an impact on glass waste management is landfill levies. The jurisdictional landfill levy regulations need to change in favour of glass recycling. For instance, in Europe, the glass industry has been driving legislation to ensure that it attracts the highest rate of landfill levy and, therefore, the greatest incentive to recycle the glass at higher value opportunities[387]. At the same time, tax levy exemptions are needed for glass waste residual for recycling facilities. According to ASBG, to counter the impact of the landfill levy on recycling, options such as the provision of a partial levy exemption for the recycling industry, better funding and grants to support the recycling industry, and the use of PS programs, should be considered[49].

9.7 Glass waste generation

Previous literature suggests that glass waste can emerge throughout the lifecycle of this building material. Various reasons are given to outline the source of waste generation, but it seems that cutting is the most frequently mentioned in research studies .

Table 83. Main reasons for glass waste generation

Reference	Description
Tam (2011)	• Damages during transportation • Improper cutting to the required dimensions
UK's Glass and Glazing Federation (2000)	• Cutting activities: • Poor storage and handling techniques; • Inadequate maintenance of equipment and machines; • Lack of checks leading to downstream processing problems; • Poor staff awareness of optimum operating techniques and process settings.

9.7.1 Glass waste quantity

Generally, glass waste only takes up a small portion of waste generated during C&D activities. However, glass waste takes one million years to break down naturally.[388] A study in Hong Kong

[386] Gabr, A.R., Cameron, D.A., Andrews, R. and Mitchell, P.W., 2011. Comparison of specifications for recycled concrete aggregate for pavement construction. *Journal of ASTM International*, 8(10), 1-15.

[387] DeBrinca, G and E. Babic. 2013. Arup: Re-thinking the life-cycle of architectural glass. Construction flat glass recycling Viability study & value report. https://bit.ly/3enMpiq

[388] Suez. 2017. Fact sheet: Glass Recycling. https://bit.ly/3v6cvgA

reported that the volume of glass waste from five construction projects ranged from as little as 0.3 per cent to 16.5 per cent[389]. The construction industry is not a significant contributor to glass waste generation in Australia. According to the latest data released in the *NWR 2018*[83] , Australia generated 1,078,831 t waste glass in all waste streams in the period 2016-17 (Table 84). The largest producers of the glass waste in Australia were NSW (338, 255), Qld (240, 753) and Vic (212, 253). From the total glass waste generated, only 0.62 per cent came from the C&D waste stream. Among the jurisdictions, NSW, Vic and SA had the highest rate of C&D waste-based glass waste to total glass waste ratio, with 1.90 per cent, 0.58 per cent and 0.23 per cent, respectively.

[389] Tam, V.W., 2011. Rate of reusable and recyclable waste in construction. *Open Waste Management Journal*, 4(1), pp.28-32.

Table 84. Glass waste generation and fates in Australia

	Waste generation (t)		Waste landfill (t)		Waste recycling (t)	
State	**C&D**	**Total**	**C&D**	**Total**	**C&D**	**Total**
ACT	21	20,661	21	6,539	n/a	14,122
NSW	6,442	338,255	0	136,926	6,442	201,329
NT	5	13,036	5	7,864	0	5,172
Qld	60	240,753	60	133,534	0	107,219
SA	192	81,959	192	14,959	0	67,000
Tas	1	38,199	1	14,521	0	23,678
Vic	1,238	212,253	1,238	74,935	0	137,318
WA	14	133,715	14	77,978	0	55,717
Total	6,735	1,078,831	1,531	467,256	6,442	611,555

Source: Department of Environment and Energy. 2016-17[83]
Note: the values for waste generation are the result of adding together waste landfilling and recycling values.

9.7.2 Types of glass waste

Table 85 presents various glass waste types which are categorised based on different characteristics.

Table 85. Various types of glass waste

Type	Description
Internal glass cullet	Glass that is crushed and ready to be re-melted is called cullet; internal cullet is composed of defective products detected and rejected by a quality control process during the industrial process of glass manufacturing, transition phases of product changes (such as thickness and colour changes) and production offcuts
External glass cullet	Waste glass that has been collected or reprocessed with the purpose of recycling; external cullet (which can be pre- or post-consumer) is classified as waste; the word 'cullet', when used in the context of end-of-waste, will always refer to external cullet
Glass (powder) fine	A lower grade product which is used in asphalt, sand/abrasive grit blasting, asphalt (glassphalt), construction and road aggregates, concrete aggregate, sports turf/drainage, brickmaking, water filtration, insulation batts and as an alternate day cover for landfills
Mixed cullet	Contains a mixture of glass types (sealed window units, laminated glass, mirrored glass, tinted glass, printed glass, old glass from wooden frames); a lower price will be paid for mixed cullet, as it requires additional processing to remove contamination
Clear cullet	Consists of standard flat glass only

Glass cullet management

While it is possible to minimise the total amount of cullet generated, it is generally not possible to eliminate its production. Cullet is produced during manufacturing and in secondary activities. It is important to consider cullet management from all processes in any waste management strategy. Flat glass cullet can be recycled into flat glass, glass fibre or glass wool insulation. Good cullet management will improve cullet quality and thus increase the amount that can be recycled. The level of contamination in the cullet load has a direct influence on its value and saleability. Generating contaminant-free cullet is, therefore, vital to the financial viability of cullet recycling. There are two main types of contamination:

- inclusions—non-glass materials, for example, sealed unit and window frame materials or laminated glass;
- colour contamination—mixed cullet of different colours.

Improving the purity of cullet and preventing colour contamination will increase the value and recyclability of cullet. There are techniques to improve the purity of cullet, such as thermal treatment, which is conducted in a batch, high-temperature electric oven and then in the continuous infra-heated thermal reactant[390]. Table 86 presents strategies that facilitate subsequent recycling activities of glass cullet generated during glass production.

Table 86. Strategies to better manage glass cullet

Theme	Description
Reducing contamination	• Prevent non-glass materials from becoming mixed with cullet contamination • Segregate waste streams to prevent mixing of different colours and types of glass • Provide alternative skips for other waste materials • Label all skips clearly
Management	• Make one person responsible for ensuring that cullet skips are inspected daily for inclusions and colour contamination, well-maintained and clearly labelled • Mark skips clearly with which types of cullet are acceptable and which are unacceptable

[390] Isa, H. 2008. The need for waste management in the glass industries: A review. *Scientific Research and Essay*. 3(7), 276-279.

	• Provide skips for unacceptable waste next to cullet bins; this will reduce inclusions • Make workers aware of the cullet specification required by the cullet collector Ensure that cullet generated offsite (e.g. breakage during window fitting) is returned and placed – without any inclusions – in the appropriate skips
Training	• Provide staff with regular training in cullet management • Provide clear, written procedures so that everyone knows exactly what to do • Ensure that contractors do not use cullet skips for their waste
Pick-up	• Check that the cullet in the skips has no inclusions before cullet collectors collect the skips • Use a limited number of cullet collectors to ensure training and communication on cullet handling remain effective • Ensure that contaminated loads are not forwarded to recyclers; prices for consignments may change if minimum requirements are not met

Source: UK's Glass and Glazing Federation (2000)

9.8 Glass waste management

The aim of this section is to provide an insight into the sustainable management of glass waste through various opportunities that emerge throughout the glass life cycle. The section also discusses the various waste management methods, which are supplemented by case studies that showcase success stories in sustainable glass waste management.

9.8.1 Waste during manufacturing

Pre-consumer waste is generated during manufacturing (before reaching the consumer) and has exclusively an industrial origin. It represents approximately 25 per cent of waste glass generated in the EU.[377] There are plenty of opportunities to reduce glass waste during the manufacturing of glasses used in the construction industry. Due to technical and economic reasons, there is a minimum glass-to-glass market in Australia. However, from the environmental protection perspective, use of recycled glass in manufacturing glass products is a viable option. According to Writer (2018),[391] recycled glass requires a lower melting temperature than the raw materials used to produce glass from scratch, meaning production that utilises recycled glass can extend the lifetime of the furnace and save large amounts of energy. The recycling process does not generate any harmful by-products either, making it extremely efficient. Because recycled glass also lowers the demand for raw materials, its use supports natural resource conservation – one tonne for every tonne of glass recycled – and decreased manufacturing costs. On top of those savings, glass recycling has a critical impact on the reduction of carbon dioxide emissions: for each metric ton of material recycled, manufacturers avoid producing approximately 315 kg of carbon dioxide emissions.

A selection of the strategies that are identified by Tangram Technology[392] based on the recommendations of the UK's Glass and Glazing Federation (2000) to improve glass waste management in the glass production industry is provided in Table 87. These strategies fall under 10 categories which cover the entire production system.

Table 87. Strategies to reduce waste during various stages of glass production

No	Title	Description
1	Walk-around	A 'walk-around' is designed to gain an overview of the processes and to identify rapid no-cost or low-cost improvements to save money; take an unannounced walk around the site at mid-shift. If there is no night shift, it can also be profitable to take a walk around the factory when there is no production being carried out

[391] Writer, S. 2018. Reducing Waste Through Glass Manufacturing & Packaging. Thomas Insights. https://bit.ly/3neRGgh
[392] Tangram Technology. 2015. Waste minimisation in glass processing. https://bit.ly/3v50dVI

2	Storage and handling	• Avoid breakages by improving storage and handling techniques (especially after the value has been added by processing) • Stack glass correctly to avoid problems with de-stacking • Ensure that the correct lifts and equipment are used for lifting and manoeuvring glass from delivery vehicles to factory storage areas • Maintain racks with unworn felt/rubber padding and set at the correct angle, i.e. 30
3	Finding hidden costs	Estimate the 'true cost' of waste, which is not only the cost of the raw materials but is also a function of how much added value has been put into the product before it is lost from the production process; for example, if a product is broken in the goods-out department, causing it to be lost as waste, the true cost of that waste will be: The true cost of waste = *Cost of wasted raw materials* + *lost time* + *cost of utilities used* + *waste treatment* + *disposal costs*
4	Production	• Plan production to minimise changeover losses • Record glass utilisation wherever possible; track, locate and reduce any variations
5	Packaging waste	Re-use any packaging for products, where appropriate; find ways of minimising packaging with both suppliers and customers; the packaging is paid for twice –once to buy it and again to dispose of it
6	Cutting	• Set aggressive improvement targets for glass utilisation that are relevant to a business • Fully optimise cutting to minimise waste – do not stop optimising at the first 'acceptable' result • Check for any surface and edge defects before cutting • Check the accuracy of the 'squareness' of cutting equipment • Box in cutting tables so that cullet does not fall underneath them • Contaminated cullet decreases in value and is often disposed of rather than recycled • Catalogue and store significant offcuts for future use
7	Waste collection	• Optimise waste segregation and recycling to minimise the amount of waste requiring disposal • Collect waste flat, float and clean glass separately from other glass types and contaminants (e.g. wood and metals) for recycling • Collect coated, coloured and laminated glasses separately for recycling • Make sure that ceramic, coloured or fire-retardant glass does not contaminate flat, float and clean glass forwarded for recycling • Order replacement skips for cullet collection before the ones in use become full; this will avoid glass spilling on the ground and having to be disposed of to landfill because it is contaminated
8	Maintenance	• Ensure that all machinery is well-maintained and clean to reduce mistakes, accidents and breakage • Assign machines to operators to increase operator ownership • Train staff to handle glass and end-products correctly to avoid bruising, scratching and damage
9	Site layout	Layout production areas to optimise material flow logistics.; this reduces both the potential for breakage and the time taken to move the product
10	Performance measure	• Production performance in the glass fabrication and the processing industry is often measured according to overall output and 'due date' • Using performance measurements that relate directly to process efficiency will improve overall control and help to develop good practice • Examples of these measures include cutting yield, glass waste per tonne of saleable product and energy costs

Source: Tangram Technology[392]

In addition to the general strategies presented in Table 87, there are specific opportunities to reduce waste in glass fabrication, focusing on the manufacture of sealed units and frames, and glass processing, which is concerned with activities such as laminating, toughening, bevelling and grinding (Table 88). These opportunities are identified by the UK's Glass and Glazing Federation (2000).

Table 88. Opportunities to reduce waste in glass fabrications and processing

Good practice in glass fabrication	
Sealed units	• Check for waste at key points in the manufacturing process; record the amounts and consider ways of eliminating or reducing this waste • Collect steel and aluminium off-cuts separately for recycling or return to the engaged supplier • Minimise desiccant use by calculating the exact amount required for the volume of the sealed unit • Maintain the correct temperature for sealant storage and use to avoid wasting batches and to optimise sealant application • Stagger breaks in production to avoid the need to purge sealant from machines before and after breaks • Ensure that the optimum amount of sealant is used for a given gap between panes of glass by monitoring actual and target use • Check the quality of two-part sealant mixes to ensure correct performance • Store finished products in safe areas to minimise damage
Fabrication of frames	• Check that the dimensions and quality of the profile material (for example, look for rubs, marks and frames scratches) are acceptable to avoid subsequent wastage • In sawing processes, minimise grip waste and, on mitres, cut to the width of the blade • For PVC-u profiles: – order steel and aluminium reinforcement in pre-cut lengths to avoid on-site waste; – recycle waste PVC-u by regranulating and blending it into secondary profiles, i.e. not the all-weather sections but the secondary parts of the profile; – sell PVC-u swarf from drilling/cutting and sprues from welding operations to a reprocessor. • If mistakes do occur: – recover fittings, hinges, handles, locks and glass in a material reclaim unit; – granulate uncontaminated PVC-u frames; – recycle aluminium frames.
Good practice in glass processing	
Acid processes	• Use a high-quality sealing coating to avoid mistakes and thus minimise waste and rework
Sandblasting	• Check the pattern cutting (the most critical stage) to ensure accurate sandblasting. This will avoid waste generation and the need for reworking • Re-use grit and change it only when necessary • Use the best quality sealing coating to avoid mistakes and thus minimise waste and rew
Drilling	• Cut a slot from the edge of the glass to reduce the incidence of breakage
Laminating (resin)	• Before starting to laminate, ensure that the glass is clean and dry to avoid trapping moisture (resin) • Use demineralised water to avoid staining on internal surfaces • Ensure that glass is securely clipped to avoid movement during processing • Check that bubbles are not present in the resin before curing with ultraviolet light • Use the correct cure time
Laminating (pvb)	• Maintain suitable conditions for the storage and use of pvb laminate. This will avoid (pvb) deterioration of the laminate and ensure efficient application. • Keep the lamination equipment free of dust to avoid contaminating the product • To guarantee accurate application, check that the lamination equipment is square to the laying table • Inspect the laminated glass after autoclaving to ensure that downstream processes are not supplied with faulty material • Trim the pvb overhang from laminated glass to avoid slippage and damage in subsequent processes, for example, on double glazing lines • Maintain autoclaves, cranes and hot air systems correctly to provide efficient and optimum operation • Integrate driers with compressed air systems and autoclaves to avoid staining due to solid deposits, and the need for cleaning
Bevelling and grinding	• Turn on the water supply to bevelling and grinding machines only when they are in use • Turn off the water when the machines are not in use

	• Recycle the water from bevelling and grinding machines to reduce water and effluent costs
Bending	• Check moulds thoroughly to prevent quality problems • To avoid unnecessary cracking, raise the oven hood at an appropriate speed and reduce the hood temperature correctly • Utilise the bed space under the oven hood as much as possible to optimise production rates • Operate the oven hood overnight when cheaper energy is available
Toughening	• Plan work to maximise periods of continuous operation. This avoids start-up and shutdown, thus reducing energy use and other production costs. • To avoid rejects, check the glass for staining before processing • Ensure that ovens and chillers are programmed accurately for each job to optimise heating/cooling time and to minimise the potential for breakage • If a print is applied to the glass, place the print face-up to avoid damaging the rollers and having to stop the process to clean them • Operate the toughener overnight when cheaper energy is available

Source: UK's Glass and Glazing Federation (2000)

9.8.2 Waste reduction opportunities during design, planning and contract

Proper design that guarantees the least variation and adjustment during construction leads to minimum waste generation. For instance, the design of custom glazing panels to use multiple replicates of the same size units wherever possible can assist with reducing glass waste. Engineering company Arup's report on construction glass circularity provided some insight into the need for design with a view to recyclability[393].

The glass design equivalents would be to design out the use of laminate glass units or ceramic frit, which both currently make glass recycling challenging or impossible. Ceramic fritted glass cannot be recycled, and the process of delamination crushes the glass in small particles – which cannot be used in the highest level of recycling – back into float glass. This means designers need to review the current trend of laminated double-glazed units, which are often required to achieve the safety performance of the building façades. The other approach to address this challenge is to benefit from research and technical development to find a better way to delaminate glass, altering the interlayers or upgrading the delamination process.

9.8.3 Reducing waste during procurement

A significant challenge for the implementation of glass recycling on renovation and demolition projects is the existing procurement structure and processes used in the industry. In the early stages of renovation and demolition projects, clients and design teams should be defining the specification for the removal and recycling of building materials during the works. Knowledge of appropriate and available recycling methodologies needs to be disseminated to clients and specifiers to allow a greater uptake of recycling early in the life of a project, specifying the requirements to contractors prior to their engagement on the project. For instance, Arup has successfully specified the contractor's requirement to recycle glass at this high-level closed-loop process during renovation and glass replacement projects.[Error! Bookmark not defined.]

Defining standard clauses that can be included in contractual documents would assist the industry to adopt these requirements for recycling building materials. Tender responses could require the contractors to state the level of recycled glass content from their supply chain and allow a measure between contractor returns. This could potentially have a positive effect on the promotion of increasing recycled content by the glass manufacturers, as they currently do not openly advertise this information. The commercial sensitivities of building product manufacturers may require some overcoming, as we have found the glass manufacturers to be particularly secretive of their processes

[393] DeBrinca, G and E. Babic. 2013. Arup: Re-thinking the life-cycle of architectural glass. Construction flat glass recycling Viability study & value report. https://bit.ly/3efWZHX

to maintain a competitive edge. Legislation may be required to make the release of this information compulsory for clarity on recycled content of products.

9.8.4 Reducing waste during transportation and delivery

The occurrence of glass wasted during transportation and delivery is common. One study in Hong Kong[389] reported that one of the two main reasons for glass waste generation is damages during transportation. Furthermore, the delivery of glass panes with large sizes increase the likelihood of glass waste, hence there are restrictions from handling, processing and transportation that limit the use of larger glass sizes in the construction industry[Error! Bookmark not defined.]. The other issue that arises during removal, storage and transportation is the contamination of glass waste. Minor contact with stainless steel can cause significant contamination that may cause critical inclusions[Error! Bookmark not defined.]. Tangram Technology[377] report identified strategies to reduce glass wastage during delivery as follows

1. Use 'just-in-time' delivery to minimise storage time and damage;
2. Develop delivery quality checks to improve the quality of glass used and reduce defects/breakages;
3. Measure all breakage in deliveries and chargeback to the supplier.

9.8.5 Reducing waste during construction

One study in Hong Kong[389] reported that the main reason for glass waste generation at a construction site is cutting to the required dimensions. Therefore, glass installation subcontractors have a pivotal role in reducing waste by excercising due diligence when cutting the glass delivered to a construction site. Tangram Technology[377] identified strategies to reduce waste during construction as follows:

1. Increase the stillage size to reduce space and number of glass lifts.
2. Maintain stillages at an angle of 50 or 60.
3. Use battens to optimise storage conditions and avoid glass damage.
4. Keep storage areas free of water leaks and dust to reduce staining.

9.8.6 Reducing waste during demolition and renovation

Glass resulting from demolition and renovation activities account for a large percentage of glass waste in the construction industry. For instance, renovation projects in the UK hold the majority of glass material for recycling, representing almost 85 per cent of the glass quantity available for recycling.[394] While recycling waste glass is viable in refurbishment projects, the demolition projects present a bigger challenge.

However, with current demolition practices, it is likely to be economically challenging to recycle glass from demolition projects because it is often broken during demolition and mixed with other materials. Once mixed with foreign materials, it is very difficult to separate glass to the standard required by quality specifications for glass manufacturing. Therefore, as demonstrated by research[395] in Europe, most glass from demolition activities is mixed with recycled hard core to create an aggregate material that can be used for foundations.

The best opportunity with demolition projects is in the case of high-rise buildings where, for safety reasons, demolition is controlled, and introducing measures to keep glass separated may not add significantly to the cost and time of the process. Research in the UK[Error! Bookmark not defined.] demonstrated that the value of the cullet paid by the float manufacturers represents sufficient incentive to transport and deconstruct the materials in this way, using unskilled staff in the breakdown operations. It was found that moving the cullet following breakdown and bagging

[394] Hestin M., de Veron S., Burgos S., 2016. Economic study on recycling of building glass in Europe. Deloitte Sustainability.
[395] Glass fpr Europe, 2010. Recyclable waste flat glass in the context of the development of -end-of-waste criteria. Glass for Europe input to the study on recyclable waste glass.

appears to be most cost-effective when the glass manufacturers backhaul the material on otherwise empty transportation following material deliveries in the local area of the recycling facilities.

Recycled glass generated from demolition and renovation projects is collected in two main different ways: mono-material collection (optionally with colour differentiation) or mixed with other dry recyclables (multi-material collection). Both options have advantages and disadvantages that are tabulated in Table 89:

Table 89. Characteristics of glass waste collection systems

	Disadvantages	Advantages
Mono-material system	• Requires existence of a reprocessor with adequate sorting technology within reasonable transport distance, otherwise, it is likely that the material will be used for open-loop recycling applications, such as aggregates, resulting in virtually no environmental benefits. • The additional stage of colour sorting may have a significant cost impact and even become economically not viable. • More demanding for consumers. • More costly in terms of collection than multi-material systems, especially if colour-separated.	• Normally results in higher quality. The amount of non-glass is significantly lower, making it easier to process and remove the lids, labels, foils, ceramics and any other impurities. • Cullet has higher quality, and it is thus fit for a larger range of glass recycling uses. This is especially valid if there is colour separation. • Increased added value over the recycling chain, also higher with colour separation. • Lower costs of reject disposal (non-glass material fraction) or bad quality cullet batch disposal. • In general, higher overall recycling rates (even though collection rates may not in all cases be higher). • Better image to the public, as the multi-material collection may result in the perception that glass is not being recycled • Avoidance of landfill levy for storage at material recovery facilities.
Multi-material system	• Higher reprocessing costs to achieve the same quality as mono-material collection, if at all achievable • Lower recycling rates because of high contamination • Higher glass loss during processing (typically 12-15% is wasted in material recovery facilities, compared to 1% for mono-material processing) • Cullet frequently not suitable for further reprocessing with the aim of re-melting in glass manufacturing facilities; experts reported that even in some cases the cullet is not suitable for use as aggregates because of its high organic contamination – as a consequence, the cullet from multi-material systems is sometimes rejected by aggregate companies	• Easier for C&D companies, as less sorting space is needed • Cheaper collection

Source: Pharosproject (2005)[377]

9.8.7 Reducing waste through reusing

Most of the flat glass used in buildings could be dismantled and recycled in glass furnaces. However, re-using the unwanted or damaged glass products without processing is difficult. According to anecdotal evidence and some industry reports, when re-using glass waste and its derivatives in the fabrication of construction, the glass material is minimal. For instance, a sustainability study[394] in the UK showed that, despite its excessive recyclability, end-of-life glass is almost never recycled into new glass products. However, with technological advances, new techniques such as electrolysis, filtration, reverse osmosis and centrifugation emerged through which re-using can be facilitated during glass manufacturing processes and construction activities[396]. In the UK, waste recovery services usually take a separated waste glass from site free of charge, or require the builder to pay transportation costs. From the builder's perspective, this is a saving, compared to the landfill tax (regardless of the landfill tax rate) and should be actively encouraged to support glass recycling. After the glass waste is processed at the glass recycling facility, which includes removal from frames and sorting into three categories of quality, they sell the cullet to float glass manufacturers. The following is a description of a case study in which the construction glass waste is re-used.

A case study in the UK[397]: Lloyd's building, London, by Richard Rogers

In 2010, Lloyd's decided it required more daylight and improved views from the iconic Richard Rogers-designed building originally completed in 1987. Some of the original rolled sparkle glass panes were replaced with clear flat glass, and 123 t of the original glass was removed from the building and sent back to Saint-Gobain Glass in Eggborough for re-melt back to float glass. Additionally, some of the sparkle glass was re-used. The panels were cut into the new required size and re-installed or stored for any replacements required in the future (Figure 61). Some of the offcuts were used in furniture designs for the building, such as tops for coffee tables. The work on Lloyd's demonstrates re-use and the recycling of glass at the highest standard and with minimum environmental impact.

Figure 61. Lloyd building in London, UK
Source: Lloyd's© Arup (2013)[397]

9.8.8 Waste recovery (recycling and upcycling)

Technically, glass can be recycled several times for use in different applications. However, due to the reasons stated earlier, in the real world, the rate of re-usability and recyclability of glass waste is not as high as it should be. According to a study[398] on the extent of recycling C&D-based glass waste in five construction project case studies in Hong Kong, the average recycling rate was pretty low (29.6 per cent) compared to other construction waste materials such as concrete, metal, timber, paper and plastic. One study in the EU[397] showed that, across the EU, the proper recycling of all building glass waste compared to the business-as-usual scenario could avoid 925,000 t of landfilled

[396] Lawson, E. 2018. 8 Effective Ways to Reduce Manufacturing Waste. Fishbowl. https://bit.ly/3gqFCH2
[397] DeBrinca, G and E. Babic. 2013. Arup: Re-thinking the life-cycle of architectural glass. Construction flat glass recycling Viability study & value report. https://bit.ly/3dA2KkU
[398] Tam, V.W., 2011. Rate of reusable and recyclable waste in construction. *Open Waste Management Journal*, 4(1), 28-32.

waste every year and could save around 1.23 Mt of natural materials annually (of which 873,000 t is sand), and reduce carbon emissions by in excess of 230,000 t annually.

In Australia, the latest glass waste statistics (Table 90) show that, except for NSW where 100 per cent of glass waste generated in the C&D sector is recycled, other jurisdictions landfill their entire glass waste. However, the recycling rate for all waste streams is significantly higher, reaching 56.7 per cent in Australia and ranging from 36.7 per cent (NT) to 81.7 per cent (SA). One possible reason for these contradictory trends could be the negligible amount of waste generated during C&D activities, making less economic sense for construction firms to send it to recycling facilities. As a result, it seems that reducing waste and focusing on green building/infrastructure schemes can be sustainable solutions. The following describes the applications of recycled and upcycled glass waste.

One of the widely approved applications of glass waste-based materials in recent years is in the production of concrete. This application seems to be the most viable option in glass due to excessive breakage in the collection and sorting resulting in mixed colour glass cullet, which is unsuitable for recycling into containers. The finely ground (38–45 lm) glass powder with high silica content (SiO_2> 70 per cent), high surface area and amorphous nature suggest that glass powder could perform as an alternative supplementary cementitious material to partially replace cement in concrete.[399]

The other application of glass waste is in building road pavement. The incorporation of glass in asphalt concrete, otherwise commonly known as glassphalt, was first introduced into several international markets in the late 1960s[400]. When the glass is properly crushed, this material exhibits a coefficient of permeability similar to coarse sand. Also, the high angularity of this material, compared to rounded sand, may enhance the stability of asphalt mixes. In general, glass is known for its heat retention properties, which can help decrease the depth of frost penetration.**Error! Bookmark not defined.**

A report prepared by engineering company GHD**Error! Bookmark not defined.** listed the various applications of glass waste in the construction and other industries. These include:

- aggregate in road base and sub-base
- aggregate in asphalt, including glassphalt
- aggregate in tiles
- aggregate in decorative concrete for architectural façades
- alternative to mulch
- filtration material
- alternative to sand in golf courses
- alternative to fill and bedding material
- aggregate in concrete and cement.

Table 90 provides a summary of studies investigating the quality of glass waste recycling and upcycling.

[399] Omran, A.F., Etienne, D., Harbec, D. and Tagnit-Hamou, A., 2017. Long-term performance of glass-powder concrete in large-scale field applications. *Construction and Building Materials*, 135, 43-58.

[400] Mohajerani, A., Vajna, J., Cheung, T.H.H., Kurmus, H., Arulrajah, A. and Horpibulsuk, S., 2017. Practical recycling applications of crushed waste glass in construction materials: A review. *Construction and Building Materials*, 156, 443-467.

Table 90. Summary of studies investigating the applications of glass waste

	Application	Summary of findings	Reference
Upcycling	Use of glass aggregate as an agricultural reflective mulch	Reflective mulches had an influence on aromatic profiles of the study grapes harvested without altering yield components or traditional harvest parameters; the effect was made through a change in soil and canopy environment conditions.	Mejias Barrera (2012)
Upcycling	Use of glass cullet as a filter medium for swimming pool water treatment	Results show that despite the larger negative zeta potential of cullet particles, filtration efficiency was comparable and recycled glass can be a useful material for optional filtration medium	Korkosz et al. (2012)
Upcycling	Use of recycled glass as a growing medium component for turfgrass in golf course	The results of field experiments showed an equal performance of recycled glass to conventional quarried sand	Philp (2011)
Recycling	Use of glass powder as a filler material in concrete production	Glass powder (3% passed through a 0.075 mm sieve) achieved the highest stability of the three fillers with an optimum of 7% for all types of filler	Jony et al. (2011)
Recycling	Use of glass powder as a replacement forcement	It is found that glass powder can be used as cement replacement material up to particle sizes less than 75 µm to prevent an alkali-silica reaction	Vijayakumar et al. (2013)
Recycling	Use of glass aggregate in road surface production	The test results reveal that glass waste is a viable material for asphalt concrete	Su and Chen (2002)
Recycling	Use of unsorted recycled glass mix to create segmental retaining wall (SRW) brick	The durability of bricks made of optimum glass plastic mixture compared well with that for current SRW bricks in commercial use; the life cycle cost analysis suggested that the cost of manufacturing glass plastic bricks is much cheaper than SRW bricks – hence the outcome of this study is the production of a viable, superior and inexpensive SRW brick made from recyclable materials that is sent to landfills	Meegoda (2011)
Recycling	Waste glass in fired clay brick production	Waste glass addition enhances the physical and mechanical properties of fired clay brick	Phonphuak et al. (2016)
Recycling	Waste glass in the production of gypsum composites	Analysis comparing composites with glass waste content to reference gypsum showed that it is viable to prepare gypsum composites with the addition of glass waste to reduce water absorption by capillarity, improve mechanical strength, and increase surface hardness; the resultant composites comply with the minimum requirements set by regulations and can be applied in the manufacturing of gypsum-prefabricated elements or as interior coatings requiring special surface hardness, improved water behaviour, and mechanical strength properties	Villoria Sáez et al. (2018)
Recycling	Waste glass in the production of ceramic tile	The final products obtained using recycled glasses can be proposed in different fields: building materials, artistic ceramics, furniture industry and ceramic tiles; the products are distinguished from those already existing for the highest percentage of recycled glass used and for the versatility of forming shaping processes	Andreola et al. (2016)
Recycling	Waste glass in the foam glass production	Since the glass foams used glass waste as a reactant, the results suggest the development of an alternative route for glass recycling	Bento et al. (2013)

The use of recycled glass in road applications comes with a risk of leaching contaminants such as heavy metals into the groundwater table.[401] This risk has been proven to be negligible[402] and can

[401] Mohajerani, A., Vajna, J., Cheung, T.H.H., Kurmus, H., Arulrajah, A. and Horpibulsuk, S., 2017. Practical recycling applications of crushed waste glass in construction materials: A review. *Construction and Building Materials*, 156, 443-467.

meet the requirements of local road authorities and other environmental protection agencies such as EPA Victoria. The main strategies to mitigate environmental concerns are identified[401] to be:

- application of appropriate design and methodology can mitigate the leaching of contaminants
- application of recycled glass in places with a sealed surface; for example, an asphalt paved surface or in elevated grounds
- appropriate processing of recycled glass prior to application to remove contaminants before they can harm the water table.

A case study: Trafalgar Park, Nelson City (US)

The use of recycled glass in the landscape and horticulture industry has achieved some success. The examples of this application are the use of recycled glass as a reflective mulch (Philp, 2011) and growing medium (Table 90). An analysis of a golf course (Trafalgar Park, in Nelson City) upgrade in the US[403] showed that recycled glass aggregates have a satisfactory performance as quarried sand. The project manager of this project reported that the use of recycled glass could save US$50,000 to US$100,000 in production and transport costs than using conventional quarried sand.**Error! Reference source not found.** shows the growth of turfgrass on a medium that comprises recycled grass in a golf course.

Figure 62. A cross-section showing established turfgrass grown on a glass sand medium
Source: Opus International Consultants Ltd

A case study: Fletcher Insulation: recycling glass into an insulation[404]

Fletcher Insulation is a manufacturer and supplier of insulation materials for buildings in Australia. The company uses the glass waste stream for the production of glass wool insulation. Up to 74

[402] Disfani, M.M., Arulrajah, A., Bo, M.W. and Sivakugan, N., 2012. Environmental risks of using recycled crushed glass in road applications. *Journal of Cleaner Production*, 20(1), 170-179.
[403] Philp, M., 2011. Spinning Glass into Grass. *Engineering Insight*, 12(4), 19-20.
[404] Edge Environment Pty Ltd. 2011. Construction and demolition waste guide - recycling and re-use across the supply chain.

per cent of the total raw materials input is from waste sources, such as C&D waste, offcuts from the glass manufacturing industry and bottle glass from the packaging industry and recycling stream.

Fletcher Insulation has been refining its manufacturing process to be able to input as much recycled glass as possible. The production of glass wool insulation relies on a precise mix of inputs to create the correct conditions in the furnace. The formulation of the raw materials is critical and ultimately dictates the proportion of recycled input that the process will tolerate. It is estimated that the glass wool insulation industry in Australia produces 80 kt of insulation per year. Up to 70 per cent of this can be recycled glass and, therefore, the industry has the capacity to recycle more than 50 kt of glass per year from the C&D waste stream including bottle glass, scrap car-windscreen glass and glass industry production waste.

The main driver for re-use is economics – using post-consumer waste glass is less expensive than virgin glass material and has the added benefit of reducing the energy process for manufacturing glass wool insulation. The other benefits include social responsibility, the ability to deliver a product to the construction industry that is produced from a high proportion of post-consumer material, and process efficiency: the energy efficiency gained from the use of recycled glass reduces the energy required in the furnace. The production of glass from raw materials requires temperatures of 1,600 °C. Cullet melts at 800 °C to 900 °C and is, therefore, less energy intensive to use.

Case study in Australia: Waverley Council: recycled glass in NSW's roads[405]

In 2010, the Waverley Council, in partnership with the then NSW Department of Environment, Climate Change and Water, the former NSW Roads and Traffic Authority, the Institute of Public Works Engineering Australasia and the Packaging Stewardship Forum provided the first site within NSW to demonstrate an alternate use of crushed glass in pavement construction as an accepted product in NSW roads. Two 100 m sections of pavement containing glass product were constructed. The first site, at Blair Street, Bondi, used glass product in asphalt and the second site, at O'Brien Street, Bondi, used glass product in concrete pavements. Using recycled and re-used material, Waverley Council substituted 15 t of glass cullet into the road projects, 7.5 t into asphalt and 7.5 t into concrete.

9.8.9 Illegal dumping and stockpiling

In the case of glass, illegal dumping and stockpiling is quite prevalent in Australia. There is a number of reasons for this trend. The majority of stockpiling occurs in recycling centres where facility owners state there is no viable market for recycled glass.[406] The other reason is related to the cost associated with creating glass products in Australia, which is currently in favour of imports. The local production of glass can absorb a portion of recycled waste. The situation has become tougher for recycling companies who need to deal with EPA regulations which restrict large stockpiling on the one hand, and long-term contracts with councils to collect glass waste on the other hand.

Unfortunately, not all glass waste dumped into recycling companies is stored. Figure 63 shows the situation of a recycling company warehouse with a large volume of glass waste being stockpiled. These giant bags of glass waste are regarded as almost worthless sources in current market conditions. As can also be seen in **Error! Reference source not found.**, there are instances**Error! Bookmark not defined.** of stockpiling activities outdoors, where there is a risk of leaking into the ground.

405 National Waste Policy. 2011. Case Study: Waverly Council: recycled glass in roads. https://bit.ly/3stLwK0

406 Meldrum-Hanna, C., A. Davies and D. Richards. 2017. Recycling companies stockpiling thousands of tonnes of glass as cheap imports leave market in crisis. ABC News: https://ab.co/3eljzim

Figure 63. Inside a recycling company's warehouse (Plytrade)
Source: Meldrum-Hanna (2017)[Error! Bookmark not defined.]

In NSW, a report by the federal goverment[405] showed the estimations of glass waste stockpiled in the state. The estimations indicated that 60,000 t of glass waste is stockpiled in Sydney. According to a report received by the NSW EPA from industry, in 2017, the issue with stockpiling continued to present itself and it allegedly has reached crisis point[Error! Bookmark not defined.].

9.8.10 Waste disposal

Despite a higher level of recycling glass waste relative to landfilling in all waste streams, landfilling is prominent in the C&D waste stream. Glass waste landfilling comes from various streams. After recycling (56.7 per cent), it is the major waste fate in all Australian jurisdictions, with a 43.3 per cent ratio. According to the latest available data (2016-17)[Error! Bookmark not defined.] on the annual volume of glass waste going to landfill (Table 84), 467,256 t of glass waste was landfilled; of this figure, the C&D waste stream comprised 1,531 t or 32.7 per cent. The average landfilling rate of glass waste in the C&D stream is 82.3 per cent. Except for NSW, which experienced 100 per cent recycling, the total waste generated in the C&D stream in 2016-17 was landfilled in all Australian jurisdictions.

In the same period, the degree of landfilling of all glass waste differed in the eight states and territories. The highest rank of glass waste landfilling is attributed to the NT (60.3 per cent), WA (58.3 per cent) and Qld (55.5 per cent). In the C&D sector, only NSW registered recycling activities for C&D-based glass waste (Table 84). In NSW, a report received by the local EPA in 2017 revealed that, due to the lack of a viable market for recycled glass plus increasing freight costs, landfilling has become an attractive option for many regional/rural areas.

9.9 Glass waste market

The glass waste market is currently not as efficient as it could be due to the several reasons reviewed below. An economic analysis of using recycled glass, with all the issues attached to it including contamination and the undesirable marketability of recycled glass, reveals that, at the moment, there is not an economic incentive for recyclers as well as manufacturers. The main reason is the low-cost overseas outsourcing of glass materials. However, with promising results from new initiatives across Australia, it is likely that current trends in the market will change for the better.

Estimations made in 2011[405] in Sydney indicated that if the concrete industry was to use the crushed glass fines, it would avoid using 75 kt of natural sand at $30 per tonne. This would generate a saving to the industry of $2.25 million. Such is a solution that not only provides economic benefits, but also contributes to protecting the environment through reduced sand excavation activities. Research in the UK[Error! Bookmark not defined.] demonstrated that the value of the cullet paid by the float manufacturers indicates sufficient incentive to transport and deconstruct the materials in this way, using unskilled staff in the breakdown operations. In WA, a recent field trial on a 250 m road (Wanneroo Road / Flynn Drive realignment) with the usage of crushed glass waste[407] provided some insight into the economy of glass waste management. According to the work's contractor, the crushed glass waste used was cheaper than limestone; it uses up to 10 per cent less water in order to achieve the same compaction levels as limestone. In Qld, it was reported that 80 per cent of recyclables, including glass waste fines, is sent to local processors, and glass fines are used in Brisbane's asphalt production[49]. In NSW, in an insulation manufacturing company, up to 70 per cent of the ingredient can be recycled glass using post-consumer waste glass. This material is less expensive than virgin glass material and has the added benefit of reducing the energy process for manufacturing glass wool insulation[408].

9.9.1 Existing and future markets for glass waste

The *Handbook of Alternative Uses for Recycled Glass* divided the recycled glass market into two sections: established alternative markets and promising markets for which glass has yet to be fully accepted, or that still requires additional study.[409] Under the established categories, the handbook outlined the following applications:

1. **Construction aggregates**
   A. Roadway construction
   B. Paving applications (glass in asphalt)
   C. Bedding and backfill (pipe/utility trenches, retaining walls, foundations, embankments)
   D. Drainage (French drains)
   E. Septic fields
   F. Landfill cover
   G. State specifications and guidelines
2. **Recycled aggregate in concrete**
   A. Cement/concrete applications
   B. Pavers, blocks, countertops, tiles etc. (a) 'glascrete', (b) binders, (c) fused and kiln-fired tiles
3. **Decorative landscaping aggregate**
   A. Decorative coloured-glass gravel (mulch, footpaths)
   B. Fountain and aquarium gravel
4. **Abrasives**
   A. Blast media
   B. 'Sand' paper
   C. Traction (non-skid surfaces)
   D. State specifications for abrasives
5. **Filtration media**
   A. Waste water and potable water treatment systems
   B. Pool filtration
   C. State specifications for filtration media.

Andela and Sorge (2005)[439] reviewed several research projects to identify the new markets for recycled glass. However, some of these applications, 15 years after the publication of this reference, are already operationalised on a wide scale. **Error! Not a valid bookmark self-reference.**shows 11 applications for recycled glass in the construction and other industries that were deemed new at the time including transport, medicine, landscape and horticulture.

[407] Bettini, L. 2019. Personal communications with WA's Main Roads.
[408] Edge Environment Pty Ltd. 2011. Construction and demolition waste guide - recycling and re-use across the supply chain.
[409] Andela, C. and E.V. Sorge. 2005. *Handbook of Alternative Uses for Recycled Glass*. https://wasteinitiatives.com.au/wp-content/uploads/2017/10/Glass-Uses-Handbook-Complete.pdf

Table 91. The future applications of recycled glass

No	Application	Description
1	**Fillers**	For glass to be employed as an industrial filler, it needs to be ground to a consistency of fine powder. At that point, it could be used to replace calcium carbonate in paints, as an additive to plastic lumber and in tyre production to replace a variety of clay fillers.
2	**Hydroponics**	In a study conducted by Clean Washington Centre (CWC)[410,411], researchers found no statistical difference between glass-grown basil and control-grown basil employing an expanded clay aggregate as the soil substrate.
3	**Soil amendment**	In another CWC study,[412] topsoil replacing 60% of the sand with glass cullet produced plants of equal or greater growth size compared with plants grown in a standard topsoil
4	**Foamed glass insulation**	An inorganic insulator that does not burn, it has a low heat conductivity, exceptionally high strength, and tends to be water-insoluble and corrosion resistant in most acids[413]
5	**Traction deicer**	Michigan Technology University has incorporated glass, limestone waste and food waste into a new product called Trac-Deicer;[414] the mixture of crushed glass and calcium magnesium citrate is proving as effective as salt for maintaining winter roads and appears to be much less corrosive on steel and road surfaces
6	**Glass cable**	Replacing steel with glass fibres may extend the life of a typical bridge from 50 years to 200 years; surprisingly, when woven, glass is stronger than steel[415]
7	**Frictionator**	Glass has been found to serve as a 'frictionator' for lighting and firing in the production of matches, matchbook striker surfaces and ammunition[416]
8	**Fluxing agent**	Glass as a brick fluxing agent reduces firing temperatures and firing time, leading to an increase in production capacity and reduced fuel consumption[417,418]
9	**Medical uses**	Micron-size ground glass serves as a fine abrasive in dentistry; radiation housed in micro-spheres of glass bead is also being used to fight inoperable liver cancer – the US Food and Drug Administration recently approved glass's use in this application[419]
10	**Insecticide**	Terrestrial insects breathe through a complex network of air tubes called trachea that open to the outside through a series of small, valved apertures (spiracles) along the sides of the body; operators of fine grind facilities note that insects are seldom seen nearby, suggesting that fine, micron-size glass dust particles may clog the spiracles and cause suffocation
11	**Adsorbent and cation exchange material**	Glass can substitute for zeolites (naturally occurring compounds used to separate molecules based on differences in size, shape and polarity) or in ion exchange systems like water softeners that swap softer alkaline metals for 'hard' calcium

Source: Andela and Sorge (2005)[Error! Bookmark not defined.]

9.9.2 Integrated supply chain and glass lifecycle model

In this section, three specific supply chain models for glass material are presented: WRAP's model, the Scottish supply chain network and Sustainability Victoria's supply chain. Furthermore, the model

[410] Clean Washington Center Report #GL 96-2, Testing the Use of Glass as a Hydroponic Rooting Medium.
[411] Hydroponics as a Hobby. http://www.ext.vt.edu
[412] Moller K. and Leger, S. 1998. Crushed Glass Cullet Replacement of Sand in Topsoil Mixes. CWC Report #GL97-10, 1998. http://www.cwc.org
[413] Foamed Glass http://www.permonline.ru
[414] Michigan Technology University, Researchers Seek Replacement of Road Salt, Technical Topics: 1997. https://bit.ly/3suWbnD
[415] Glass Bridges https://bit.ly/2REOpuH
[416] Secondary Uses of Cullet: Frictionator http://www.gpi.org/cullet.html
[417] Fluxing Agent, Universal Ground Cullet, (216), 267-8057 https://bit.ly/2Q9Eqxl
[418] Fluxing Agent, PA DOT: Recyclable Materials Supply & Demand Workpaper, Alternative Uses. http://www.dep.state.pa.us
[419] University of Missouri-Rolla, Research News, Delbert Day Elected into the National Academy of Engineering for Cancer Research, 2/12/2004. https://bit.ly/3viI9rl

for supply chain that is based on the opportunities for minimising glass waste landfilling in this study is also presented.

9.9.3 WRAP's supply chain model[420]

This model, which underpins the WRAP, a UK environmental agency, is based on the philosophy of circular economy. It is driven by two substreams of glass waste: mixed cullet and clear cullet. The model showcases how glass waste recovery can take place in collaboration with manufacturers, builders and waste recycling facilities (Figure 64).

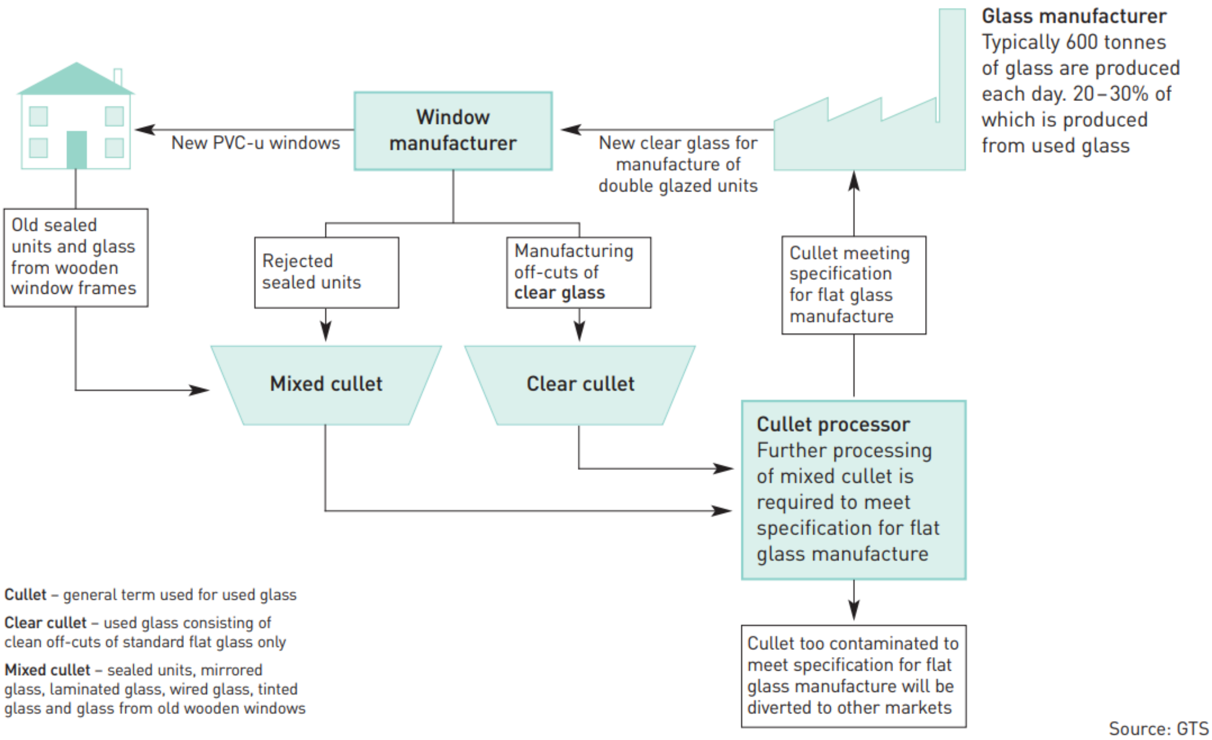

Figure 64. The flow of recovered flat glass for recycling
Source: GTS (2018)

9.9.4 The Scottish supply chain network

The growth of the construction glass recycling industry requires a new network to develop. In Scotland, such a supply chain network is already naturally growing, which could be duplicated in Australia to create a sustainable industry that can supply the demand of high-quality glass cullet to the glass float lines nationwide. A simplified model (Figure 65) of this Scottish network is suitable for universal adoption but based on local coordination. The developing network in the central belt of Scotland has a number of sites, which include building renovation and demolition projects from all sectors. Each of these include a design team, contractor and client. A small number of collectors are active who are willing to collect and transport the glass units to the order of 80 km to break down the glazing units, removing frames and spacer bars for financial benefit.

[420] WRAP. 2008.

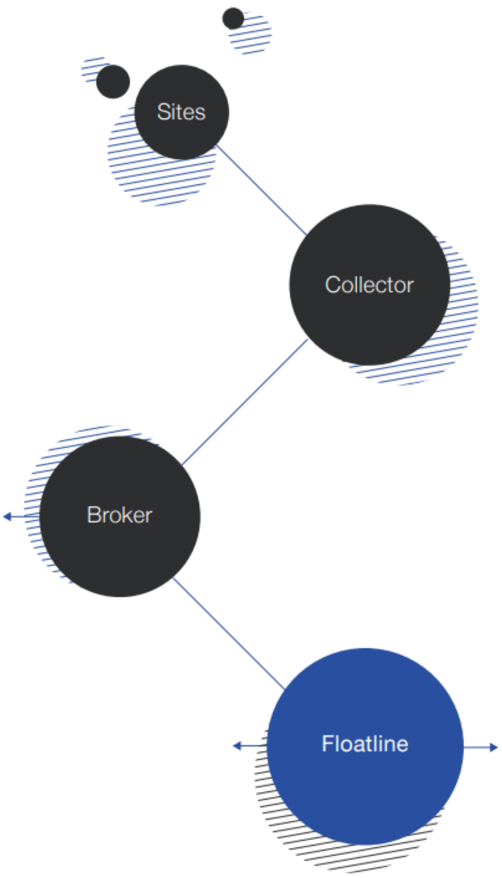

Figure 65. A simplified model of a new glass-recycling supply chain network
Source: DeBrinca and Babic (2013)[Error! Bookmark not defined.]

A broker coordinates the cullet materials available from a number of small collectors; this broker has connections with the float glass manufacturers and the experience and business acumen to develop this relationship to gain the best financial rewards for larger quantities of high-quality cullet from a number of collectors. The broker can organise, arrange transportation and gain best economies by utilising backhaul opportunities from the float manufacturers' glass delivery logistical systems. In the observed model, the transportation distance between the collector and float glass plant is in the order of 322 km. The transportation distances between main populations and glass-manufacturing plants does not vary greatly across much of the developed world.

9.9.5 Sustainability Victoria's supply chain[421]

In Vic, the glass waste supply chain is shared among the three main waste streams. Glass collected for recycling primarily comes from food and drink bottles and jars and includes clear, green and amber glass (Figure 66). Glass not suitable for recycling includes cookware glass, light globes, drinking glasses and C&D glass. These types of glass have different melting points compared to food and drink bottles and jars. Plate or window glass may be reprocessed in Australia into insulation. However, this is not widespread and a large quantity goes to landfill. Plate glass can also be used as aggregate and for blast cleaning. Glass is typically sorted from mixed recycled waste at a MRF, and then further refined (beneficiated) to be suitable for reprocessing.

[421] Sustainability Victoria.2015.Fact Sheet: Market summary–recycled glass. https://bit.ly/3sFVKY0

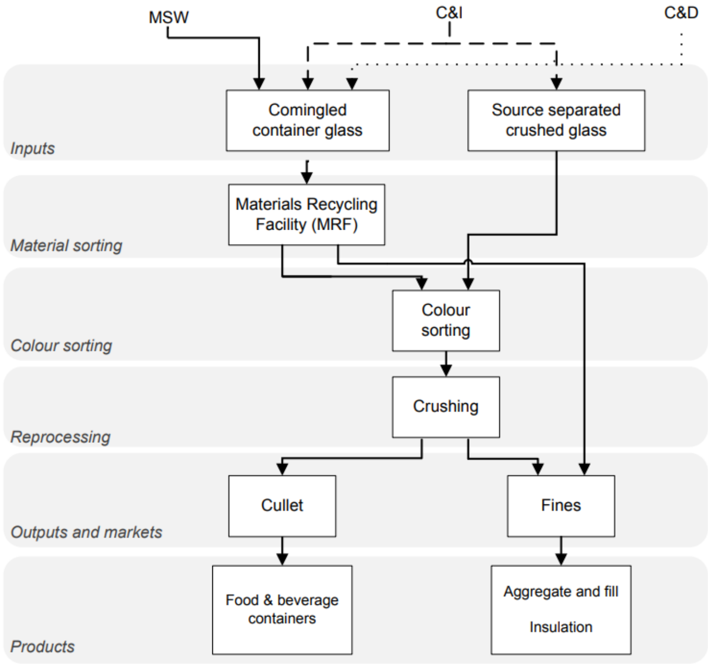

Figure 66. The flow of glass through the recycling chain
Source: Sustainability Victoria (2015)[421]

Some businesses use on-site bottle crushing equipment in the hospitality sector for onsite bottle crushing, which allows for reduced transportation volumes, improved occupational health and safety standards and higher recycling yields. These machines reduce amount to at least 80 per cent of the original bottle. However, the cullet is still suitable for beneficiation and provides a cleaner stream than MRF recovered glass due to less contamination. Glass bottles and jars are separated by colour either by hand or using automated sorting equipment. Glass can now be sorted down to 8 mm for use as cullet and fragments smaller than 8 mm are mixed together to produce glass fines for use in aggregate and abrasives. The colour-sorted glass is transferred to a beneficiation plant where contaminants are removed, and glass is crushed to produce cullet, which is sorted by size.

9.9.6 Glass LoWMor model

In this model, there are 11 points wherein glass waste can be efficiently managed. Figure 67 depicts these opportunities and the relationships among them.

Figure 67. The integrated supply chain lifecycle LowMor model for glass waste

9.9.7 Barriers towards the establishment of a market for glass waste-based materials

The barriers to the effective establishment of a market for glass waste are numerous. Table 92 presents the main barriers that are outlined by a few organisations.

Table 92. Main barriers to market development for C&D based glass waste.

Reference	Strategies to remove barriers to market development for glass waste
ACT NoWaste (2018)[422]	• Low-value economics of recycled glass compared to imported glass, combined with contamination issues and limitations on the market to absorb recycled glass
GHD (2008)[423]	• Limitations in glass crushing infrastructure, facilities infrastructure and facilities for glass fines
National Waste Policy (2014)[405]	• Reluctance by road engineers to move towards recycled glass as an alternative to virgin material in construing asphalt • Shortage of tradespeople who are able to work with the inconsistencies of reclaimed and recycled materials
Howling Pixel (2012)[424]	• A typical glass furnace holds hundreds of tonnes of molten glass, and so it is simply not practical to shut it down every night, or in fact in any period short of a month;

[422] ACT NoWaste. 2018. Waste Feasibility Study Roadmap and Recommendations. Discussion Paper. https://bit.ly/3dzCF58
[423] GHD. 2008. Packaging Stewardship Forum, Australian Food and Grocery Council. The use of Crushed Glass as both an Aggregate Substitute in Road Base and in Asphalt in Australia Business Case.
[424] Howling Pixel.2012. Glass production. https://howlingpixel.com/i-en/Glass_production

	factories, therefore, run 24 hours a day, 7 days a week – this means there is little opportunity to either increase or decrease production rates by more than a few per cent • New furnaces and forming machines cost tens of millions of dollars and require at least 18 months of planning; given this fact, and the fact that there are usually more products than machine lines, products are sold from stock • The marketing/production challenge is, therefore, to predict demand both in the short 4- to 12-week term and over the 24- to 48-month long term • Despite its positioning as a mature market product, glass does enjoy a high level of consumer acceptance and is perceived as a 'premium' quality packaging format
Sustainability Victoria (2015)[421]	• Markets for glass fines are likely to be characterised by a pattern of inconsistent demand (i.e. transactions will be large but irregular, often as a result of large civil infrastructure projects) • Increasing the production of cullet from glass waste will reduce the availability of glass fines • Although cullet has higher value than fines, its recovery is likely to be more costly (as the cost of sorting technology, for example, must be considered) • Glass available for recycling currently exceeds the processing capacity of the recycling industry; however, capacity constraints in Vic cannot be alleviated by exporting glass for reprocessing, as stakeholders note that the cost of transport will make reprocessing uneconomical • The recycled glass market is typically very strong; however, the volume of reprocessing activity remains sensitive to price – when prices are low, it is common for materials to be stockpiled

9.9.8 Strategies towards the establishment of a market for glass waste-based materials

Together with the responses to the barriers identified in Table 92, a number of strategies that can facilitate the establishment of a sustainable market for glass waste-based materials are presented in Table 93.

Table 93. Strategies to boost the market for C&D waste-bassed glass materials

Reference	Strategies to remove barriers to market development for glass waste
ACT NoWaste[425]	• Establish government buy-back schemes for recycled products through procurement commitments, including road bases from crushing of inert waste and glass fines
National Waste Policy (2014)[405]	• Use the potential of industry associations such as the Institute of Public Works Engineering Australasia to create a course to educate road engineers as well as tradespeople in how to use alternative materials in construction projects
Sustainability Victoria (2015)[39]	• To ensure continued access to high-quality glass cullet feedstock, stakeholders need to shift towards medium- to long-term contracts for supply in order to hedge against price volatility • The concentration and size of these contracts mean that processor capacity must be adequate to meet both current and future demand
ARUP (2013)[Error! Bookmark not defined.]	• As the window frames and glass units need to be removed more carefully than during demolition, they are more likely to be stored separately, which makes it easier to collect the glass without contaminating it at source – a crucial enabler for recycling • Opportunity and value is increased due to the viability of recycling the uPVC frames and other elements such as aluminium spacer bars from the window units; these replacement works are likely to be undertaken by a specialist window supply and installation company, often directly appointed by the building/homeowners or, for public housing, local authorities • We have observed in our research a number of window companies actively seeking to improve their recycling process through their own initiatives – this is encouraging and should continue to be promoted; these companies utilise this process as part of their social corporate responsibility and promote their business activities as 'green' or 'sustainable' to potential customers • A key driver for this move is growing consumer awareness and desire to buy green products and that such activity may win more work; education of the public to grow awareness of the issues and accessibility to these companies will continue to promote these opportunities • For public and social housing, legislation should be established that requires the contracts for window replacement to include recycling of all removed materials in closed-loop

[425] ACT NoWaste. 2018. Waste Feasibility Study Roadmap and Recommendations. Discussion Paper. https://bit.ly/3dzB1k1

	schemes so that the large opportunities and quantities of potential materials are not overlooked in this sector; government buying standards could be more ambitious to encourage further uptake of recycled content entering the supply to glass manufacturers

9.10 Economics of glass waste recovery in Australia

According to Sustainability Victoria,[421] the average cost of collection, transport and recovery of C&I and MSW materials is in the region of $110 and $124 per tonne, respectively. The price paid to reprocessors ranges between $0 to $49 per tonne. The market value of recycled glass product is not clear, as there is limited information available. Estimates are in the range of $100 and $149 per tonne delivered, for glass cullet, and $0 to $49 per tonne delivered, for glass fines.

In the C&D waste sector, for either renovation or demolition activities, the glass is required to be deglazed from the framing system. Depending on the framing system employed, this may be undertaken onsite, such that only the glazing units are removed; for example, in the refurbishment of curtain wall systems. Alternatively, the frame and glazing is removed in one unit, which may be appropriate for a residential window, and deglazing undertaken at ground level or in a factory environment. The costs associated with these activities will be project-specific and need to be considered when specifying glass recycling on a project.[387] The demolition or façade contractors would provide a price for undertaking these works as part of a tender process. Table 94 shows the costs associated with C&D-based glass waste management and recovery.

Table 94. Cost estimation of C&D-based glass waste management and recovery

Company	Pricing mechanism	Waste fate
Bingo	• $600 including dropping, renting and picking up a skip bin with a capacity of 6 t of glass waste in Vic • $150/t to accept the waste at the facility	The acceptable waste is recycled and the rest is sent to landfill

9.11 Relevant industry associations

In this section, the relevant industry associations that specifically work towards better management of glass and the waste associated with glass waste are identified. These associations are to collaborate with the public sector towards recognising opportunities for further reducing, reusing and recycling glass waste in Australia. Table 95 summarises the main industry associations with a focus on glass waste in Australia.

Table 95. Industry associations relevant to the management of glass waste

Associations	Vision	Website
The Australian Glass and Window Association (AGWA)	The AGWA is the peak association representing more than 1,000 member companies, covering window manufacturers, glass manufacturers, glass processors, merchants, glaziers and suppliers of supporting machinery, services and materials; the association endorses compliant, sustainable and fit-for-purpose products and provides services to members who support their efforts to operate successfully	https://www.agwa.com.au/
The Australian Glass & Glazing Association (AGGA)	The AGGA is a peak industry body that brings together more than 600 manufacturers, importers, processors, installers, glaziers and suppliers to the building and window industry, and promotes and encourages the trade and business interests of its members	https://www.agwa.com.au/
Auto Glass Association (AGA)	The AGA was formed in 2013 to give all sides of the automotive glass industry a unified voice, becoming a central conduit for communication, training and representation operating in the interest of the industry as a whole	https://www.autoglass.org.au/The-AGA

O-I Australia	O-I Australia has four manufacturing plants, located in Brisbane, Sydney, Melbourne and Adelaide; the company has a diverse product range, making glass packaging for Australia's world-renowned beverage and food brands	https://recycleglass.com.au/
The Institute of Public Works Engineering Australasia (IPWEA)	The IPWEA is the peak association for the professionals who deliver public works and engineering services to communities in Australia and New Zealand; IPWEA provides services to its members and advocacy on their behalf	https://www.ipwea.org/about-ipwea/aboutipwea

9.12 Key stakeholders and their role in glass waste management

In this section, the role of the key stakeholders in effective market development for glass waste is provided (Table 96). The role of the stakeholders is reviewed in 11 stages with the view to reduce, recover, and divert waste from landfill.

Table 96. Role of various stakeholders in the reduction of glass waste

No.	Stage	Stakeholder(s)	Contributions
1	Design	Designers, construction firms, clients	• Design a new building to facilitate its re-use in the future • Consider building standardisation to improve buildability and reduce the number of offcuts
2	Manufacturer	Manufacturers, recyclers, suppliers	• Develop an agreement where a contractor sells back the recycled waste from the original material supplier • Participate in the EPR and PS schemes
3	Procurement and contract	Construction firms, quantity surveyors, government	• Construction firms should order glass products more accurately using the best take-off practice • Use other materials in substitution of glass
4	Transportation & delivery	Construction firms, transporters, recycling companies	• Just-in-time delivery of materials to construction to avoid damage taking place due to insufficient space for proper storage and adverse weather conditions • Do due diligence and exercise standard work practices
5	Construction	Construction firms, subcontractors, waste collectors, recyclers, universities and research centres	• Research and develop specifications for further testing to increase acceptance of the crushed glass product • Remove window frames and glass units separately and more carefully to avoid contamination in renovation projects to encourage recycling
6	Demolition	Demolition contractors, waste collectors, recyclers	• Consider selective deconstruction to maximise the re-use potential of its components
7	Reusing	Construction firms, state and territory governments, EPAs and other equivalent organisations, waste collectors	• Facilitate market development • Adjust specifications in favour of greater usage of glass waste-based materials in new construction projects
8	Recycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations, training courses provider	• Facilitate market development • Fund the development of waste recovery infrastructure • Adjust specifications in favour of greater usage of recycled glass waste in new construction projects • The jurisdictional landfill levy regulations need to change in favour of glass recycling • Create a course to educate road engineers in how to use alternative materials in construction projects • Promote the usage of crushed glass in road projects such as asphalt and road base and sub-base • Improve the purity of cullet and prevent colour contamination to increase the value and recyclability of cullet
9	Upcycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Facilitate market development • Adjust specifications in favour of greater usage of glass waste-based materials in new construction projects • Fund the development of waste recovery infrastructure
10	Stopping illegal dumping and stockpiling	State and territory governments, EPAs and other equivalent organisations	• Reinforce activities that stop illegal dumping and stockpiling • Set stricter regulations with a higher rate of penalty fees to discourage illegal dumping and stockpiling • Strengthen controls over licensed landfill sites
11	Landfill	State and territory governments, EPAs and other equivalent organisations	• Design appropriate landfill levy schemes to discourage glass-waste landfilling

9.13 Recommendations

Following are the recommendations to maximise the opportunities for reducing glass waste in various stages of C&D activities.

1. Promote the use of glass aggregate in asphalt.
2. Change jurisdictional landfill levy regulations in favour of glass recycling.
3. Design a partial levy exemption for residual waste in the recycling industry.
4. Conduct more research projects to establish new applications for glass waste such as use in the landscape industry.
5. Grow consumer awareness and desire to buy ‘green” products—such activity may win more work.
6. Establish legislation for public and social housing that requires the contracts for window replacement to include recycling of all removed materials in closed-loop schemes so that the significant opportunities and quantities of potential materials are not overlooked in this sector.
7. Improve the purity of cullet and prevent colour contamination to increase the value and recyclability of cullet.

10. Timber- Resource Circular Economy: Opportunities to Reduce Waste Across the Supply Chain

10.1 Introduction

Due to its flexibility, durability and appealing visual attraction, timber has multiple applications in the construction industry. The main areas of applications include structural, exterior and interior. Timber is used extensively to construct single-unit housing and multi-unit apartments and renovation projects. The definition of timber (wood) waste in the Australian context presents challenges, as it does not reflect the total timber waste and varies in different regulations and policies.[426] Timber waste from C&D activities is generated in large quantities all over the world. The main timber waste includes untreated timber, preservative-treated timber, engineered wood products, coated or painted timber, timber packaging, sawdust and offcuts.

10.2 Application of timber in the construction industry

Trees and their derivative products have been used by societies around the world for thousands of years for their versatility, strength and natural beauty. While there are limitless possible designs, and construction is based in both engineering and cultural practice, timber has a high strength-to-weight ratio and is used most efficiently in structures where it is carrying a lot of its own weight. Table 97 lists and describes timber applications in the construction (highly relevant) industry.

Table 97. Various applications of timber in the construction (highly relevant) industry

Application	Description
Architectural roof trusses	A truss is a structure comprising one or more triangular units. Each triangle is constructed with straight and usually slender members of timber, connected at the ends by joints. The benefits of timber trusses are notable and numerous. Timber roof trusses are an ecologically sound choice compared to conventionally pitched roofs, they use smaller dimension timbers that span greater distances and this, in turn, reduces the total timber volume contained within. There are two forms of trusses within a building: nail plated and architectural trusses. Nail-plated trusses are trusses hidden from view that use nail plates as connectors. Architectural trusses refer to those attractively detailed timber trusses, exposed to view. Architectural timber trusses are lightweight, enabling speedy and efficient construction and installation that results in a visual feature to be enjoyed for decades.
Cladding, external	No other cladding material can offer the design freedom, ease of handling, range and natural beauty of timber. Timber cladding can create a building to suit almost any environment, taste or style. Timber cladding has an inbuilt flexibility that provides natural advantages on sites subject to high winds, extreme climate, highly reactive soils, subsidence or earth tremors. And unlike masonry and other rigid materials, the natural resilience and high strength-to-weight ratio of timber enable it to withstand far greater stresses and movement. Modern finishes give a long-lasting and attractive appearance to timber cladding and can be used to change the colour and style of the building, making it a versatile material that will keep pace with changing tastes and fashions.
Decking	Timber decks are a practical and attractive addition to any outdoor landscape. Natural timber decks blend seamlessly with their surrounding environment and will serve as popular entertaining areas all year long. As an external structure, carrying large loads of traffic, timber decking has high structural performance requirements. In addition, decks are usually raised clear off the ground and fully exposed to the weather, meaning an effective deck must be able to cope with wear and tear from repeated use and, in addition, discharge rainwater efficiently. Timber decking is available in both seasoned and unseasoned wood, in a wide range of species, sizes and grades.
Fencing	The inherent appeal and strength of timber make it the obvious choice for fencing. Timber fencing not only provides a natural look in keeping with the outdoor environment, but it also enables the construction of a long-lasting, durable property boundary. Fences come in many forms including the traditional paling, picket, post and railing styles. Most rely on a structural frame of posts embedded into the ground and two or more rails spanning between the posts. The ultimate selection of a suitable fence type or style is determined by application and aesthetics. A fence can serve a variety of purposes including the provision of security, privacy and safety, in addition to

[426] Taylor J. and M. Warnken. 2008. Wood recovery and recycling: A source book for Australia. Forest & Wood Products Australia: Knowledge for a sustainable Australia. Market Access & Development: Project Number: PNA017-0708.

	defining property boundaries.
Flooring	Whether for structural or finished flooring applications, timber offers durability, versatility and adaptability. The warmth, strength and natural beauty of timber flooring have proved enduringly popular in a wide variety of interior settings. Timber flooring is a timeless product, offering warmth and natural beauty largely unmatched by other flooring options. It is typically supplied as either solid timber or laminated wood products, made from layers of bonded timber There is a wide variety of species to select flooring from, and the right species for a given application will be dependent on numerous factors.
Framing	Lightweight timber construction typically comprises framed and braced structures to which one or more types of cladding are applied. Framing configurations can range from the closely spaced light timbers commonly seen in stud-frame construction to large, more widely spaced timbers. A timber-framed building can be placed on a concrete slab or on posts/poles or bearers resting on piers/stumps supported on pad footings. Used in houses or multi-residential dwellings, lightweight timber construction offers the flexibility of a wide range of cost-effective design options. When the timber comes from sustainable sources, this construction method can be environmentally advantageous, as it combines timber's low-embodied energy with its capacity to store carbon.
Packaging	From pallets to customised packing solutions, timber is a highly flexible, efficient packaging material that delivers value, performance and environmental benefits. As packaging usually uses lower grades of timber, it also optimises log utilisation. Wood consistently delivers value across the supply chain.
Pergolas	Timber pergolas offer an attractive and economical way to create functional living and entertainment areas in the outdoors. Pergolas designed with care can maximise both winter sunshine and summer shade, ensuring outdoor living is enjoyed all year round. With its natural look, durability and versatility there are few other materials that can match the advantages of timber in pergola construction. A protective finishing coat will preserve the life of the pergola and a variety of paints and stains are available on the market to facilitate this.
Rails and balustrades, exterior	The versatility, strength and natural beauty of timber make it the ideal material choice for external handrails and balustrades. Usually built from treated softwood and durable hardwoods, these timbers can be turned to create a range of styles and designs, resulting in balusters that are as unique as they are individual. Painting, staining and oil-based finishes broadly cover the wide range of finishing options available, and with the appropriate care and attention a timber balustrade can last a lifetime.
Rails and balustrades, interior	When used internally, balustrades and handrails are typically finished with a clear lacquer to showcase the natural beauty of the timber,and with appropriate care and attention will last a lifetime.
Retaining walls (landscaping)	Timber is an excellent choice for retaining walls used in landscaping. Retaining wall systems include cantilevered round or sawn timber, mass-wall and crib-wall construction. Walls up to 1 m in height follow a basic design and can usually be constructed using standard proprietary wall systems. An engineer will be required to plan and design walls greater than 1 m, including the footings and drainage. Drainage for retaining walls is a critical factor in influencing the long-term stability of the wall and should thus form a significant part of the design and planning process. Regular care and maintenance of retaining walls is essential to ensure the long-term stability and safety of the structure.
Stairs, exterior	All exterior stairs serve a functional purpose, but the choice of timber in the application will turn a functional building element into an aesthetically pleasing feature. While the construction of stairs is demanding, the investment of time will be returned, with a well-constructed timber staircase typically lasting decades. Exterior stairs are usually built from treated softwood and durable hardwoods and typically finished with paint. The construction procedure described here applies to most general-type stairs of either conventional or contemporary construction. When it comes to stairs there is a multitude of variations available for application, depending on the structural requirements of the building.
Stairs, interior	Interior staircase work is considered a specialised area of carpentry and joinery, as its construction requires high levels of workmanship, detail and accuracy. Many interior stairs are built from quality joinery timber, cut and seasoned especially for staircases. Interior stairs differ considerably in design, from simple, straight flights, commonly used in domestic work, to more elaborate stairs, constructed purposely as stand-out features in public and commercial buildings.
Windows	With natural aesthetic appeal, versatility and sound structural performance, timber provides excellent window joinery design options. Whether stained to bring out natural tones or painted to complement particular décors, timber windows can be tailored to suit a huge variety of styles and can be installed into any type of building.

Shingles and shakes	A shingle, generated from a sawn piece of timber, is characterised by its relatively smooth face and back, while in contrast a shake, essentially a split piece of timber, is dominated by a strongly textured surface. Timber shingles and shakes are most commonly used on roofs as cladding. While they are typically applied in straight, single courses, this can be varied to achieve other, more decorative effects.
Doors	Whether manufactured from solid or engineered timber, there are many stylish and practical door options that won't compromise on strength and structural performance. A distinctive timber door can also create visual impact, adding value to any commercial or domestic building. Timber makes an attractive choice for door design and construction, offering a strength, flexibility and versatility that other materials find hard to match. Protected from moisture, a timber door will perform satisfactorily for the life of any building. With regular maintenance, carefully designed and finished timber doors can perform in the toughest external environment and, if required, can be refurbished or updated easily and effectively.
Panelling, interior	Internal panelling, also known as appearance boards and linings, is not just a practical means of covering one or more walls and ceilings in a building – its inclusion in a room's interior design can generate looks that are both dramatic and stylish. Internal panelling comes as either solid natural timber panelling or as sheets of engineered wood products that provide a durable and hardwearing surface for areas subject to high impact. As they typically function as appearance products, panelling generally has no structural requirements.
Structural insulated panel systems (SIPS)	SIPS are a modern alternative to traditional timber-framed construction and function as the structural element for walls, roofs and suspended floors. They consist of two outer layers of oriented strand board (OSB) sandwiched around an expanded polystyrene core. In the fabrication of OSB, 85-90% of the log can be used. Compared with conventional milling, where the recovery is typically 50-70%, the board makes use of timber that would be otherwise discarded.
Portal frames	For buildings that require large spans and column-free interiors, timber portal frames provide one of the more aesthetically pleasing solutions. Utilising modern engineering technology, portal frame design transforms timber into a highly effective, efficient and economical structural product. Timber portal frames offer a strong, sound and superior structure. Structural action is achieved through rigid connections between column and rafter at the knees, and between the individual rafter members at the ridge. These rigid joints are generally constructed using nailed plywood gussets and, on occasion, with steel gussets.
Shear walls	Lateral loads such as wind or earthquake on framed timber buildings – either post and beam or stud and joist – need to be resisted and shear walls and diaphragms offer an effective and economical solution. Framed timber buildings, of post and beam or stud and joist construction, resist lateral loads (wind, earthquake or impact) by using rigid frames (portals), braced frames (trusses and cross-bracing) or structural sheathing elements (diaphragms).
Structural timber poles	Timber poles are utilised in structural construction to provide support for gravity loads and resistance against lateral forces. Not only serving a structural function, timber poles also provide many aesthetic benefits, with their use in construction often complementing architectural designs aimed at harmonisation with the natural environment.
Temporary structures	Wood has an important role in providing temporary structural support during the building process. Common wooden temporary structures include formwork and scaffolding.

Source: www.woodsolutions.com.au

Figure 68 shows 22 different applications of timber in the construction industry in Australia that are listed in Table 97.

Figure 68. Applications of timber in the construction industry

10.3 Timber industry overview

Generally, two major industries operate in the field of timber production and supply. These include the commercial forestry industry and the wholesale timber industry. Also, other industries directly contribute to supply, demand and wastage of timber products namely log sawmilling, hardware and building supplies retailing, construction and hardware wholesaling, structural wooden component manufacturing, wooden furniture and upholstered seat manufacturing, timber resawing and dressing, pallets and other wood product manufacturing. The following section provides information on the current status of these two industries in Australia. The major sources from which this information was extracted are the Australian Bureau of Agricultural and Resource Economics and IBISWorld 2019.

10.3.1 Commercial forestry industry

The forestry industry is the main source of domestic production of timber material. The total log harvest in 2017-18 was 32.9 million m^3 (Figure 69), a 1 per cent decrease from the record high 2016-17 log harvest of 33.2 million m^3 and 44 per cent higher compared with 2012-13. In 2017-18, the gross value of log production reached a record high of $2.7 billion (mill door prices); from 2016-17 this was a 4 per cent increase.[427] The majority of the annual total log harvest stems from commercial plantations. The remainder is sourced from native production forests. In 2017-18, commercial plantations accounted for 87 per cent of Australia's total log harvest by volume and native production forests contributed 13 per cent.

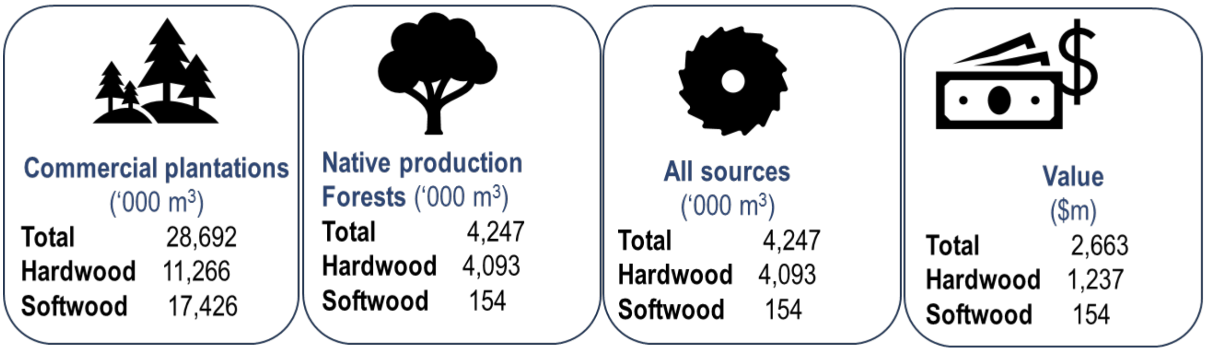

Figure 69. The indication of local timber production in Australia based on log harvested between 2017-18
Source: Australian Bureau of Agricultural and Resource Economics, 2019.

In contrast with the modest growth in the native production forest hardwood log harvest since 2012-13, the hardwood plantation log harvest more than doubled over the past five years to 11.3 million m^3 in 2017-18, down 1 per cent from the previous year (Figure 70). The pulp log harvest decreased to 10.5 million m^3 (down 4 per cent from 2016-17) and the sawlog harvest increased to 810,000 m^3 (up 69 per cent from 2016-17). In 2017-18, pulp logs harvested mainly for woodchip exports represented 93 per cent of all hardwood logs harvested from commercial plantations. Sawlogs, veneer logs and other log products made up the remaining 7 per cent. Plantation hardwood logs represented 73 per cent of total hardwood logs harvested in Australia in 2017-18. In 2017-18, the total value of plantation hardwood logs increased to a record $851 million (mill door price), up 6 per cent from the previous year.

[427]Australian forest and wood products statistics: Industry performance.2018 Australian Bureau of Agricultural and Resource Economics, 2018. https://bit.ly/3uYS1WO

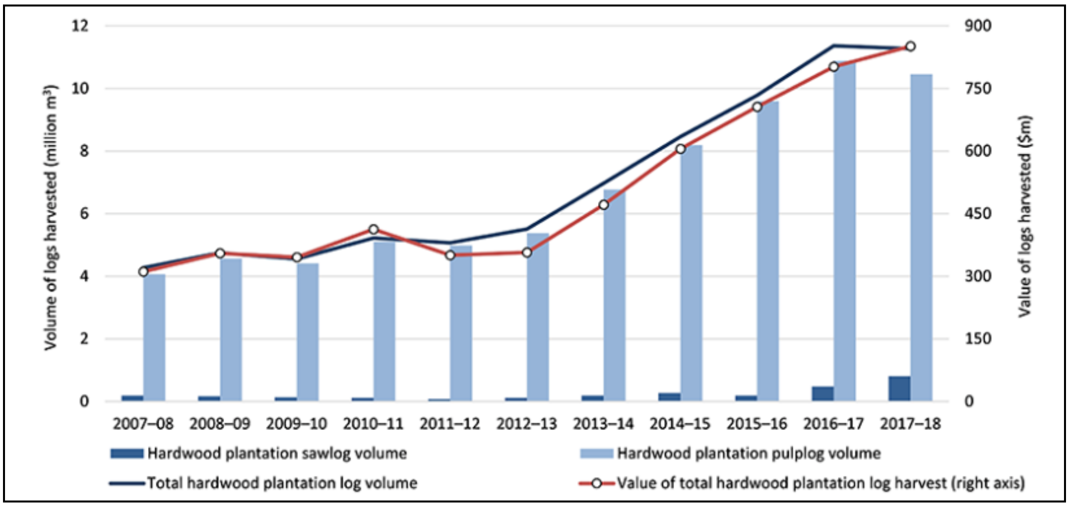

Figure 70. Volume and value of logs harvested from commercial hardwood plantation
Source: Australian Bureau of Agricultural and Resource Economics, 2019.

The total volume of softwood plantation logs harvested annually in Australia – comprising sawlogs, pulp logs and other log products – has fluctuated over the past decade, largely in response to changes in housing construction. Since 2012-13 the annual harvest volume of softwood plantations has been increasing, but at an average slower rate than the plantation hardwood log harvest (**Error! Reference source not found.**10.4). In 2017-18, the total volume of softwood plantation logs harvested was 17.4 million m^3, down 0.6 per cent from the previous year. The softwood plantation sawlog harvest decreased in 2017-18 to 10.7 million m^3 (down 0.1 per cent from 2016–-17) and the softwood plantation pulp log harvest decreased to 6.3 million m^3 (down 3 per cent from 2016-17). The majority of softwood logs harvested from commercial plantations in 2017-18 were sawlogs and veneer logs (61 per cent). Softwood plantation pulp logs – used for woodchip exports and domestic paper, paperboard and panel production – comprised 36 per cent of the total plantation softwood log harvest. Other log products, including round wood, posts and poles, made up the remainder. In 2017-18, the total value of plantation softwood logs increased to a record $1.4 billion (mill door price), up 4 per cent from the previous year (Figure 71).

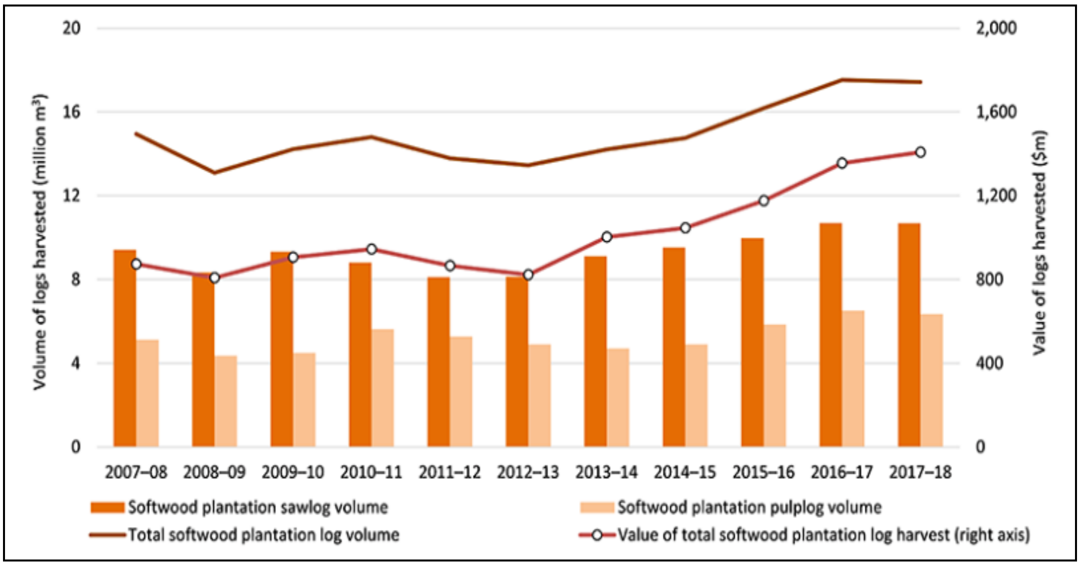

Figure 71. Volume and value of logs harvested from commercial softwood plantation
Source: Australian Bureau of Agricultural and Resource Economics, 2019

The annual wood production in Australia yields 32,940 m^3 of hardwood (native and plantation) and softwood logs. Victoria (29.8 per cent), NSW (20.5 per cent) and Tas (19.2 per cent) are the largest producers of wood log in Australia. The individual figures of the volume of the logs harvested for various Australian states are presented in Figure 72.

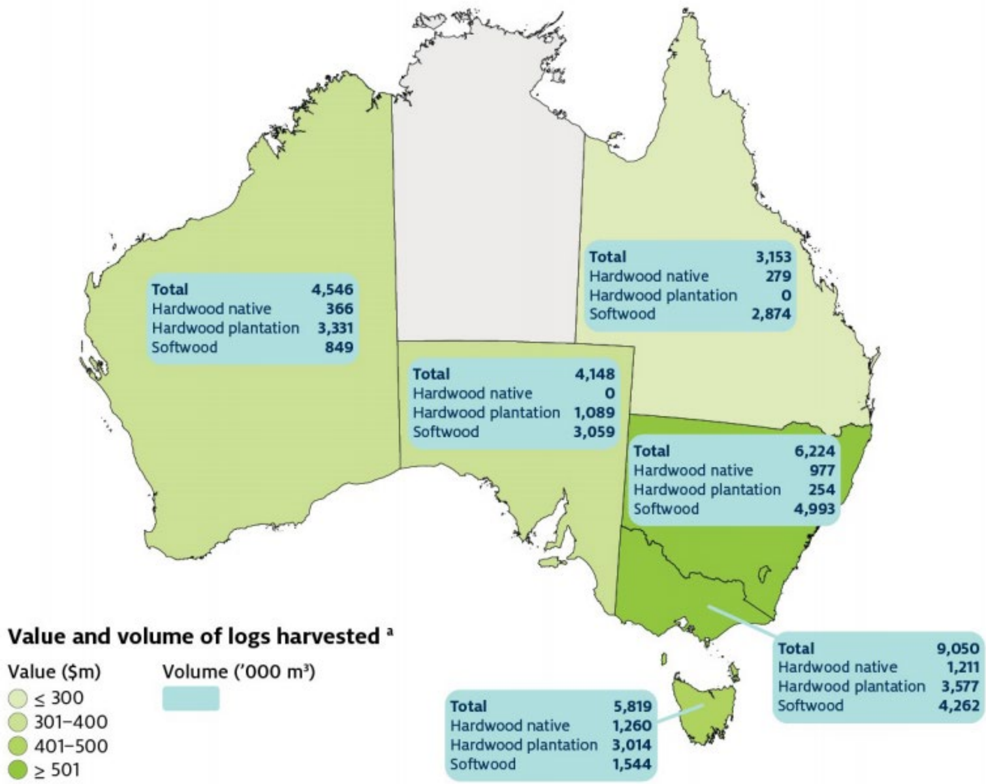

Figure 72. Some statistics on logs harvested in Australia.
Source: Australian Bureau of Agricultural and Resource Economics, 2019

10.3.2 Timber wholesale industry

Industry operators wholesale sawn timber and other wood products to retailers such as hardware stores, commercial and residential construction companies, carpenters and furniture manufacturers. The industry revenue is $4.4 billion, with $178.8 million profit.[428] Operators in the timber wholesaling industry (TWI) have experienced difficult trading conditions over the past five years. Timber wholesalers have lost market share to alternative building materials such as steel. However, the TWI is forecast to moderately grow over the next five years (2019–2024), supported by positive demand conditions from residential building construction and improved demand from structural wood component manufacturers. The key drivers and major demand and supply industries for TWI are tabulated in Table 98.

Table 98. Key drivers and the major industries dealing with timber wholesaling (demand and supply)

Key economic drivers	Demand industries	Supply industries
Demand from residential building construction	Structural wood component manufacturing	Fabricated wood manufacturing
Demand from non-residential building construction	Wooden furniture and upholstered seat manufacturing	Log sawmilling
Demand from structural wood component manufacturing	Construction	Pallets and other wood product manufacturing

[428] Youren, M. (IBISWorld) 2019. Far from the tree: Increasing wholesale bypass trends have contributed to revenue declines. IBISWorld Industry Report F3331: Timber Wholesaling in Australia. IBISWorld publications.

Demand from wooden furniture and upholstered seat manufacturing	Hardware and building supplies retailing	Timber re-sawing and dressing
		Structural wood component manufacturing

Source: IBISWorld 2019

Timber products in Australia are divided into four main categories (Figure 72): carpentry and joinery timbers (46 per cent), hardwood and particle board timbers (28 per cent), plywood and veneer timbers (15 per cent) and other timber products (11 per cent).

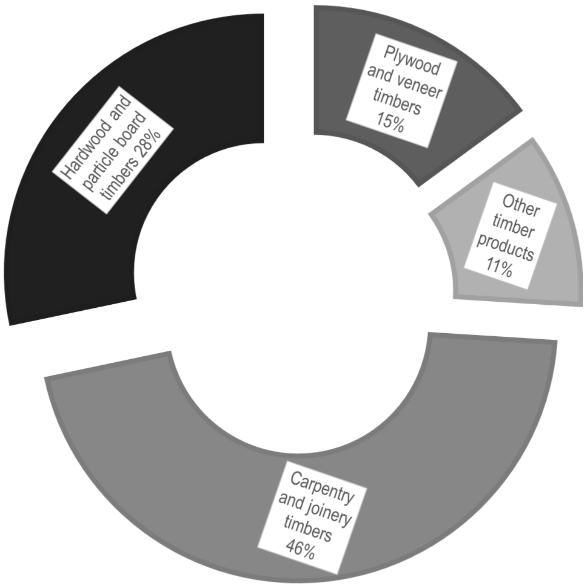

Figure 73. The major timber products in Australia in 2019.
Source: IBISWorld 2019

According to IBISWorld 2019, the annual Australian domestic price of timber is forecast to decrease by 0.3 per cent in 2019–2020, to 143.8 index points. Decreased demand from construction in previous years, in combination with greater timber stockpiles due to reduced construction activities, is likely to exert downward pressure on the price index. However, the price decline may be limited by greater demand from structural wood component manufacturers. Figure 74 provides an insight into the fluctuations in and projections of the TWI's revenue from 2014 to 2021.

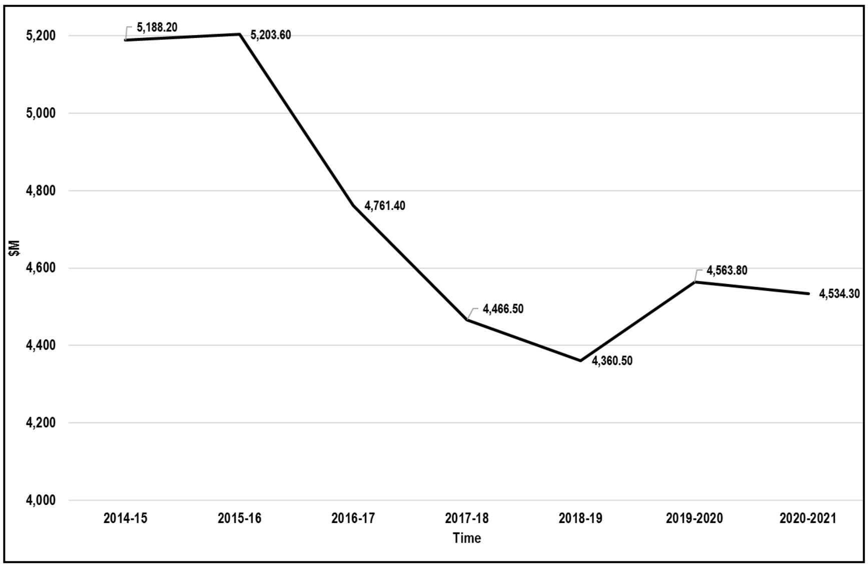

Figure 74. Statistics pertaining to the TWI (revenue) in Australia between 2014 and 2021.
Source: IBISWorld 2019

10.3.3 Major timber market shareholders in Australia

The TWI features a rather scattered market, with only two major shareholders that own only 22.1 per cent of the market. These major shareholders of timber wholesaling in Australia are Wesfarmers Limited/Bunnings (13.6 per cent) (https://www.wesfarmers.com.au/) and Metcash Limited/Home Timber & Hardware (8.5 per cent) (https://www.metcash.com/). The remaining 77.9 per cent market share belongs to many small- to medium-size industry operators that service narrow geographic markets. These operators work alongside a handful of medium- to large-scale, multi-establishment firms that supply timber products to clients across state and regional markets. Employment data in 2019 showed that 7, 476 people worked in the industry. Table 100 provides financial information for the major timber market shareholders in Australia.

Table 99. The financial profile of the major timber market shareholders in Australia.

Company name	Scope	No. of employees	Market cap
Westfarmers Limited/Bunnings	A trust that is ranked number 1506 out of the top 2000 companies in Australia. The company generates the majority of its income from the Property Operators in Australia industry	n/a	AUD $2.36 bn
Metcash Limited/Home Timber & Hardware	A public company that is ranked number 36 out of the top 2000 companies in Australia. The company generates the majority of its income from the Grocery, Liquor and Tobacco Product Wholesaling in Australia industry.	6,378	AUD $2.60 bn

Source: IBISWorld 2019

10.3.4 Demand determinants

The demand for timber product is largely dependent on market conditions in the building construction sector. Typically, increased activities in the building construction industry will increase the demand for industry products, as greater amounts of products, such as glue-laminated timber, are needed to fulfil the demands by this sector. Also, the demand for timber from the wooden furniture and upholstered seat manufacturing industry also determines industry demand.

10.3.5 Raw materials

In this section, the raw materials for timber production that are used in the construction industry are reviewed. In broad timber terms, there are two different categories of wood: softwood and hardwood. Timber is cut from logs into different shapes and sizes. Softwood is mainly used for structural purposes in housing construction such as wall and floor framing, lining boards, and roof trusses and cladding. In Australia, it accounts for the majority of total sawn wood production (85 per cent in 2017-18).[429] As a result, one of the key factors influencing sawn-wood consumption is domestic dwelling commencements. Hardwood-based timbers are heavy, strong and stable. They are generally used for their durability or appearance in flooring, piers, decking and joinery applications. Primarily, they are sourced largely from native production forests. In 2017-18, Australia produced 4.6 million m^3 of sawn wood, a two per cent decrease from 2016-17. Softwood sawn wood production in 2017-18 decreased to 3.9 million m^3 (down one per cent from the previous year) and hardwood sawn wood production decreased to 711,000 m^3 (down six per cent).[429] Following a set of preparatory and manufacturing work, the harvested timber from the forest is converted to marketable products. According to the timber product taxonomy, timber products are divided into three major categories (Figure 75) namely solid timber, composites and engineered timber products (ETPs).

[429] ABARES 2019, Australian forest and wood products statistics, September and December quarters 2018, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, June. CC BY 4.0. https://doi.org/10.25814/5cf8f713b3782.

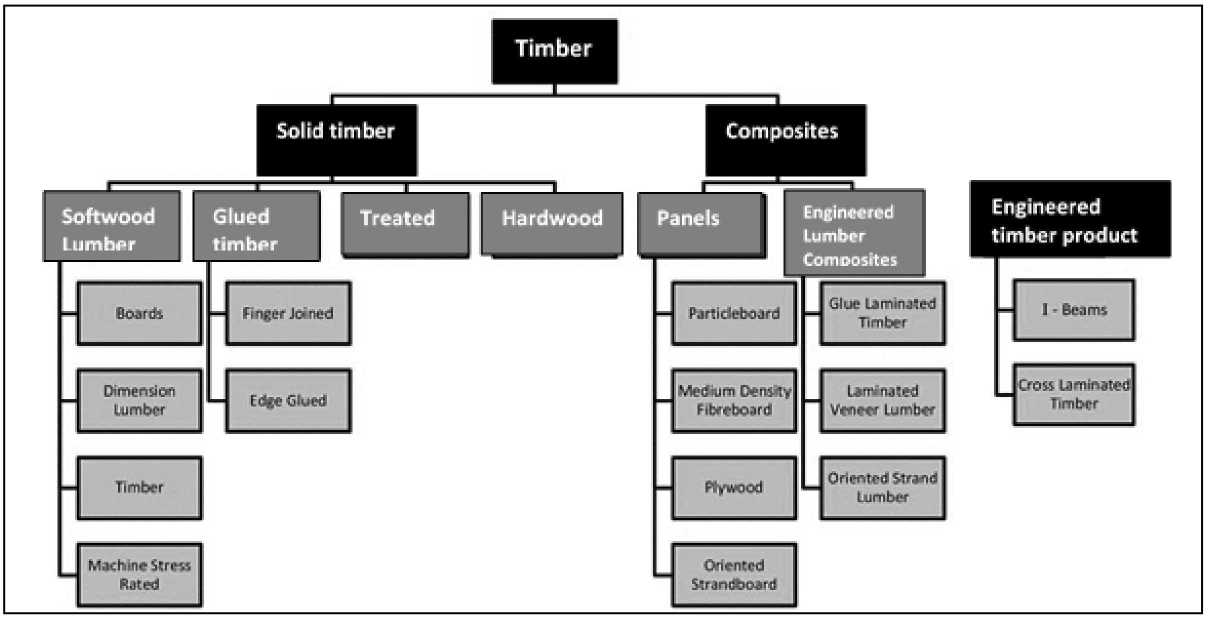

Figure 75. Timber product taxonomy.

ETPs are the products that are bonded together with adhesives, typically manufactured from wood fibre, particles, strands, flaks, veneers, solid timber sections or any combination of these. Figure 76 exhibits the most common ETPs produced and used in the construction industry.

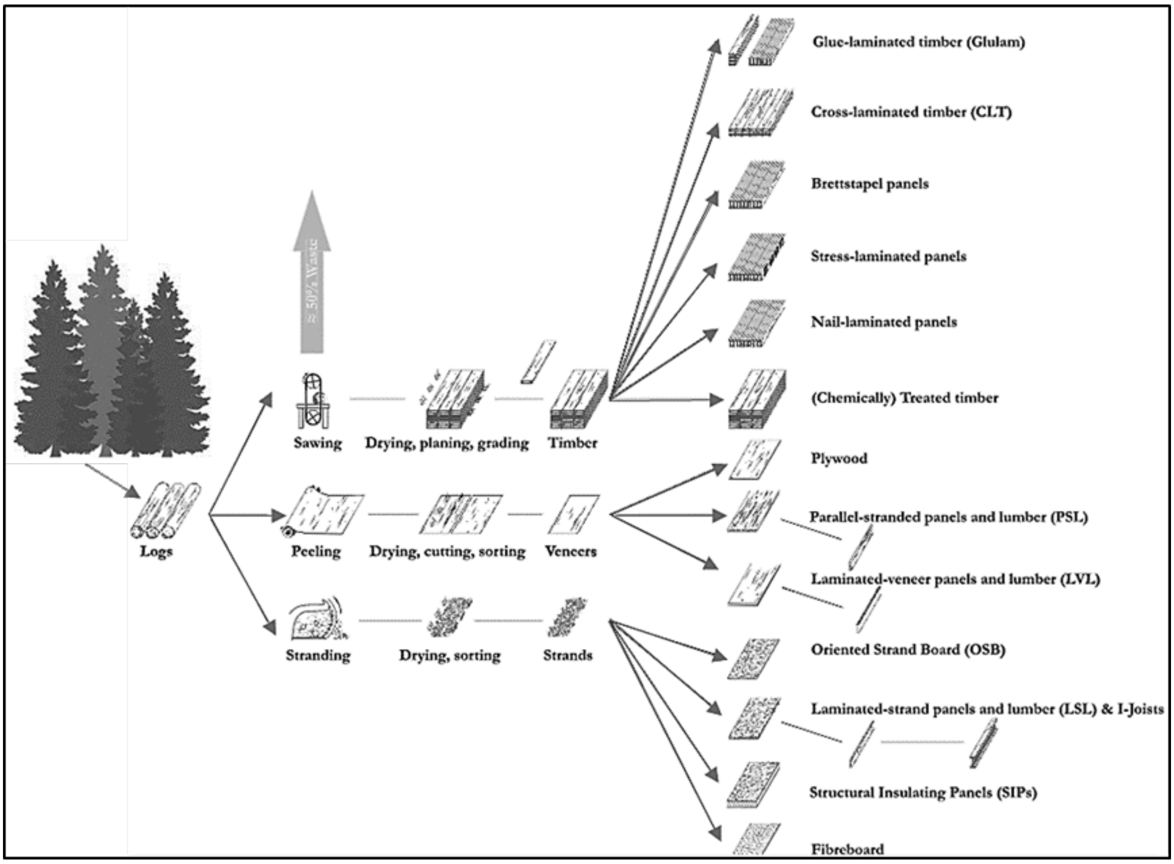

Figure 76. A schematic overview of ETPs.
Source: Ramage et al. (2017)

10.4 Manufacturing process

The typical timber manufacturing process involves five steps: log preparation, processing, log break down, green sawn and seasoning (Figure 77). The following is a brief description of timber manufacturing in the Australian context which is adapted from the guideline provided by WoodSolutions accessible through their official website at www.woodsolutions.com.au.

Figure 77. The five main phases of the timber manufacturing process.

10.4.1 Log preparation

The first step in the conversion of logs to wood is the preparation of the log. The branches and bark are removed from the tree trunks prior to any processing. Removing the bark leaves all the hardwood and most of the sapwood. This process now takes place in a matter of seconds on the forest floor with specialised machinery. Where the logs are to be used as poles or piles, some specifications may call for the removal of the sapwood. This can shape the log so that it is perfectly round, has 16 or more faces, or is true to the original shape of the tree.

10.4.2 Processing

Logs classified as ‘saw logs' are sent to a sawmill to be processed. Logs are stockpiled under water sprays to prevent them from splitting as they rapidly dry out. The logs are then sawn into rectangular shapes in the ‘green mill'. Here the logs are fully saturated, and the saws leave a rough surface on the wood, as some of the fibres are torn out rather than cut. If timber is to be seasoned, or dried, then this will take place next with the removal of much of the moisture from inside the timber. Seasoned products are then machined to give smooth or shaped surfaces.

10.4.3 Log breakdown

Logs present handling difficulties due to their cylindrical shape, so the first steps in a normal saw mill operation involve cutting the logs to provide flat surfaces. There are many different cutting patterns used to produce timber – the most common cutting methods are splits and cants, as described below:

- Splits - the first saw cut is through the centre of the log to give two splits, each of which has a flat face for registering in further cutting operations.
- Cants - the first saw cuts go either side of the corewood in the very centre of the log. The pieces that are left on the outside are called wings, and the almost-rectangular piece from the centre is called a centre cant.

10.4.4 Green sawn

Once the breakdown saw has established some flat surfaces, the other saws in the green mill can cut the various pieces into marketable timber. Each mill establishes its own cutting patterns for different sized logs, in an attempt to maximise the number of pieces cut in the most popular sizes.

10.4.5 Timber seasoning

Timber seasoning is done in two common ways: kilin drying timber and air drying. These two methods are described below:

I. Kiln drying timber

The most common commercial process for seasoning of timber is kiln-drying. Kiln seasoning accelerates the process of seasoning by using external energy to drive the moisture out. The timber is stacked in much the same way as it is for air drying and is placed inside a chamber in which the conditions can be varied to give the best seasoning results. Air is circulated around the charge (stacked timber) and the temperature and humidity can be varied to give optimum drying. Each species has different cell characteristics and therefore requires different drying schedules. Typically, the timber may be in the kiln for a period of between two days to one week. Generally, it is not feasible to kiln-dry structural timber in thicknesses greater than 45 mm, although there are limited amounts of 70 mm thick kiln-dried softwood members in the marketplace. All untreated structural pine and some commercial hardwoods are seasoned, mostly using kilns that are often heated by sawmill by-products or gas. Kiln-seasoning of softwoods such as pine can be done fairly quickly, however, seasoning of hardwoods tends to be a much longer process, due to the different cell structure of hardwoods.

II. Air drying

he traditional method of seasoning timber was to stack it in air and let the heat of the atmosphere and the natural air movement around the stacked timber remove the moisture. The process has undergone a number of refinements over the years which have made it more efficient and reduced the quantity of wood that was damaged by drying too quickly near the ends. The basic principle is to stack the timber so that plenty of air can circulate around each piece. The timber is stacked with wide spaces between each piece horizontally, and with strips of wood between each layer ensuring that there is a vertical separation too. Air can then circulate around and through the stack, to slowly remove moisture. In some cases, weights can be placed on top of the stacks to prevent warping of the timber as it dries.

Moisture loss from the side of the wood is at about the correct rate so as not to cause the collapse of the cells, but near the ends of the wood, the moisture loss can prove to be too fast. Often the ends are wrapped or painted to slow the moisture loss from the end grain. While little additional energy needs to be supplied for this type of seasoning, the stacks of timber require a lot of land, represent a potential fire hazard, and the product is not able to be sold for a considerable time. Air-drying of timber is really more controlled facilitation of what happens to unseasoned sawn timber, once it is placed into its ‘work' environment. The amount of drying that can occur is decided by the relative humidity of the drying environment and will often vary within individual boards as well as within the stack itself. The time taken for air-drying is a function of the thickness of the timber. Air-drying is a slow process, particularly for hardwoods, particularly for hardwoods, typically taking six to nine months to reach a moisture content in the range 20 per cent to 25 per cent.

Sawing patterns

Each cutting pattern produces timber with a distinct appearance and character. Each type has its advantages and disadvantages. The following describes various types of sawing patterns.

I. Quartersawn timber

Also called quarter cutting, with quarter-sawn timber the growth rings are parallel to the short face. The long face of every board is close to a radial face. A large number of growth rings can be seen on this face. Quarter sawing timber is best for hardwood species that are prone to collapse during drying.

II. Back sawn timber

Also known as back cutting and tangential cutting, back sawing is the most common sawing method used in Australia. Back sawing helps to obtain high-grade timber from logs. Most structural timber and many appearance products are backsawn. With backsawn timber, the long face of each board is close to a tangential face, and the short face is close to a radial face. Growth rings are parallel to the long edge and the wide face does not intersect many growth rings. The growth rings on the wide face appear to be very wide apart, and some interesting patterns can be seen. This cut offers more flexibility in that quite large boards can be backsawn from the wings of logs. Here the maximum depth can be just less than the diameter of the log.

III. Radial sawn timber

This cut is not very common, and, if required, would need special negotiation with the mill. However, radial sawing has an efficiency that the other cuts cannot achieve and makes optimal use of a log. Because of the cutting pattern, each piece of radially sawn timber is a wedge shape. It has sapwood on the wider edge and pith or corewood at the point. As real logs are not perfectly round and not perfectly straight, each radially sawn board reflects the longitudinal shape of the log. These details can make for interesting architectural use of the timber. Apart from flooring, radial sawn timber is used mainly for external applications such as cladding, decking, poles, wedges and timber screens. Sawn timber will either be available as unseasoned or seasoned:

- **Unseasoned timber** is classified according to its moisture content. Any timber with a moisture content > 25 per cent is said to be unseasoned or green. However, for practical reasons, most timber sold as unseasoned has a moisture content > 15 per cent rather than the stricter definition of unseasoned timber (> 25 per cent).

- **Seasoned timber** production is the process of drying timber to remove the bound moisture contained in walls of the wood cells. Seasoning can be achieved in a number of ways, but the aim is to remove water at a uniform rate through the piece to prevent damage to the wood during drying (seasoning degrade). Seasoned timber has a moisture content between 10 per cent and 15 per cent. Timber in this condition will be in equilibrium with internal environments in many parts of Australia.

Seasoned timber has a reduced weight and improved strength, and the cross-sectional dimensions remain almost constant. It is more stable than unseasoned timber and is much less prone to warping and splitting. It also provides improved gluing and nail-holding properties and increased joint strength. In higher grades of timber, particularly hardwoods, the process of seasoning can enhance the basic characteristic properties of timber, increasing stiffness, bending strength and compression strength. Seasoned timber should be chosen for indoor use where it is particularly important not to have shrinkage associated with drying out in service.

10.5 Regulations, policies, and guidelines

There are several examples of the regulation of timber waste. For instance, the EU has several directives that directly impact timber waste disposal and recycling, including the Directive on Packaging and Packaging Waste,[430] with the aim of 50 per cent to 60 per cent recovery of packaging waste and 24 per cent to 45 per cent recycling. The UK has developed its own regulations based on this European directive, using two regulations: Producer Responsibility Obligations (packaging waste) Regulations 2007[431] and the Packaging (essential requirements) Regulations 1998.[432] The goal of these two regulations is 50 per cent recovery and recycling of packaging waste.

Germany has the most specific national legislation on timber waste management: Ordinance on the Management of Waste Wood 2003[433]. This ordinance classifies timber waste and specifies technologies for timber waste recycling or combustion. In the US, the federal government is responsible for overriding environmental legislation and regulation. Each state has an independent authority to develop environmental protection policies. This has led to inconsistencies in the way that timber waste is dealt with in the various US states.

In Australia, the regulation of wood wastes is independently legislated in each state by an EPA or equivalent. It is embedded within the legislation that covers the management of general waste. Timbers treated with hazardous preservatives are classified based on the level of protection required to ensure structural integrity. These standards are monitored by the state EPA, as chemicals used to preserve wood can have impacts on air, water and human health. The preservation industry is reviewed through the EPA's compliance audit program, whereby the EPA ensures preservers comply with environmental laws. Protection ranges from H1 to H6 – the lowest to the highest level of protection needed, respectively. H1 preservatives protect the timber from insects such as termites, and H6 protects the timber from marine borer attack and decay. Timbers treated with preservatives must also be stored in well-ventilated areas to prevent them from contaminating other products.

In the last decade, the timber industry in Australia has voluntarily formed a National Timber Product Stewardship Group (NTPSG) to address the environmental impacts arising from the disposal of timber products.[434] The NTPSG comprises timber companies and national associations from all parts of the timber supply chain together with importers, wholesalers and retailers of timber and wood products. The group has prepared a National Product Stewardship Strategy for post-consumer timber and wood products. The NSW's Department of Planning, Industry and Environment's protocol for infrastructure timber waste recycling provides useful information about safe and productive recycling of timber waste. Timber waste is one of the 16 materials that are in the scope of EPR that is NSW waste management policy.

10.6 Timber waste generation

10.6.1 Timber waste quantity

International reports indicate that timber waste comprises a significant portion of waste materials. However, the timber waste composition rate largely depends on the technology and style of

[430]European Environmetn Agency. 2019. Directive 94/62/EC on packaging and packaging waste. https://bit.ly/2QjJy1F
[431]UK Staturoy Instruments. The Producer Responsibility Obligations (Packaging Waste) Regulations 2007. https://bit.ly/3dxwqyQ
[432]UK Statutory Instruments. 1998 No. 1165. The Packaging (Essential Requirements) Regulations 1998. https://bit.ly/32toRmD
[433] Protection Federal Ministry of Justice and Consumer. Ordinance on the Management of Waste Wood 2003.
[434] NTPSG .2017. http://www.timberstewardship.org.au/

construction. For instance, in Finland, timber waste composes 36 per cent of C&D waste.[435] In Germany, 401 million tonnes of wastes were generated in 2015, of which waste wood accounts for 11.9 million tonnes.[436,437] These reports indicate that the C&D waste stream is accountable for 27 per cent of timber waste generated per year. The results of a report by the US Environmental Protection Agency indicated that timber waste accounted for 16 per cent and 42 per cent of non-residential buildings and residential buildings, respectively.[438].A Malaysian study[439] found that timber waste contributed to the largest percentage of construction waste, ranging from 35 per cent to 69.5 per cent in three separate projects.

In Australia, traditionally, the challenge with reporting timber waste data is mostly concerned with the separation of the waste source. However, during recent years data reporting systems have improved, and as a result more accurate data is available. In 2008, a report on timber waste showed that 1,781 kt of timber waste were generated annually.[440] In Vic, Sustainability Victoria reported that between 2013 and 2014 the quantity of waste timber collected from C&I (primarily from packaging- pallets) and C&D waste streams was 505 kt,[441] from which 165 kt was recovered and 340 kt sent to landfill sites. The results of a survey[442] that was conducted by Zero Waste SA in 2007 showed that C&D timber waste accounts for 21.03 per cent of the total timber waste received in seven landfills and transfer stations; the remainder (79 per cent) was contributed by the C&I waste stream. The latest data for timber waste was reported in 2018,[443] in a report prepared by Blue Environment Pty Ltd and Randell Environmental Consulting.

[435] Meinander, M, U. Mroueh , J. Bacher, J. Laine-Ylijoki, M. Wahlström, J. Jermakka, N. Teirasvuo & H. Kuosa. 2012. Directions of future developments in waste recycling. VTT TECHNOLOGY 60. https://bit.ly/3aqwRZW

[436] Sommerhuber PF, Welling J, Krause A .2015. Substitution potentials of recycled HDPE and wood particles from post-consumer packaging waste in wood-plastic composites. *Waste Management*. 46:76–85

[437] Garcia CA, Hora G .2017. State-of-the-art of waste wood supply chain in Germany and selected European countries. Waste Management 70:189-197.

[438] Ward, J., Mackes, K., Lynch, D., 2004. Wood Wastes and Residues Generated Along the Colorado Front Range as a Potential Fuel Source. Res. Pap. RMRS-RP-50. Fort Collins, Colorado. USDA Forest Service, Rocky Mountain Research Sta.

[439] Lau,H.H., Whyte, A., & Law, P.L. Composition and Characteristics of Construction Waste Generated by Residential Housing Project. *International Journal of Environmental Research*. 2(3): 261-268.

[440] Taylor J. and M. Warnken. 2008. Wood recovery and recycling: A source book for Australia. Forest & Wood Products Australia: Knowledge for a sustainable Australia. Market Access & Development: Project Number: PNA017-0708

[441] Sustainability Victoria. 2015. Factsheet: Market summary – recycled timber. Netbalance.pp.1-5.

[442] Waste Audit and Consultancy Services (Aust) Pty. Ltd. (2007) Disposal Based Survey, Zero Waste SA, Oct. Nov. 2007. 133.

[443]Department of Environment and Energy. 2018. P863 National waste data and reporting cycle 2017-19. https://bit.ly/3nbAWq8

Table 100. Timber waste data in various jurisdictions (2016-17)

	Waste generation (t)				Waste landfill (t)				Waste recycling (t)				Energy recovery (t)			
State	**MSW**	**C&I**	**C&D**	**Total**	**MSW**	**C&I**	**C&D**	**Total**	**MSW**	**C&I**	**C&D**	**Total**	**MSW**	**C&I**	**C&D**	**Total**
ACT	4,672	15,246	32,558	73,236	4,486	14,640	31,264	50,390	-	-	-	20,760	186	606	1,294	2,086
NSW	34,310	546,443	181,994	762,747	25,309	359,776	76,725	461,810	8,099	173,844	102,534	284,477	902	12,823	2,735	16,460
NT	1,237	5,111	7,422	13,771	1,215	5,020	7,290	13,525	-	-	-	-	22	91	132	246
Qld	18,457	200,078	92,255	413,549	18,085	180,201	90,394	288,680	-	-	-	102,758	372	19,877	1,861	22,111
SA	11,197	273,193	58,411	342,801	10,437	6,101	17,963	34,501	500	210,000	40,000	250,500	260	57,092	448	57,800
Tas	1,740	26,879	1,491	30,109	1,699	26,249	1,456	29,404	-	-	-	-	41	630	35	705
Vic	24,907	313,330	205,967	544,203	5,727	107,767	138,809	252,303	18,880	199,922	59,892	278,694	300	5,641	7,266	13,206
WA	12,879	144,512	31,873	189,264	10,646	94,407	20,776	125,829	2,029	48,296	10,699	61,024	204	1,809	398	2,411
Total	109,399	1,524,792	611,971	2,369,680	77,604	794,161	384,677	1,256,442	29,508	632,062	213,125	998,213	2,287	98,569	14,169	115,025

Table 100 summarises the waste data reports on national and jurisdictional timber waste in various waste streams in 2016-17. As can be seen in the table, Australia generated 2,369,680 t of timber waste in the year reported. The share of the C&D sector as the second-largest timber waste generator was almost 612 kt (25.8 per cent), preceding C&I with almost 1,524 kt (64.3 per cent). Among the jurisdictions, NSW, Vic and Qld had the largest amount of timber waste in total and in the C&D waste stream in 2016-17.

10.6.2 Types of timber waste

The amount of wood waste generated from C&D is influenced by the life span of the building materials. Solid hardwood can last up to 90 years, and softwood furniture and preservative-treated pine could last for 50 years, while plywood, particleboards and MDF for cabinetry only last for about 30 years[444]. Timber waste is defined in different ways by various national and jurisdictional policies and guidelines. In Europe, in the European Waste Catalogue (EWC) timber waste is classified under 170201 Code[445]. In Australia[446], timber waste is classified into three major categories: untreated timber (Type A), engineered timber products (Type B), and treated timber (Type C). The following describes these types of timber waste.

10.6.2.1 Untreated timber (Type A)

Untreated timber is a material that is not treated with a preservative, such as copper chrome arsenic (CCA). Common sources of untreated timber are furniture and framing for houses. This timber is generally of high quality. Timber log products are untreated timbers that are usually categorised as either 'softwood" or 'hardwood". The softwood is identified as timber that comes from coniferous (cone-bearing) trees (for example, pines or firs). Hardwood comes from trees with broad leaves that produce seeds in an enclosed case (for example, eucalypts, oak and walnut).

10.6.2.2 Engineered timber products (Type B)

Engineered wood products are manufactured in a variety of ways using wood (for example, veneers, flakes, chips and fibres) and resins (adhesives), which bond the pieces together to form a variety of products, including structural applications. Common engineered wood products include plywood, laminated veneer lumber (LVL), glued laminated lumber, particleboard and medium-density fibreboard (MDF). Finger-jointed timber is also a common engineered wood product, manufactured by gluing and joining small pieces of timber end to end to form a longer piece of timber.

10.6.2.3 Treated timber (Type C)

Treated timber is timber with timber preservatives, or coated or painted to improve the timber products' resistance to attack by biological agents such as fungi, insects and animals. In Australia, treated timber consists primarily of softwood treated with preservatives such as Copper Chromium Arsenic (CCA) (also known as Chromated Copper Arsenate), synthetic pyrethroids as Light Organic Solvent Preservative (LOSP) or creosote. Small volumes of hardwood timber are also preservative treated for various uses including marine pilings and poles. Timber painted with lead-based paint, although phased out in Australia in 1970, still appears in the waste stream. A large quantity of Australian softwood framing is now H2F treated against termites. Common timber preservatives are tabulated below (Table 101):

[444] Jaakko Poyry Consulting 1999, Usage and life cycle of wood products / Jaakko Poyry Consulting (Asia-Pacific), National Carbon Accounting System Technical Report: no. 8.', Australian Greenhouse Office, Canberra

[445] European Waste Catalogue and Hazardous Waste List. 2002. Ireland's Environmental Protection Agency http://www.nwcpo.ie/forms/EWC_code_book.pdf

[446] Taylor J. and M. Warnken. 2008. Wood recovery and recycling: A source book for Australia. Forest & Wood Products Australia: Knowledge for a sustainable Australia. Market Access & Development: Project Number: PNA017-0708

Table 101. The common preservatives applied to timber materials in Australia.

Type	Description
Copper Chromium Arsenic (CCA)	Compounds of copper, chromium and arsenic that are recognised by a characteristic green colour in the timber.
Other chemicals usually including creosote-in-oil, pigment-emulsified-creosote (PEC), double treatment (CCA followed by creosote), treatment with boron compounds and treatment with sodium fluoride.	Used only to produce timber for specific customer needs
Other water-based treatments such as alkaline copper quaternary (ACQ) and copper azole.	None
Supplementary treatments	Applied on-site to improve the timber products' resistance to attack by biological agents such as fungi, insects and animals.
Light Organic Solvent Preservative (LOSP)	Incorporating a synthetic pyrethroid is used to introduce pesticides into the timber, and usually associated with little or no colour change.

Source: Taylor and Warnken (2008).

10.7 Timber waste management

In Australia, the quantity of timber waste generated at the national level is significant and its recycling rate is low in comparison with other C&D wastes such as concrete and ferrous metal.[447] The following sections demonstrate the opportunities to minimise waste generation or reduce the waste volume going to landfill during various steps of the timber life cycle.

10.7.1 Waste during timber harvest

Generation of waste during the timber lifecycle begins with the log harvest from commercial or natural forests. There is evidence proving that this waste can be significant in large quantities. For instance, Dionco-Adetayo (2001) found that out of 1 m^3 of the trees removed from the forest, about 50 per cent goes to waste in the form of damaged residuals, followed by abandoned logs (3.75 per cent), stumps (10 per cent), tops and branches (33.75 per cent), and butt trimmings (2.5 per cent). The results of a survey[448] that was conducted by Zero Waste SA in 2007 showed that C&D timber waste accounts for 21.03 per cent of the total timber waste received in seven landfills and transfer stations; the remaining part (79 per cent) was contributed by the C&I waste stream.

10.7.2 Waste during manufacturing

During manufacturing timber, approximately 50 per cent is recovered as viable board and plank products,[449] with the remaining dust, shavings and fibre by-products typically used as biomass fuel or as fibre in engineered timber panel products. A study in Ghana[450] identified the major sources of timber waste including low-quality logs with large defects, bark, offcuts, sawdust, slabs and edged trimmings from sawn timber. However, there are new technologies for the utilisation of low-quality logs, which can significantly reduce the timber wastage as well as specialised equipment that enables the maximisation of timber recovery.[451] One example of these technologies is large cone-beam computed tomography.[452]. In this technology, a computer is used to calculate the best way to cut the timber to avoid defects and increase yield by eight per cent, which adds up to a lot of wood. The logs fly through the machine at 180 m per minute. It also obtains the most out of 'decadent', or

[447] Daian, G. and Ozarska, B., 2009. Wood waste management practices and strategies to increase sustainability standards in the Australian wooden furniture manufacturing sector. *Journal of Cleaner Production*, 17(17), 1594-1602.

[448] Waste Audit and Consultancy Services (Aust) Pty. Ltd. 2007. Disposal Based Survey, Zero Waste SA, Oct. Nov. 2007133.

[449] Ramage, M.H., Burridge, H., Busse-Wicher, M., Fereday, G., Reynolds, T., Shah, D.U., Wu, G., Yu, L., Fleming, P., Densley-Tingley, D. and Allwood, J., 2017. The wood from the trees: The use of timber in construction. *Renewable and Sustainable Energy Reviews*, 68, 333-359.

[450] Eshun JF, Potting J, Leemans R 2012 Wood waste minimization in the timber sector of Ghana: a systems approach to reduce environmental impact. *Journal of Clean Production* 26, 67–78.

[451] Adhikari, S. and Ozarska, B., 2018. Minimizing environmental impacts of timber products through the production process 'From Sawmill to Final Products'. *Environmental Systems Research*, 7(1), 1-15.

[452] Treehuggers. How to reduce timber waste: put your logs through a CT scanner. 2019. https://bit.ly/3anl1zx

old and decaying logs which might otherwise go to waste. The CT log scanner chooses the cutting pattern that maximises the overall resale value of *all* boards cut from a log, thereby minimising waste.

Timber manufacturers can also utilise their timber production residual for their energy demands. For example, the US timber industry met more than 65 per cent of its energy needs through timber residuals, which in turn represented more than 90 per cent of total timber fuel usage by US manufacturing industries[453]. Another method to reduce C&D waste during manufacturing is to utilise C&D waste of other construction materials in the production of various timber products. For instance, in Brazil it is proven that particleboard manufacturing industries can utilise C&D waste timber to produce MDF inner layers (Azambuja et al., 2018). Table 102 summarises examples of manufacturing timber using other C&D waste materials.

Table 102. Application of other c&d wastes in the production of timber.

Waste material	Summary of study	Reference
Construction material packaging materials (e.g. cardboard and paper)	Packaging stuff from C&D activities can be used to make flanks that can be used in construction activities	www.citymetric.com[454]
Particle obtained from four types of timber waste: MDF, medium-density particleboard (MDP), plywood and solid timber	The results proved that C&D timber waste has the potential to be used as raw material for particleboard. The properties of the resultant product were promising, and the industries are recommended to use these waste resources for the production of the inner layer of MDP products	Azambuja et al. (2018)

Reviewing several studies on the use of timber waste in creating pasteboard, Hossain and Poon (2018) reported that these products meet the standards on mechanical performance and exhibited excellent noise reduction and low thermal conductivity. These features promote the potential application of pasteboards as lightweight acoustic and thermal insulating materials. Another timber waste-based product is cardboard timber, which was first launched in Norway, where more than one million tonnes of paper and cardboard are recycled every year. The wood is created by rolling up paper and solvent-free glue to create a log-shaped material, then it is chopped into usable planks. The timber can then be sealed, so it is waterproof and flame-retardant and used to build anything that would be normally built with timber (Figure 78).

Figure 78. A cardboard made from timber
Source: www.citymetric.com

[453] EPA. 2007. Energy trends in selected manufacturing sectors: opportunities and challenges for environmentally preferable energy outcomes. Report, Environmental Protection Agency.
[454]CityMetric. 2015. 9 Building materials made entirely from waste product. https://bit.ly/3tBASSW

10.7.3 Waste reduction opportunities during design, planning, and contract

The design of a building has a huge impact on the quantity of timber waste generated. Generally, there is little opportunity to minimise timber waste on small construction sites due to the necessity of cutting standard-sized timber to fit the project design and the unavoidable nature of waste originating from cutting[455].

10.7.4 Reducing waste during procurement

Procuring timber products from recognised suppliers that provide timber materials from well-managed farms can lessen the quantity of timber waste. In the US[456] the Forest Stewardship Council sets standards (called certified wood) that guide construction firms' procurement methodology to obtain high-quality timber products. Another strategy at the procurement stage to minimise waste is to source construction materials from suppliers that use materials other than wooden pallets for packaging. Furthermore, the implementation of stock control measures was identified to have the greatest potential for minimising waste on small-scale construction projects.[455] Such measures are intended to avoid over-ordering of materials and ensure that all materials are available when required.

10.7.5 Reducing waste during transportation and delivery

The waste generation during transportation and delivery can be notable. The transportation of timber product begins with shipping timber from the forest to sawmills, then carrying sawn timber from sawmills to manufacturing companies, and finally to end-users. At each of these stages, there is potential for waste generation.

10.7.6 Reducing waste during construction

Reduction of timber waste during construction proved to be a significant contributor to waste generation. Early defect studies often link the wood waste onsite with poor craftsmanship and negligence.[457] Several studies have also linked the occurrence of defects to the organisation and, more specifically, poor communication.[457] Therefore, organisational learning is a key ingredient for the successful application of quality management procedures. Among different strategies, education can provide benefits to the industry to minimise waste during the construction phase. At the heart of strategies to reduce the waste generated at a C&D site is the human factor. Operators play a key role in minimising the waste generated, and waste management systems can effectively guide and inform their waste minimisation attitudes and behaviour. Both of these factors can benefit from an educational program aiming to inform the waste management system and thus human attitude and behaviour. In Australia, an educational program collaboration between Forest and Wood Products Australia and the University of Tasmania's Centre for Sustainable Architecture with Wood was created to provide available-on-demand timber education and skills development opportunities. This program, called WoodSolutions Campus is for those who design and build with timber, study-related courses or work in Australia's timber and wood products supply chain. WoodSolutions is Australia's leading online resource for people designing and building with wood and wood products. Table 10310.6 presents the courses now offered to applicants. Table 103 presents the courses now offered to applicants:

455 Williams, I.D. and Turner, D., 2011. Waste management practices in the small-scale construction industry. https://bit.ly/3n2pD3k

456 Yates, J.K., 2013. Sustainable methods for waste minimisation in construction. Construction Innovation. *Construction Innovation*. 13 (3): 281-301.

457 Johnsson, H. and Meiling, J.H., 2009. Defects in offsite construction: timber module prefabrication. *Construction Management and Economics*, 27(7), pp.667-681.

Table 103. The timber specific courses delivered by WoodSolutions Campus.

Course title	Theme	Description
Laying Timber Flooring	Construction, installation	A comprehensive introduction to timber flooring for professional and DIYers
National Construction Code (NCC) Design of Mid-rise Timber Building: Specific Requirements	Design, relevant to waste management	This course introduces the NCC's design requirements, terminology and specific fire requirements for the design of mid-rise timber buildings
NCC Design of Mid-rise Timber Building – Overview	Design, relevant to waste management	An overview of changes to the NCC's deemed-to-satisfy provisions that allow the use of lightweight and massive timber construction systems
NCC Design of Mid-rise Timber Buildings: Fire, Sound and Non-habitable Area Requirements	Design, relevant to waste management	This course covers fire, sound and non-habitable area requirements
Timber Inspection	Maintenance	This module course introduces Australian Standards and the process of inspecting and certifying timber for house construction
Timber and Wood Products	Manufacturing, relevant to waste management	An overview of products, their manufacture and major applications areas, generally available sizes and major standards controlling their manufacture or use
Introduction to Building Regulations and Standards	Design and procurement	Most aspects of the building are regulated – this course helps provide understanding of how regulations and standards affect how timber is produced, specified and supplied for use in buildings in two key areas: timber product standards and building regulations
Design for Durability	Design, relevant to waste management	This topic introduces knowledge for building in bushfire areas. It will aid choice and specify appropriate timber and wood products
Managing Timber's Moisture Content	Maintenance	This topic introduces knowledge to determine an appropriate MC for timber in applications, and handle and store timber and wood products to maintain moisture content
Design for Bushfire	Design	This topic introduces knowledge for building in bushfire areas; it will aid choice and specify appropriate timber and wood products
Timber Grades and Grading	Procurement	This topic introduces major grading methods, the structure and application of grades in industry, and their regulation through standards
Selecting Fit-for-purpose Timber for Applications	Procurement	This topic provides an overview of consumer law, and discusses the key questions to be asked of the customer and the performance requirements for major application types
Timber and Wood Properties	Design and procurement	This topic introduces knowledge about timber and wood properties
Environmental Characteristics of Timber	Design and procurement	This topic introduces timber and wood products' environmental characteristics, describes their potential contribution to sustainable development and compares them with those of major materials – as forestry practice can have significant impacts on the

		forest’s renewability and other impacts, the benefits and limits of forest and chain-of-custody certification are discussed

The use of timber material within modular-based construction technology proves to produce less waste than a traditional build. Studies in the UK demonstrated that application of offsite modular timber frame systems could save 50 per cent and 35 per cent of embodied carbon and energy respectively, compared to traditional builds[458]. Figure 79 exhibits example of offsite timber construction in the US which was installed in five days, in 2017.

Figure 79. Entekra’s floor panels being lifted onto what will be a two-story, 260 m^2 house in Los Banos, US. Source: Enterka

Other advantages of offsite timber construction involve reduced labour, reduced time, safer working conditions and increased productivity.[103] In Australia, however, offsite timber construction has not been fully exploited and is still in its infancy. A source of timber waste generation identified at construction sites is the temporary use of timber materials. Temporary uses of the wood include formwork for concrete moulding, temporary offices on buildings sites and installations for safety purposes (scaffolds and collective protective equipment). According to recent studies in China,[459] the waste emerging from the formwork for concrete moulding in high-rise buildings is responsible for the greatest amounts of wood residue, and it represents about 30 per cent (by volume) of construction waste. The use of alternative permanent materials for scaffolding, collective protective equipment and container offices can reduce wood waste generation by approximately 50 per cent. The use of wooden formwork systems only can reduce 75 per cent of wood waste generation. The use of precast concrete structures could possibly reduce wood waste generation to approximately zero[460].

10.7.7 Reducing waste during demolition

Sorting the timber waste extracted during demolition can assist in further waste recovery. Sorting is an important phase in the utilisation of timber waste, as it removes 'gross contamination' that can interrupt the recovery process. In the sorting process, contamination control is applied. Sorting methods also minimise the risk of wood contamination in wood waste utilisation. For example, the timber waste industry depends on quality parameters such as the potential of contamination from the residue of post-burning wood waste for energy generation[461]. However, the growth of automated demolition processes that are more economical for operators to run but result in more homogenous C&D waste to landfill will also contribute to less clean streams of timber waste. One study in the UK recommended the use of skips for segregation of specific materials and onsite

[458] Wood for Good and PE International Ltd. Life Cycle Database, Glue Laminated Timber. Technical report, Wood for Good. 2013

[459] Lu, W., Yuan, H., Li, J., Hao, J.J., Mi, X. and Ding, Z., 2011. An empirical investigation of construction and demolition waste generation rates in Shenzhen city, South China. *Waste Management*, 31(4), pp.680-687.

[460] Kern, A.P., Amor, L.V., Angulo, S.C. and Montelongo, A., 2018. Factors influencing temporary wood waste generation in high-rise building construction. *Waste Management*, 78, pp.446-455.

[461] Lestari, R.Y 2015. Assessment of reusing and recycling wood waste for production of furniture and furniture components in Victoria. MSc. Thesis. School of Ecosystem and Forest Sciences, Faculty of Science. University of Melbourne.

sorting of wastes as the main strategies to reduce timber waste going into landfill[455]. However, sometimes this practice is difficult to implement due to the lack of space required for several waste skips. The resolution to this could be the provision of bulk bags rather than skips,[462] which ensures waste minimisation practice without infringing on onsite space.

10.7.8 Reducing waste through reuse

Timber waste can be utilised easily and directly in other construction projects after cleaning, de-nailing and sizing. Undamaged wood can be re-used as plank, beam, door, floorboard, rafter, panel, balcony parapet and pile[463]. Furthermore, particleboard manufacture is increasingly utilising recycled wood packaging and offcuts in the production of new particleboards. However, one caveat to keep in mind is the use of coated timber waste in certain applications such as mulch or soil additives. Re-use of timber waste can particularly take place in infrastructure projects wherein timber waste is recovered in large quantities of almost similar quality. One example of this application taking place is a project in Myanmar. The renovation of the world's longest teak bridge, the U Bein Bridge, was planned to be accompanied by the re-use of timber waste. The old posts that support the deck of the bridge were successively replaced and were re-used as handrails or rest benches along the 1.2 km footbridge (Figure 79).

Figure 80. U Bein Bridge in Myanmar; the longest teak bridge
Source: The Myanmar Times: Phyo Wai Kyaw.

The literature also places emphasis on the on-site usage of timber waste to reduce timber waste landfilling. On-site usage can take place in the form of fuel. This is particularly attractive as it reduces the emissions associated with transportation, often by road, of timber waste to another site (for energy recovery or panel production), as well as the empty return journey of the transport vehicle.

10.7.9 Waste recovery (recycling and upcycling)

and climate change prompted both timber suppliers and consumers to turn to a more sustainable timber source. Post-consumer timber can be recycled if it is not contaminated or treated. The recyclable timber should be kept separated from painted, coated and preservative-treated (timber) materials. Timber waste from infrastructure projects such as utility poles and bridges are now found to be more viable than landfill and energy recovery as the hardwood timber supplies are reducing.

In Australia, the latest statistics (2016-17)[476] (Table 104) show that timber waste recovery (recycling and upcycling) has gained some successes in some of the jurisdictions. However, the data gathered might not best represent the timber waste recycling activities, and results in the ACT, NT and Tas

[462] Fox, J. and Hilton, M. (2008). Evaluation of recycling feasibility trials to develop recycling services for SMEs. Waste and Resource Action Plan, Oxon, UK

[463] RILEM 2000. *Sustainable raw materials: construction and demolition waste*. CH. F. Hendriks & H. S. Pietersen (eds.). Cachan Cedex, France: RILEM Publications.

should be noted with this caveat in mind. In general, the rate of timber waste recovery in the C&D stream was lower than the total waste streams. The exceptions are NSW and WA which have a marginally higher rate in the C&D waste stream. Among the jurisdictions, SA and NSW were the most successful states, with 68.5% per cent and 56.3% per cent waste recovery rates, respectively (Table 104).

Table 104. Statistics on recycling/upcycling of timber waste in Australia.

States & territories	C&D waste (t)	Total waste (t)	C&D waste recycling /upcycling(t)	Total waste recycled /upcycled (t)	%C&D waste Recycling/ upcycling	% total waste Recycling/ upcycling
ACT	32,558	73,236	-	20,760	-	28.3
NSW	181,994	762,747	102,534	284,477	56.3	37.3
NT	7,422	13,771	-	-	-	-
Qld	92,255	413,549	-	102,758	-	24.8
SA	58,411	342,801	40,000	250,500	68.5	73.1
Tas	1,491	30,109	-	-	-	-
Vic	205,967	544,203	59,892	278,694	29.1	51.2
WA	31,873	189,264	10,699	61,024	33.6	32.2
Total	611,971	2,369,680	213,125	998,213	34.8	42.1

Timber waste can be recycled and upcycled for various purposes. There is overwhelming evidence about timber recycling and upcycling as tabulated in Table 105. The recovery product of timber waste can be used in wood furniture and upholstered seat manufacturing, the electric power industry, agriculture, and the construction material manufacturing industry.

Table 105. Summary of studies investigating the applications of recycled timber waste

Application		Summary of findings	Reference
Upcycling	Use as a raw material to make furniture	In 2004, Japan developed a new technology in turning timber waste into furniture, shoring wooden pile for relocated pine trees, wood bench and timber stair	Hendriks and Pietersen (2000)
	Use of fuel or charcoal for power generation	In the Netherlands, 400,000 t of wood from C&D activities are generated	Hendriks and Pietersen (2000)
	Use as soil additives and mulch	Timber waste can be recycled to be used in the landscape industry	EPA NSW (2012)[464]
	Ash from sawdust timber waste used as a cement replacement material	From the results obtained in this study, 10 per cent replacement of cement with sawdust ash shows good performance giving the desired workability and strength	Elinwa and Mahmood (2002)
	Animal bedding	Recycled timber can be converted into animal bedding	EPA NSW (2012)[465]
Recy…	Use as aggregate special lightweight concrete	The aggregate is made from a recycled small wood chunk that undertakes blast furnace deoxidization.	Tam and Tam (2006)

[464]EPA NSW. 2010. Industry fact sheet: Timber and furniture industry. Reducing business waste. https://bit.ly/3arWvxh
[465]EPA NSW. 2012. Materials fact sheet: Wood and Timber. Reducing business waste. https://bit.ly/3amNTIk

	Use of timber waste as particles to make construction particleboards.	Use of micro-factory technology to incorporate used wood and non-toxic mix waste plastics	SmaRT (2017)[466]
	Use of timber railway sleeper waste (TRSW) to create cement-woord composite materials (CWC) materials	TRSW is found to be technically suitable for building construction such as panelling, ceiling and partitioning	Ashori et al. (2012)
	Use of wood particles derived from construction waste for making CWC.	The results showed that the use of CCA-treated timber particles for making lightweight CWC panels would not create a compatibility issue. The use of timber waste resulted in better toughness index.	Wolfe and Gjinolli (1999)

However, it should be noted that not all types of timber waste can be recycled and there are restrictions for certain waste types. Timber wastes with the following features cannot be recycled:

- nails, metal connectors, plastic wrapping, dirt and sand
- paint, oil and other coatings, laminates, edge bandings, glues and resins
- plywood, MDF
- timber treated with CCA preservative (Figure 81)
- other wastes (for example, garbage, building rubble) within the same load.

Figure 81. An evidence of the application of preservatives in the timber products in infrastructure projects

The most common source of timber waste contamination originates in CCA and several methods are used worldwide to remove this preservative from the wood waste. These include laser-induced breakdown spectroscopy (LIBS),[467] X-ray fluorescence (XRF),[468] ion mobility spectroscopy (IMS)[469] and near-infrared (NR)[470] technologies. These methods can detect the depth of timber waste to which the pollutants penetrate; therefore, recyclers can know how much surface material must be removed to eliminate them (Figure 82).

[466] UNSW's SMaRT Group. 2017. SMaRT Construction Panels. https://bit.ly/3efQPaZ
[467] Uhl, A., Loebe, K. and Kreuchwig, L., 2001. Fast analysis of wood preservers using laser induced breakdown spectroscopy. Spectrochimica Acta Part B: *Atomic Spectroscopy*, 56(6), pp.795-806.
[468] Fellin, M., Negri, M. and Zanuttini, R., 2014. Multi-elemental analysis of wood waste using energy dispersive X-ray fluorescence (ED-XRF) analyzer. European Journal of Wood and Wood Products, 72(2), pp.199-211.
[469] Velizarova, E., Ribeiro, A.B. and Ottosen, L.M., 2002. A comparative study on Cu, Cr and as removal from CCA-treated wood waste by dialytic and electrodialytic processes. *Journal of Hazardous Materials*, 94(2), pp.147-160.
[470] Feldhoff, R., Huth-Fehre, T. and Cammann, K., 1998. Detection of inorganic wood preservatives on timber by near infrared spectroscopy. *Journal of Near Infrared Spectroscopy*, 6(201), pp.A171-A173.

Figure 82. Timber waste contamination detection using XRF.
Source: Fraunhofer WKI/Simone Peist

In Europe, an EU-funded project called CaReWood (Cascade Recovered Wood) sets out to introduce an upgrading concept for recovered solid timber as a source of clean and reliable secondary wooden products for the European industry[471]. The CaReWood project aims to develop a business model for upcycled use of timber waste from C&D activities, the furniture sector and the packaging and transport industries. The main objectives of CaReWood include:

- present authoritative forecasts of volumes and qualities of post-consumer and post-industrial recovered wood
- design guidelines to facilitate future reuse
- develop software supported reverse logistic models for recovery of wood
- develop, demonstrate and evaluate the feasibility of up-grading solid recovered wood technologies
- adopt certification and labelling criteria for cascaded wood
- evaluate the environmental impacts and socio-economic viability of wood cascading

Researchers working on this project claim that it is possible to recycle timber waste without any loss of quality.[472] The necessary methods for detecting and removing contaminants are being investigated in the project. Timber waste recovery in C&D activities pertaining to infrastructure projects present a huge opportunity for sustainable waste management due to the large quantity and relative uniformity of waste generated. For instance, the use of timber railway sleepers waste can be recovered to produce CWC materials that can be used in construction activities.[473,474] NSW's former Office of Environment and Heritage (now Department of Planning, Industry and Environment) has published a guideline for recycling redundant utility poles and bridge timbers.[475] In this guideline, the protocol of pre-, during and post-recycling activities are outlined.

The use of timber waste in the furniture-making industry is prevalent and has been long practised. In Australia, recycled furniture companies typically either use 100 per cent wood waste or a mix of

[471] CaReWood: Cascading Recovered Wood - A WoodWisdom Net+ project Carewood.iam.upr.si. (2019). CaReWood: Cascading Recovered Wood - A WoodWisdom Net+ project. https://bit.ly/32ymrTz.

[472] A Second Life for Recovered Wood Science and Technology Research News. (2017). A Second Life for Recovered Wood. https://bit.ly/3aqPDR3

[473] Ashori, A., Tabarsa, T. and Amosi, F., 2012. Evaluation of using waste timber railway sleepers in wood–cement composite materials. *Construction and Building Materials*, 27(1), 126-129.

[474] Wolfe RW, Gjinolli A. 1999. Durability and strength of cement bonded wood particle composites made from construction waste. *Forest Production Journal*. 49(2),24–31.

[475] NSW's Office of Environment and Heritage. 2011. Protocols for recycling redundant utility poles and bridge timbers in New South Wales. https://bit.ly/3sArEF1

timber waste and new timber[476]. These companies supply raw materials from three major resources including demolition companies, private holders and wood recycling companies. Recycled furniture companies usually build partnerships with demolition companies.

Two major issues in timber waste management include treated timber waste presence in load and ash generated in EfW activities. It is proven that treated timber waste can be used for making CWC panels without any compatibility issue with cement[474,477]. Schmidt et al. (1994) found that the use of treated timber waste was more compatible than untreated waste. This result was based on an enhanced resistance to withdrawal of sticks embedded in cement and the elevated flexural toughness of CWC materials. The results from these studies demonstrate that the manufacture of CWC should be a promising and viable method of disposal for treated timber waste. The ash that is produced in large quantities as a by-product of timber's EfW extraction processes is a major issue. Traditionally this ash is sent to landfill; however, in recent decades a new application for its sustainable management was found: as a cement in mortar and concrete mix. A review study[478] found that the use of timber ash in the concrete mix is promising. The review outlined the following:

1. Blended cement with wood ash as a partial ordinary Portland cement (OPC) replacement material has a higher standard consistency, initial and final setting time.
2. It tends to have more soundness but a lower rate of heat development relative to neat OPC paste.
3. Concrete and mortar mixtures containing wood ash as a partial cement replacement material has higher water demands to achieve a given level of mix workability compared to equivalent neat OPC mixtures, hence it increases magnitudes of water absorption in concrete mixtures.
4. Inclusion of wood ash at low levels of cement replacement actually contributed towards the enhancement of compressive strength in concrete mixtures produced.

10.7.10 Waste energy recovery

Timber waste is of high calorific/heating value. Timber EfW is operated by a variety of means such as combustion, combustion to produce steam, or gasification to produce a combustible gas. Ethanol and methanol can also be produced from timber waste, but this is a complicated and difficult process, yet to reach commercial maturity. There are opportunities for timber waste to be used for energy generation in power stations and emerging opportunities for engineered wood products to be used for both process heat in cement kilns and energy generation in power stations. Table 106 summarises these timber EfW methods:

Table 106. Timber's EfW (bi) products.

Fuel	Description of method
Electricity	Generation of electricity can be accomplished in different ways: a) combustion boiler to produce steam and thereby drive a steam turbine b) combustion boiler to produce hot inert gas or heated air to drive a turbine c) gasification reactor to produce a gas to be combusted in a combustion boiler producing steam d) to drive a steam turbine e) gasification reactor to produce a gas to be combusted in a gas turbine f) gasification reactor to produce a gas to be combusted in internal combustion (IC) engine

[476] Lestari, R.Y 2015. Assessment of reusing and recycling wood waste for production of furniture and furniture components in Victoria. MSc. Thesis. School of Ecosystem and Forest Sciences, Faculty of Science. University of Melbourne.

[477] Schmidt R, Marsh R, Balatinecz JJ, Cooper PA. 1994. Increased wood–cement compatibility of chromate treated wood. *Forest Production Journal*. 44(7/8), 44-6

[478] Cheah,C.B and M. Ramli. 2011. The implementation of wood waste ash as a partial cement replacement material in the production of structural grade concrete and mortar: An overview. *Journal of Cleaner Production*. 55, 669-685.

	g) pyrolysis process to produce syngas for combustion in a gas turbine
Liquid fuels	Other techniques can be used to generate liquid fuels from wood waste; gasification followed by syngas reformation using a Fischer-Tropsch process is one route to synthetic diesel; pyrolysis processing can provide 'biocrude' for processing into a diesel replacement; technologies including enzymatic, thermal and acid hydrolysis are under active development for conversion of cellulosic materials to sugars and thence to ethanol; wood waste could form an important feedstock for any commercial manufacturing process
Biochar	In addition to the production of gas and biocrude, pyrolysis processing also delivers a product referred to as biochar; this solid residue, or charcoal, is mainly composed of carbon and is what remains after processing woody biomass through pyrolysis; biochar can be co-fired with coal in power stations, as it has a similar chemical composition and calorific value, and can also be upgraded for metallurgical applications; it is also emerging as a useful agricultural supplement with potential as a soil remediator that increases water retention, nutrient retention and stimulates soil microbial activity; a potential by-product of its use in agriculture is as a high volume carbon sequestration solution
Cement kilns	A cement kiln runs at approximately 1,200 °C and is usually fired with coal dust; however, the substitution of other materials is possible in this process – for example, in Melbourne, 25 old tyres are used as feedstock material; the advantage of using alternative fuels such as this in cement kilns is the high temperature at which they operate, which in turn reduces the amount of emissions; the effectiveness of combustion is improved as particle size is reduced, thus making materials such as sawdust ideal
firewood	Firewood sales are extremely seasonal.; however, there is undoubtedly a residential market for conveniently sized, consumer-oriented boxes, bags or bundles of kindling or logs. These are often sold at petrol stations, hardware stores and even supermarkets, provided they meet quality controls
Process fuel	Commercial and domestic use of pellets and briquettes as process fuel (for heat or power) manufactured from wood wastes are commercially viable; wood 'pellets' as a fuel source are generally manufactured from sawdust and wood shavings from sawmills; pellet fuel is generally standardised and substantially more uniform in composition than traditional firewood

Source: Taylor and Warnken (2008)[479]

The standard practice is that clean waste is allowed to be burned in normal power stations or private stoves,[480] while contaminated wood such as treated wood, painted wood or chipboards containing adhesives (for example, formaldehyde glue) can only be used for energy generation in special stations equipped with appropriate combustion facilities[481]. In addition to using timber waste for energy recovery, some wood is used directly as fuel (or fossil-fuel substitution) for energy supply without serving as timber products. This material called wood fuel has found a significant role in the EU energy system, such that the European wood fuel production has risen by 20 per cent from 2009 to 2013[482]. There are, however, concerns that this process is against the waste hierarchy system by which energy recovery is only acceptable where there is no possibility for use in the industry. Currently, in the UK, the timber waste recovery rate is between 65 per cent to70 per cent, of which 35 per cent to 39 per cent belongs to energy recovery.[483] During 2013 and 2014, Italy re-used 95 per cent of its waste wood to produce particleboard, while Germany holds a 34 per cent recovery rate[484].

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[479] Taylor J. and M. Warnken. 2008. Wood recovery and recycling: A source book for Australia. Forest & Wood Products Australia: Knowledge for a sustainable Australia. Market Access & Development: Project Number: PNA017-0708

[480] DEFRA. Environmental permitting guidance: the waste incineration directive. Report, Department for Environment, Food and Rural Affairs (DEFRA). 2011.

[481] TRADA Technology and Enviros Consulting Ltd. Options and Risk Assessment for Treated Wood Waste. Technical report, TRADA.2005

[482] FAO. 2013 global forest products facts and figures. Technical report, Food and Agriculture Organization of the United Nations; 2013.

[483] Ramage, M.H., Burridge, H., Busse-Wicher, M., Fereday, G., Reynolds, T., Shah, D.U., Wu, G., Yu, L., Fleming, P., Densley-Tingley, D. and Allwood, J., 2017. The wood from the trees: The use of timber in construction. *Renewable and Sustainable Energy Reviews*, 68, pp.333-359

[484] Garcia CA, Hora G .2017. State-of-the-art of waste wood supply chain in Germany and selected European countries. Waste Management. 70:189–197.

The Australian statistics for EfW for timber waste in the C&D waste stream are presented in Table 107. The figures show that EfW in Australia accounts for a small percentage of waste management of timber waste. The aggregated data from all jurisdictions show that only 4.9 per cent and 2.3 per cent of timber waste generated in Australia was energy recovered for all waste streams and the C&D waste stream, respectively, in 2016-17. The most successful state in terms of EfW is SA, wherein 57,800 t (16.9 per cent) of total timber waste was used to generate energy. However, in the C&D waste stream, the largest energy recovery occurred in the ACT and Vic, with 4 per cent and 3.5 per cent of C&D waste energy recovered, respectively

Table 107. Statistics on timber EfW activities in Australia.

States and territories	C&D stream	Total waste	C&D EfW	Total EfW	%EfW C&D stream	%EfW (total)
ACT	32,558	73,236	1,294	2,086	4.0	2.8
NSW	181,994	762,747	2,735	16,460	1.5	2.2
NT	7,422	13,771	132	246	1.8	1.8
Qld	92,255	413,549	1,861	22,111	2.0	5.3
SA	58,411	342,801	448	57,800	0.8	16.9
Tas	1,491	30,109	35	705	2.3	2.3
Vic	205,967	544,203	7,266	13,206	3.5	2.4
WA	31,873	189,264	398	2,411	1.2	1.3
Total	611,971	2,369,680	14,169	115,025	2.3	4.9

Note: units are in t

10.7.11 Illegal dumping and stockpiling

Timber waste illegal dumping and stockpiling occurs in Australia. However, there is extremely limited documentary evidence that shows the prevalence of this incident in various states and territories. In 2018, a report by Fairfax Media[485] unveiled the secret of waste companies that were using Qld recycling facilities to acquire paperwork exempting them from NSW regulations limiting the transport of metropolitan waste (including timber waste) by road more than 150 km from its source. Surveillance of Qld recycling and dump sites by Fairfax Media over several weeks, including access inside one of the facilities on multiple occasions, showed that material tipped off by interstate trucks at the recycling facilities was immediately reloaded into local trucks and taken straight to landfill (Figure 83). The amount trafficked represented up to $70 million in missed waste levies y to NSW taxpayers.

[485] Solomons. M. 2018. The Sydney Morning Herald. The heap: Construction waste piled high. CREDIT: FAIRFAX MEDIA. https://bit.ly/2QAIN4d

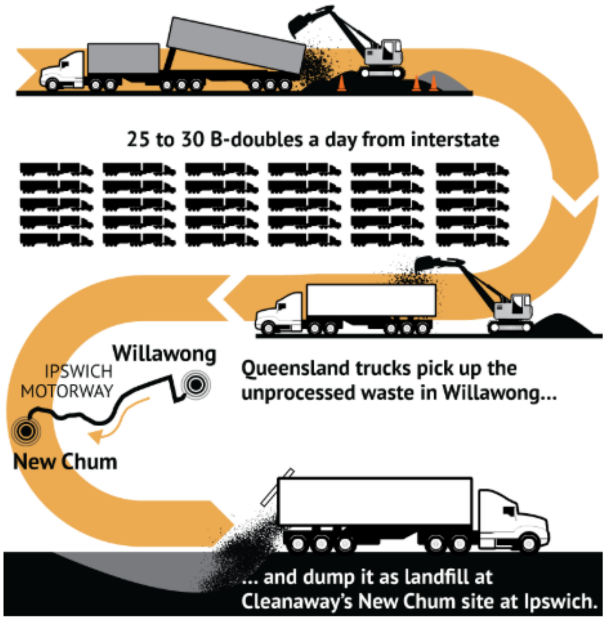

Figure 83. The plan for waste trafficking between Qld and NSW[485].
Graphic: Jamie Brown

10.7.12 Waste disposal

It is worth noting that landfill is an integral part of the current waste management system in Australia and worldwide. Particularly, low-value timber waste landfilling is slightly preferred over other C&D waste materials for two reasons. Firstly, due to the combustible nature of timber waste, it can produce energy in landfills and, secondly, the contaminated timber wastes containing hazardous components and the ash disposed of from wood-burning have no place but the landfill. However, this trend is to change in future, as evidenced in some nations such as Germany, Sweden and Austria, where restricting policies on landfilling wood waste are already implemented. Timber waste going to landfill typically consists of various types, including contaminated and non-contaminated waste. Wood waste should be sorted before it is sent to the landfill to determine whether it can be recovered or contains hazardous contaminants. Contaminated timber waste can leach hazardous constituents, such as CCA, and contribute water or soil pollution. Therefore, it is necessary for two designated, specific landfills that can accept contaminated timber waste.

One study in Australia[486] demonstrated that per tonne of waste treated, recycling stimulates greater economic activity than landfill for timber waste. However, landfill operations generate less waste per tonne of waste treated than other waste treatments methods. This volume of waste is minor compared to the total amount of waste generated in the economy. Table 108 presents the data for timber waste in different Australian jurisdictions. Vic and NSW had the largest percentage of timber waste that ended up in landfill sites.

Table 108. Estimates for timber waste landfilled and recycled in various Australia (2007)

State/territory	000's tonnes (landfilling)	000's tonnes (recycling)
NSW	345	131
Vic	470	230
Qld	48 (Brisbane only)	20
WA	150-180	10.17
SA	173	255.72
Tas	20	N/A
ACT	17.3	2.35

[486] Reynolds, C.J., Piantadosi, J. and Boland, J., 2014. A waste supply-use analysis of Australian waste flows. *Journal of Economic Structures*, 3(1), 1-16.

NT	26	0

Source: Compiled by Taylor and Warnken (2008)

The more recent statistics in 2010-11 indicate that the quantity of C&D-based timber waste sent to landfill in Australia was 120.2 kt, which is 35 per cent of the gross weight of timber waste landfilled. Engineered timber products are replacing solid timber in a range of applications. The replacement rate is several times higher than solid wood production. It is expected that the volume and proportion of engineered wood products waste will keep increasing and take over the total proportion of C&D waste in landfill. The latest data about timber waste (fate showed that a notable amount of timber waste during C&D waste activities ended up in landfill, wherein their energy is not even recovered. On average, more than 53 per cent of timber waste in all streams is landfilled in Australia. The rate of landfilling for timber waste from C&D activities is even higher, occurring at 62.9 per cent. Among the jurisdictions, the NT (98.2 per cent) and Tas (97.7 per cent) had the highest percentage of landfilling for timber waste.

Table 109) fate showed that a notable amount of timber waste during C&D waste activities ended up in landfill, wherein their energy is not even recovered. On average, more than 53 per cent of timber waste in all streams is landfilled in Australia. The rate of landfilling for timber waste from C&D activities is even higher, occurring at 62.9 per cent. Among the jurisdictions, the NT (98.2 per cent) and Tas (97.7 per cent) had the highest percentage of landfilling for timber waste.

Table 109. Timber waste landfilling status in various Australian states and territories

States and territories	C&D stream	Total waste	C&D landfilled	Total landfilled	%landfilling (total)	%C&D landfilling
ACT	32,558	73,236	31,264	50,390	68.8	96
NSW	181,994	762,747	76,725	461,810	60.5	42.2
NT	7,422	13,771	7,290	13,525	98.2	98.2
Qld	92,255	413,549	90,394	288,680	69.8	98
SA	58,411	342,801	17,963	34,501	10.1	30.8
Tas	1,491	30,109	1,456	29,404	97.7	97.7
Vic	205,967	544,203	138,809	252,303	46.4	67.4
WA	31,873	189,264	20,776	125,829	66.5	65.2
Total	611,971	2,369,680	384,677	1,256,442	53	62.9

10.8 Timber waste market

There is a high-value market for the re-use of quality hardwood timber, with prices over $1000/m^3$ for some high-grade Australian timbers, although the volume of material recovered is relatively low[487]. According to an estimation, the market for re-use of timber is estimated to be around 60,000

[487] Crossin, E., M. Hedayati and S. Clune. 2014. Waste avoidance and reuse strategies for residential buildings in Australia. Center for Design. RMIT University.

m^3 [488]. A significant source of salvageable hardwood is 'infrastructure timber', such as power poles and railway sleepers, for which there is strong demand; however, the markets for these demands are rather limited[447]. The main uses of recovered wood are landscaping mulch, fuel, salvaged (recycled) timber, animal bedding and recycling into particleboard. The main barriers to developing a market for timber waste as identified by Sustainability Victoria[489] include:

1. securing a cost-effective recycled waste stream due to competing for demand for other uses of low-value timber (that is markets for mulch and potentially WtE).
2. price competitiveness and availability of substitute virgin timber.
3. costs of labour and capital required for suitable source separation

The following section casts some light on the Australian timber waste market.

10.8.1 Integrated supply chain

The supply chain of timber waste is rarely described in Australia. One example that provides some limited information is provided by Infrastructure Victoria.[490] According to this report, most timber is converted to landscaping mulch and soft-fall, with relatively small quantities going to energy recovery, animal bedding, kitty litter, biochar production and engineered timber products. Some waste timber (10 kt to 20 kt per year) from metropolitan Melbourne is being exported to SA for biochar production and composting. Around 30 kt per year from metropolitan Melbourne and NSW is transported to the north-east region for the production of engineered timber products. There are also limited data regarding the costing of timber waste management. The costing mechanism is largely affected by geographical location and market demand. Table 110 provides some information about the costing of timber waste in NSW and Vic.

Table 110. Supply chain characteristics of the waste collector in NSW and Vic

Business name	State	Pricing mechanism	Others
Bingo Industries	NSW and Vic	Recycling: NSW: \$200/t (incl. GST) Vic: \$200/t (incl. GST) Disposal: \$380/t (excl. GST), accepted as a general waste	Waste is transferred to landfill or recycling facilities
Infrastructure Victoria report[490]	Vic	Recovery: \$40/t Upcycling: \$30/t-50/t Low value timber: \$10/t-60/t	Waste is recovered or upcycled, low-value timber is sold with low economic viability for recovery

Note: the prices tabulated above are current at November 2019

10.8.2 Timber lifecycle models

In this section, different lifecycle models proposed in previous literature for timber waste are presented. Two models that are identified are based on industrial ecosystem thinking and the EU Waste Framework Directive. In the end, the LoWMor model that is adjusted for timber waste is reviewed.

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[488] DSEWPC 2011. Construction and demolition waste guide - recycling and re-use across the supply chain. Department of Sustainability, Water, Populations and Communities.

[489] Sustainability Victoria. 2014. Market summary – recycled timber. https://bit.ly/2QKZhHe

[490] Blue Environment Pty Ltd. 2019. Infrastructure Victoria: Victorian waste flows. https://bit.ly/32xE2v6

A model based on industrial ecosystem thinking: The analogy for this model is the creation of an 'industrial ecology' that is able to 'digest' the wood waste and return resources for use back into the economy (Figure 84) . This model involves a network of collection capacity and infrastructure with the ability to transform the wrong time/place wastes into the right time/place resources. For example, the ability to return boutique recycled materials, provide a feedstock for an engineered timber product, supply animal bedding and recover energy could be part of a region-wide approach to wood waste value-adding. This model emphasises the role of the manufacturer in contribution to the cradle-to-cradle approach (through schemes such as EPR) for the management of timber waste.

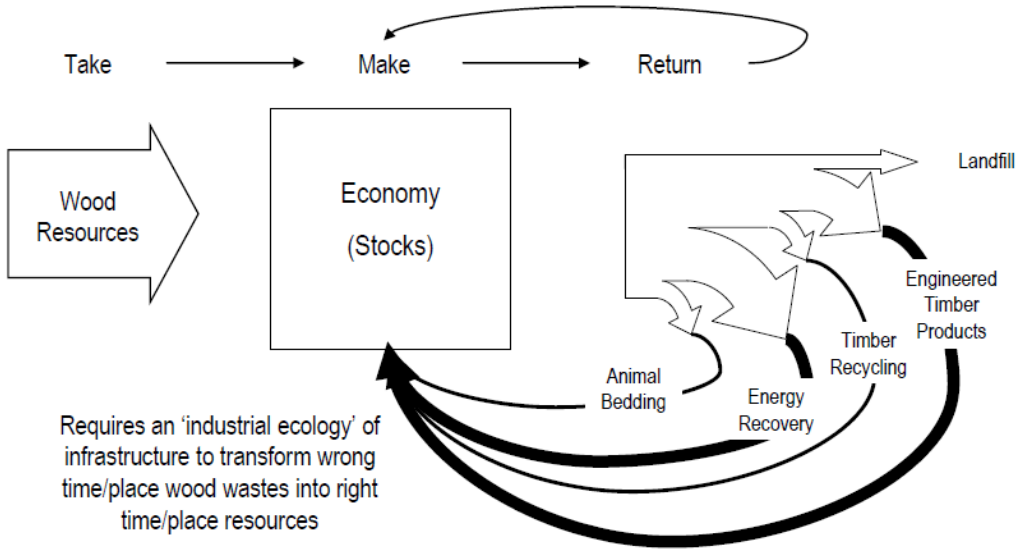


Figure 84. Timber's industrial ecosystem thinking proposed for sustainable Australia.
Source: Taylor and Warnken (2008) [491]

A model based on the EU's Waste Framework Directive: Drawing on the waste management hierarchy issued by the EU's Waste Framework Directive in 2008[492] and the upcycling principle, Ramage et al. (2017) developed a wood waste management conceptual model (Figure 85). This model only considers the end-of-life of wood in the timber life cycle. According to the model, there are only three fates for timber waste: re-use, energy recovery or landfill. This model, however, does not primarily distinguish re-use from recycling and upcycling. One interesting concept used in this model, which is on the 'preparing for re-use' principle in the EU's Waste Framework Directive, is the role of design. Timber manufacturers are recommended to design products with ease of disassembly and re-use in mind. Even if timber waste, after one service unit, does not qualify for further use, it can still be reprocessed as fibrous materials for making new timber products that are recycled.

[491]Taylor J. and M. Warnken. 2008. Wood recovery and recycling: A source book for Australia. Forest & Wood Products Australia: Knowledge for a sustainable Australia. Market Access & Development: Project Number: PNA017-0708

[492] European Parliament. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.2008.

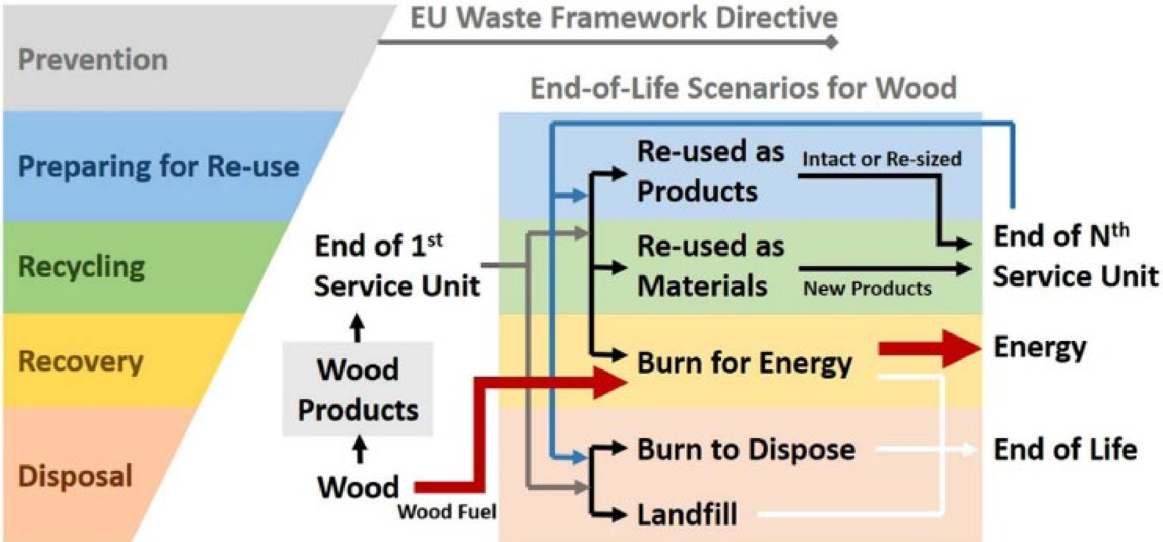


Figure 85. End-of-life scenarios for timber waste.
Source: Ramage et al. (2017).

LoWMor model: Emerging from this research project and a review of strategies presented above, LowMore identified 12 opportunities to manage timber waste (Figure 86). This supply chain model aims to show how various stakeholders can contribute first to minimising and then reducing the volume of waste sent to landfill.

Figure 86. Timber LoWMor supply chain model for timber waste management.

Drawing on this model, the role of various stakeholders in the supply chain of timber waste management is further highlighted in Table 111. The following table shows how various stakeholders can contribute to reducing timber waste generation throughout the timber supply chain.

Table 111. The role of various stakeholders in the effective management of timber waste

No.	Stage	Stakeholder(s)	Contributions
1	Design	Designers, construction firms, clients	• Re-use timber waste in their design • Design a new building to facilitate its re-use in the future • Consider precast timber frames in the designs • Consider building standardisation to improve buildability and reduce the number of offcuts
2	Manufacturer	Manufacturers, recyclers, suppliers	• Develop an agreement where a contractor sells back the recycled waste from the original material supplier • Participate in the EPR and PS schemes • Use new technologies for processing harvested log to reduce wastage
3	Procurement and contract	Construction firms, quantity surveyors, government	• Construction firms should order timber more accurately using the best take-off practice • Alter the public contracts (purchasing) for timber waste-based materials used in public projects
4	Transportation & delivery	Construction firms, transporters, recycling companies	• Just-in-time delivery of materials to construction to avoid damage taking place due to insufficient space for proper storage and adverse weather conditions • Do due diligence and exercise standard work practices
5	Construction	Construction firms, sub-contractors, waste collectors, recyclers	• Separate high-value timber waste for further use or recovery • Use non-disposable metal formwork instead of a timber one
6	Demolition	Demolition contractors, waste collectors, recyclers	• Consider selective deconstruction to maximise the re-use potential of its components • Provide bulk bags rather than skips to ensure segregation of timber waste from other waste materials
7	Reusing	Construction firms, state and territory governments, EPAs and other equivalent organisations, waste collectors	• Facilitate market development • Adjust specifications in favour of greater usage of timber waste-based materials in new construction projects
8	Recycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Take timber leftovers away to use as landscaping mulch • Facilitate market development • Fund the development of waste recovery infrastructure • Adjust specifications in favour of greater usage of timber waste-based materials in new construction projects
9	Upcycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Facilitate market development • Adjust specifications in favour of greater usage of timber waste-based materials in new construction projects • Fund the development of waste recovery infrastructure • Find new applications for timber waste
10	Energy recovery	Energy recovery facility owners	• Use technologies that can safely burn low-value contaminated timber waste
11	Stopping illegal dumping and stockpiling	State and territory governments, EPAs and other equivalent organisations	• Reinforce activities that stop illegal dumping and stockpiling • Set stricter regulations with a higher rate of penalty fees to discourage illegal dumping and stockpiling • Strengthen controls over licensed landfill sites
12	Landfill	State and territory governments, EPAs and other equivalent organisations	• Design appropriate landfill levy schemes to discourage high-value timber waste landfilling

10.9 Relevant industry associations

Table 112 shows presents the main industry associations which are potential partners for developing an integrated supply chain life cycle model. These associations have multiple functions through which they can give boost the sustainable management of timber waste in Australia. They can bridge the gap between public and private sectors (for example, manufacturers, suppliers, retailers, contractors), raise social awareness and contribute to making fair and well-received policies.

Table 112. Industry associations relevant to the management of timber waste

Title	Scope	Vision	Webpage
Australian Forest Products Association (AFPA)	National	The AFPA is the peak national industry body representing the resources, processing, and pulp, paper and bioproduct industries covering the forest products value chain The AFPA represents all elements of the value chain from the sustainable harvesting of plantations and multiple-use natural forest resource including forest establishment and management, harvesting and haulage, processing of timber resources and manufacture of pulp, paper and bioproducts	https://ausfpa.com.au
Australian Timber Importers Federation (ATIF)	National	The ATIF is the peak national body representing the business interests of timber and wood-based product importing and wholesaling companies; the ATIF represents and advocates for the importing sector of the timber industry in national fora	https://atif.asn.au
Engineered Wood Products Association of Australasia (EWPAA)	National	The EWPAA is a member association for manufacturers of engineered wood products, particularly plywood, laminated veneer lumber, particleboard and MDF	https://ewp.asn.au
Forest and Wood Products Australia Limited (FWPA)	National	The FWPA collaborates with government and industry stakeholders to determine strategy, invest in effective and relevant R&D and deliver programs designed to grow the market for forest and wood products, increase productivity and profitability across the value chain and ensure positive environmental and social outcomes	https://www.fwpa.com.au
The Australian Timber Flooring Association (ATFA)	National	The ATFA helps Australasia’s timber flooring industry to be more profitable, professional and publicised	https://www.atfa.com.au
Timber Development Association (TDA)	NSW	The TDA of NSW is an industry-funded association representing all segments of the timber industry, from manufacture to supply	http://www.tdansw.asn.au
Timber Preservers Association of Australia (TPAA)	National	The TPAA represents the nation's wood preservation industry. It is made up of timber treaters, preservative suppliers, research organisations, and individuals and bodies having an interest in the production and use of preservative-treated timber	http://www.tpaa.com.au
The National Timber Product Stewardship Group (NTPSG)	National	The NTPSG is an initiative of the timber and wood products industry to double the recovery of post-consumer timber and wood products to one million tonnes per year by 2017	https://www.timberstewardship.org.au
WoodSolution		WoodSolutions is an industry initiative designed to provide independent, non-proprietary information about timber and wood products to professionals and companies involved in building design and construction	https://www.woodsolutions.com.au

10.10 Recommendations

- To use non-disposable metal formwork instead of timber one in several construction projects
- To redefine and harmonise timber waste in national and jurisdictional regulations and policies
- To exclude timber waste recovered from construction activities from generic timber waste
- To improve existing, and employ new, varieties of machinery instead of old and obsolete mechanisms to help reduce wood waste

11. Perceptions of stakeholders: A Survey Results

11.1 Introduction

It is often argued that an increased understanding of key stakeholders' perceptions can inform policy development and be used as evidence for a broader discussion to solve lasting issues in C&D waste management. However, a limited body of research has examined key stakeholders' perception of barriers and enablers towards a national C&D waste management across Australian states and territories. After a series of desktop research on various aspects of C&D waste management system in Australia and developing an understanding of waste circularity a questionnaire survey was conducted to complement review outcome through attaining the perception of stakeholders in C&D waste management industry, government and public sectors. The questions in this survey were built on desktop research and aimed to assess and elicit participants' knowledge of effective C&D waste management. The survey was also intended to understand and ascertain any issues or discrepancies arising out of the application of C&D waste regulations and policies in different sectors. The report is structured in a way to cover various aspects obtained from participant responses including participants' profile, general questions about C&D waste, landfill tax levy scheme, C&D waste legislation, various C&D waste-based schemes, and development of a domestic market for C&D waste. In this report, the analytical findings of the semi-structured survey are presented.

11.2 Methodology

The research employed a mixed method to collect quantitative and qualitative data. Surveys are an appropriate data collection method to obtain both quantitative and qualitative information using well-planned questionnaires and are widely used by researchers within the construction management domain. In this study an online questionnaire was used as the most appropriate modality for the same reasons as explained by Saez et al. (2013), including being an efficient and flexible approach which ensure participant confidentiality. In addition, conducting questionnaires online is the most common delivery method, which means participants are familiar with the approach and more likely to respond.

11.2.1 Sample and data collection

A cross-sectional survey of a random sample of stakeholders of C&D waste management operating in different jurisdictions of Australia was conducted from June to September 2019. Purposive sampling is the most time effective sampling method available and particularly was employed to recruit a wide range of participants that represent various stakeholders across C&D waste supply chain. Recruitment was executed according to the Australian National Statement on Ethical Conduct in Human Research (National Health and Medical Research Council, 2007) and RMIT University Human Ethics Committee instructions and requirements. The project industry partners including the Australian Sustainable Built Environment National Research Centre (SBEnrc) and the Waste Management and Resource Recovery Association of Australia (WMRR) assisted with recruitment process through providing their network contact details. WMRR's members consist of businesses and experts who are engaged in recycling and waste management activities. SBEnrc members include experts from government, industry and academia who are involved in built environment issues, most notably C&D waste management. WMRR is the industry partner of project presented in this paper, whilst SBEnrc funded the research project.

Since the project study aimed to capture responses from a wider range of stakeholders, in order to increase the potential response rate, one of the main selection criteria was the adequate experience in dealing with the management of waste in Australia. Email communication was the method of recruitment. An email with the online survey link and the project information sheet, was sent to a list of participants compiled by the research team in one round. This covered 250 individuals with relevant experience in waste management and the resource recovery sector. The list consisted of the two organisation members and other experts identified by researchers. A reminder email was also sent to those who did not respond in the first round. Survey participation was voluntary, and a completed survey implies informed consent. The investigators maintained the privacy and confidentiality of all survey information as per the human ethics requirements.

11.2.2 Survey design

Survey development came from the review of the literature, regulations, policy statements, other international guidelines, and expert opinions regarding the main issues of the C&D waste management in Australia and overseas. The questionnaire was designed using Qualtrics (Qualtrics, 2014) and the final questionnaire was reviewed by experts to establish content validity and tested for online accessibility and comprehension by a group of construction professionals and experienced researchers. The content, clarity and length of the survey were modified accordingly. The questionnaire consisted of several questions covering the main issues and opportunities in the Australian C&D waste management system. The survey design consisted of a range of question types: multiple-choice questions, 5- and 7-point Likert scales (1 = 'strongly agree' to 7 = 'strongly disagree'), single and multiple text entry(ies), and rank ordering (1 to 5). Furthermore, a series of questions were presented to participants seeking their opinions about the survey validity. Most respondents (over 70 per cent) took 25 - 30 minutes to complete the survey. This paper presents four sections of the questionnaire: (1) participants' characteristics, (2) barriers to the effective management of C&D waste, (3) the Australian federal government position in waste management and (4) waste-related regulations, policies, and schemes. Responses to these questions contribute to our understanding of the main barriers to the effective management of C&D waste (Objective 1), the federal government impact on waste management (Objective 2) and known inconsistencies in waste regulations (Objective 3).

11.2.3 Data analysis and presentation

In total, 132 responses (53 per cent response rate) were received and recorded in the Qualtrics database. After screening the responses, the survey data, both quantitative and qualitative, were analysed. To explore the participants' demographic details and their opinion on the C&D waste issues and opportunities, descriptive statistical techniques were applied (Holcomb, 2016). For the quantitative data, frequency distributions were examined to compare different categories of responses received from participants. For qualitative data, a thematic analysis (Braun and Clarke, 2006) of responses to each question was made. This paper largely focusses on the qualitative data that presents participants' knowledge of the main inconsistencies in the Australian waste regulations. NVivo V.11 was used to conduct a thematic analysis of participants' qualitative responses. NVivo is a software application that helps researchers discover more from your qualitative and mixed methods data.

A questionnaire survey was performed to achieve the main aim of this survey. Qualtrics, an online survey toolkit, was used to design the questionnaire (Qualtrics, 2014) and to circulate among the participants. The questionnaire was reviewed and refined by waste management and construction industry experts. The conduction of the survey was approved by the RMIT University Human Ethics Committee (Appendix), College Human Ethics Advisory Network (CHEAN) (CHEAN A&B 21847-11/18). The questionnaire contained 45 questions about various aspects of C&D waste management in Australia. However, using the logical skip function in Qualtrics some questions appeared to only a specific group of respondents, making the number of questions to be answered smaller. The target population consisted of the main stakeholders of C&D waste management and resource recovery industry. Different recruiting strategies were adopted to ensure the representativeness of the main stakeholders in the sample size. Firstly, the researchers circulated the questionnaire survey link to their network. Secondly, the recipients were asked to forward the link to others with C&D waste interest and experience. Thirdly, two industry associations, namely The Waste Management and Resource Recovery Association of Australia and the Sustainable Built Environment National Research Centre were approached to use their internal and external industry network to invite further participants. According to Qualtrics records, the survey took 20 minutes to complete on average. In total 132 survey responses received from which only 84 had an acceptable level of response (more than 70 per cent) were considered. Below are the main questions that this report presents participants responses to which.

Q2.1. In what of the following section(s) (that is related to the C&D waste) do you have experience?
Q2.2. For how many years have you directly or indirectly dealt with the C&D waste issues?
Q3.1- Express your degree of agreement on the following statements:

a. More pecuniary imposts (for example, landfill levy increases; taxes on producers; more regulations, monitoring and enforcement) can better increase C&D waste reduction, re-use and recycling in Australia
b. More market incentives (for example, remove regulatory barriers; foster minimum recycled content in products; invest in technologies to recycle and facilitate trade such as trading platforms) can better increase C&D waste reduction, re-use and recycling in Australia.

Q.4.2. Please indicate your opinion about the quality of current landfill levy taxation and how to improve them in your jurisdiction and Australia
Q3.2. What are the main economic barriers to the effective management of C&D waste in your jurisdiction?
Q3.3. Please indicate three of the following options for the federal government to support the C&D waste reduction/reuse/recycling more effectively
Q4.1. To what extent do you agree with this statement: landfill levy is a powerful incentive to promoting C&D waste minimisation and recovery (e.g., recycling, reusing and energy recovery from waste)
Q.4.2. Please indicate your opinion about the quality of current landfill levy taxation and how to improve them in your jurisdiction and Australia using the following categories**:**
Q5.2 Do you think the current legislation support or discourage C&D waste reduction, reuse and recycling in your jurisdiction?
Q5.3 – Please indicate three inconsistencies in current C&D waste regulations in various Australian jurisdictions that you consider as a barrier to reduce/reuse/recycled C&D waste?
Q7.2. Do you agree with the following schemes as an effective measure for reducing/increase in reusing/recycling of C&D waste? please specify why?
Q12. 2. What are the main five influential factors in the sustainable operation of a C&D marketplace in Australia?
Q13.1. Please express your level of agreement with the following statements on this survey.

- The questions could effectively interact with you about the C&D waste legislation in Australia
- The questions could effectively interact with you about the economic factors related to C&D waste
- The questions can find new perspectives on C&D waste
- The questions are clear and understandable
- The questions covered most of the issues about C&D waste management
- Number of questions is about right
- It took the same time to complete as I expected
- The questions can successfully extract information from respondents

11.3 Results

After screening the survey responses, the selected data was analysed using descriptive analysis. In total, 132 participants took part in this online survey. Frequency distribution was the main statistical measure to compare different categories of responses received by participants. Excel Spreadsheet v. 2016 was used to archive, screen, and analysed the data collected. The results are categorised into eight sections, including participants profile, general questions, landfill tax levy, C&D waste legislation, waste management schemes, domestic market development and validity of the survey.

11.3.1 Participants profile

The profile of participants, including the industry and geographical zone in which they performed their main activities and the length of their experience, was explored. The sample size represents the major stakeholders with a direct involvement in the construction material end of life management: around 60 per cent of the participants belonged to the construction (24 per cent), waste recovery (20 per cent), and landfilling (15 per cent) sectors, the three sectors that are most affected by C&D waste regulations and policies. The responses also approximately align with the number of employees in each of these sectors.

As expected, the study sample consisted of experts who were largely based in the four Australian major states (i.e., Vic, NSW, Qld, and WA) that deal with the C&D waste management challenges the most and have a higher population and thus construction activities. As shown in Table 1, around 44 per cent of participants had less than six years of experience working in waste management space, and less than 30 per cent of them had worked in an industry pertaining to C&D waste management for more than 15 years at the time of survey completion (Table 113).

Table 113. A summary of survey participants' profile

Category	Frequency
State	**(%)**
ACT	1.8
NSW	24.3
NT	6.3
Qld	16.2
Tas	3.6
Vic	30.6
WA	17.1
Field of activity	**(%)**
Construction	15.9
Demolition	8.1
Landfill	14.7
Legislation	5.9
Industry association	6.3
Waste recovery	19.9
Waste delivery and transport	10.1
Consultancy	7.2
Manufacturing	3.8
R&D	2.9
EPA enforcement	5.2
Length of experience	**(%)**
<6 years	43.1
6-10 years	13.7
11-15 years	16.7
>15 years	26.5

11.3.2 Landfill levy

In waste-related literature and policies, the main three viewpoints underpinning landfill waste reduction activities are encouragement, enforcement and education. In the context of Australian C&D waste management, each of these has its own set of advantages and disadvantages, and hence received a different level of support and criticism. The survey targeted the key C&D waste stakeholders' perception about the best approach. Two questions were posed to determine the extent to which participants support a. more market incentives (encouragement) and b. more pecuniary imposts (enforcement). The questions were:

a. Express your degree of agreement on the following statements: More market incentives (e.g., remove regulatory barriers; foster minimum recycled content in products; invest in technologies to recycle and facilitate trade such as trading platforms) can better increase C&D waste reduction, re-use and recycling in Australia.
b. Express your degree of agreement on the following statements: More pecuniary imposts (e.g., landfill levy increases; taxes on producers; more regulations, monitoring and enforcement) can better increase C&D waste reduction, re-use and recycling in Australia.

For the first category, the responses showed that the respondents significantly favoured market incentives (Figure 87) with more than 92 per cent indicating agreement or somewhat agreement. The more pecuniary approach received significant but comparatively less support; the results showed that about 70 per cent of participants indicated agreement with implementing more pecuniary imposts given enforcement activities status quo (Figure 88).

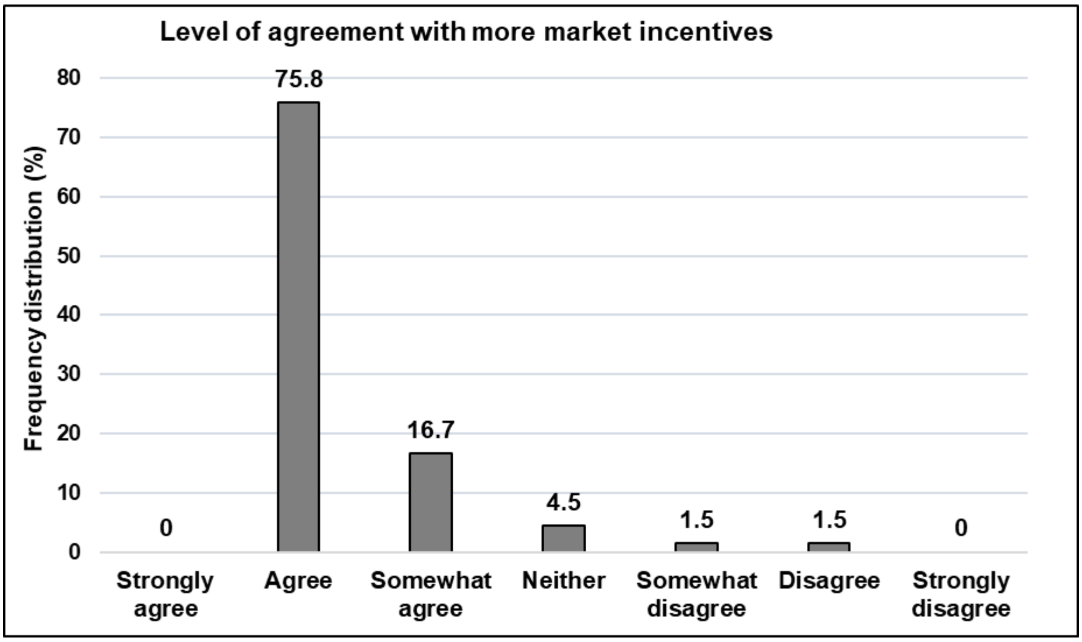


Figure 87. Frequency distribution of agreement level with the increased implementation of market incentives in construction and demolition (C&D) waste stream.

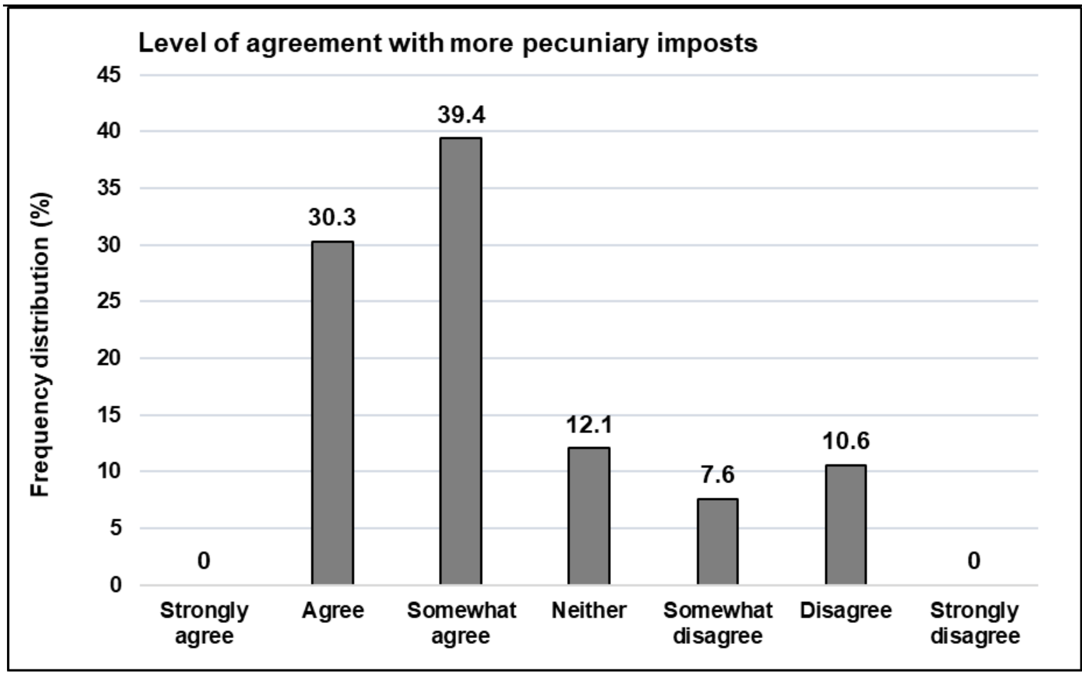


Figure 88. Frequency distribution of agreement level with increased implementation of pecuniary imposts in C&D waste stream.

11.3.3 Effectiveness of Landfill Levies in C&D Waste Management Frameworks

There are some doubts about the position of landfill levies in waste management systems and how they contribute to promoting C&D waste minimisation and resource recovery. Therefore, the respondents were also asked to express their agreement/disagreement level with a statement about the effectiveness of landfill levy. The results showed that almost 90 per cent of participants endorsed the effectiveness of the landfill levy in general (Figure 89). Therefore, it can be concluded that in the participants' opinion, the landfill levy is an integral part of any C&D waste management system.

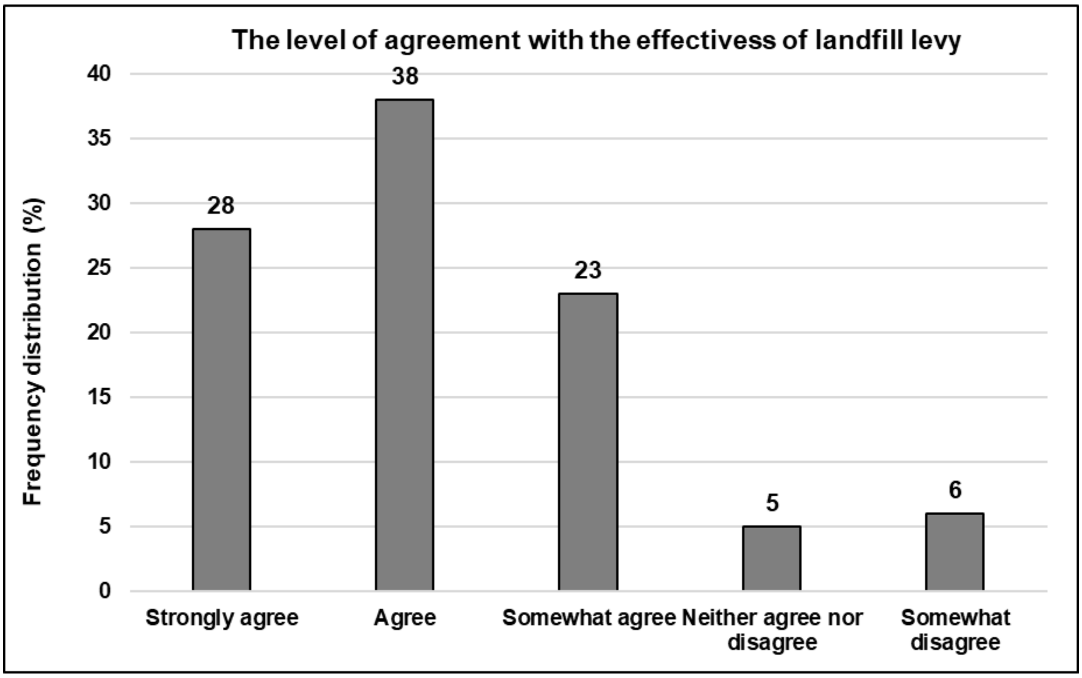
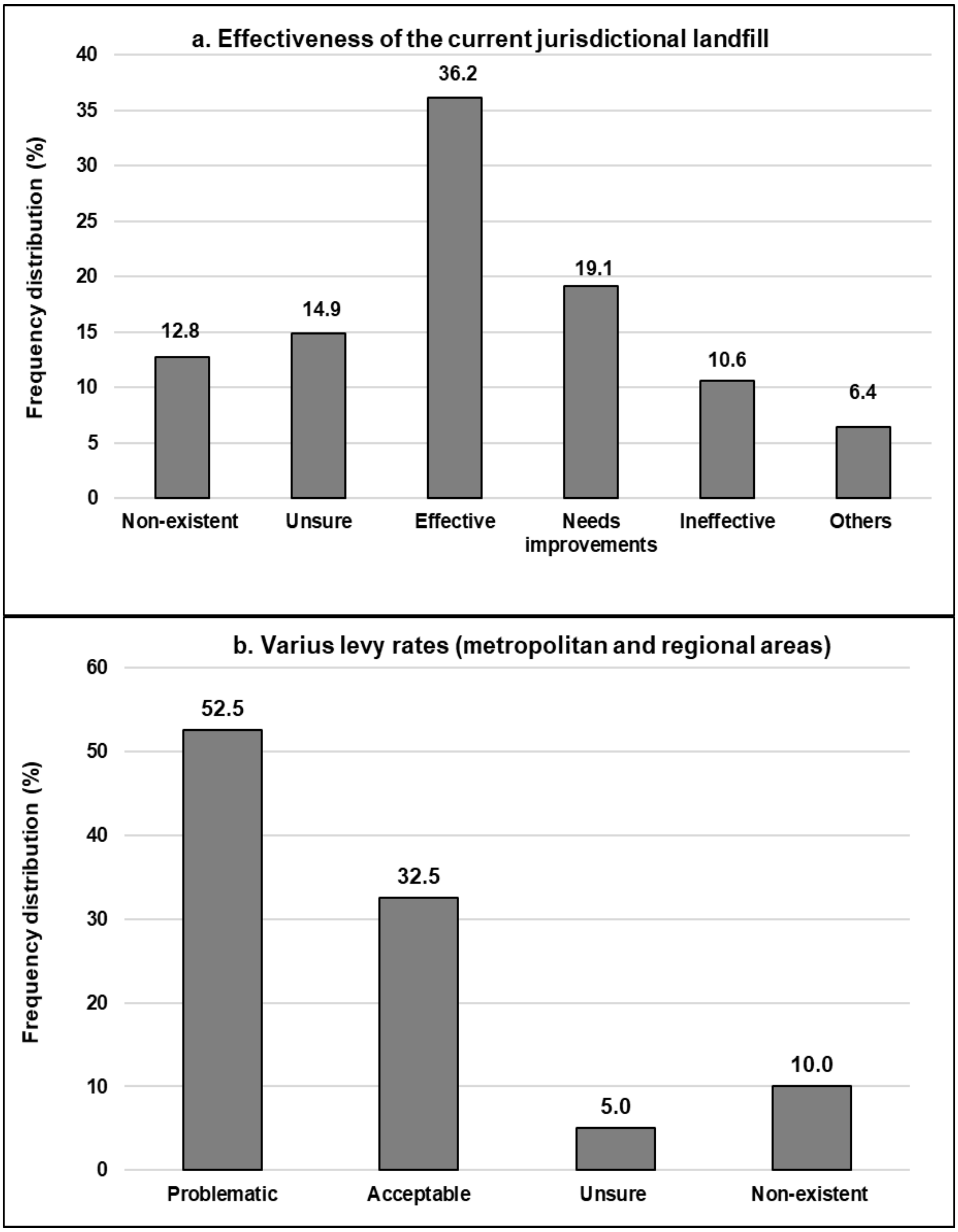


Figure 89. Frequency distribution of the agreement with the effectiveness of the landfill levy.

11.3.4 Characteristics of the Landfill Levy

To further understand the adequacy of the application of the current landfill levy regime enforced in their jurisdiction, the participants were asked to provide a descriptive response to a series of questions seeking their opinion on landfill levy characteristics. These questions were only provided to those who previously indicated that a landfill levy is an effective way to reduce the volume of waste going to landfill. Their responses were categorised based on the highest frequencies and are presented in multiple graphs below (Figure 90).



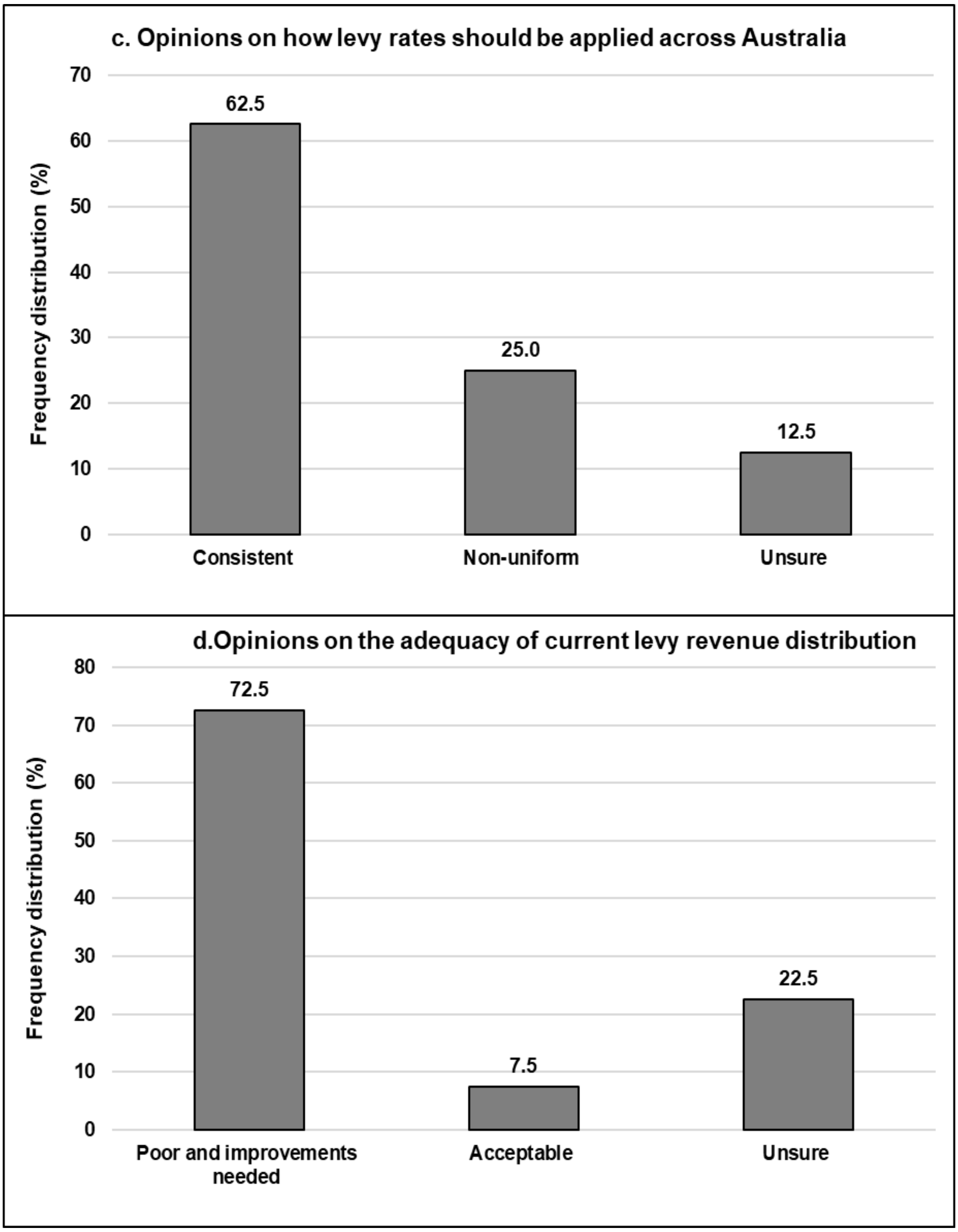


Figure 90. Participants responses frequency distribution (%) to questions related to (a) the effectiveness of landfill levy, (b) levy rate differential rate between metro and regional areas, (c) consistency of levy rate across Australia, and (d) distribution of levy revenue.

The questions required participants to comment on the effectiveness of current landfill levy specifically imposed in their jurisdiction (Figure 90a), the levy rate difference between metropolitan and regional rates (Figure 90b), the consistency of landfill levy imposition across Australian jurisdictions (Figure 90c) and adequacy of levy revenue distribution (Figure 90d). On the effectiveness of jurisdictional landfill levy, 36.2 per cent of participants endorsed that the current levy has a moderate to full impact on effective C&D waste management, while 29.7 per cent mentioned the current levy is not effective and needs improvements. The rest were either unsure about its effectiveness (13.6 per cent) or reported that they did not have levy schemes in their jurisdiction (12.8 per cent) at the time of survey, meaning they were based in NT or Tas (Figure 90a).

In some Australian states, there is a discrepancy in the landfill levy rate between regional and metropolitan areas. This cost disparity has been reported to be both positive and negative[493] and can be the source of a few issues, including waste transport or illegal waste dumping. In response to a question related to this cost disparity, participants revealed varying opinions (Figure 90a). About 52.5 per cent of participants believed that different levy rates are problematic, and consistency is needed to avoid unintended consequences and unnecessarily complications. However, about 32.5 per cent of participants indicated that differences in levy rates between metro and regional areas are practical and effective; they even stated that further discount and waivers are needed for regional areas (Figure 90b). Hence, further investigation is needed to fully understand how discrepant levy rates can act as a powerful tool for waste management or otherwise.

Cost disparity in levy rate also exists between Australian states. The participants were asked to indicate their opinion about this cost disparity. The results showed an overwhelming majority of responses (62.5 per cent) supported having a national consistent levy rate (Figure 90c). About a quarter of responses supported non-uniform levy rates. Lastly, there is a debate on how to spend the revenue generated from landfill levy imposition. Therefore, this survey targeted respondents' opinion about the current system of levy revenue distribution. The results, as shown in Figure 90d, suggested that majority of participants (72.5 per cent) believed that there is a poor distribution of the levy revenue and improvements needed to maximise waste recovery in C&D waste sector. One widely referenced recommendation was to return the revenue to the waste industry. The other interesting finding was that almost one-fifth of participants were unsure about the current distribution system.

As shown in the results, the key stakeholders were less agreeable to more pecuniary imposts and among those who agreed to it were critical about the current levy regime knowing that it is an effective tool to manage C&D waste. In response to questions related to levy characteristics, several reforms made by the participants. Among other reforms, national harmonisation of gate fees was repeatedly suggested. It is argued that a national gate fee can minimise interstate waste transfer (Wu et al., 2020) and reduce complications for companies operating in various states (Shooshtarian et al., 2019, Senate Environment and Communications References Committee, 2018). Particularly one respondent mentioned that '[levy rate disparity] *encourages waste movement vehicle accidents increased carbon emissions - just moving the issue 200 Km away*".

However, it should be noted that such an arrangement might not produce the best results. Simple harmonisation may overlook the existing contextual conditions in each jurisdiction. It may also interfere with the specific waste management system implemented in different states and territories. Below are some examples of participants' opinion supporting levy differences between regional and metropolitan areas:

- '[levy rate] *needs to be higher in regional areas to promote recycling. Otherwise there is not the market for C&D material in these locations*"
- 'Levy rates should be less in regional (Qld) where there is no option to recycle".
- *'Agreed due to the remoteness conditions of the NT, which could help preventing illegal dumping"*
- *'A differential levy works in mainland states because of the vast geographic size of mainland states".*
- *'Regions are too diverse to be able to manage the same way as metro areas due to lack of resource availability"*

[493]Environment and Communications References Committee. Never Waste a Crisis: The Waste and Recycling Industry in Australia; Parliament of Australia: Canberra, Australia, 2018.

Hence, it is better to set up the levy fees in a way that ensures the negative impact on the effective management of C&D waste across Australia is minimised. For instance, a rate disparity should be calculated to the extent that it does not prompt unnecessary long-distance waste transfer. Another point of debate was about the right rate for landfill levy that produces the best possible results. While many participants appreciated its impact on further waste recovery and supported the regular increase in the rate, others stated that rising the rate may cause illegal dumping and stockpiling, waste transfer and increased building costs. Below are some of the arguments provided by respondents:

- '*it is ineffective in WA due to DWER being unable to control illegal operations*"
- *'It increases building costs without reducing waste"*
- *'As per findings by the Waste Authority in 2014 before the Levy was increased the cost of transport is a key factor in providing incentive to recycle rather than landfill. But if your generating waste next to a landfill its cheaper to landfill than recycle in WA".*

As a result, it is suggested that any increase in levy rate should be complemented with effective compliance and enforcement regime that rely on technologies such as GPS tracker, and considering transport costs and other cost implications for construction companies.

Lastly, the comments on the levy rate revenue investment, the majority of responses suggested the return of revenue to the waste industry. In Australia, there is no nationally prescribed method for distribution of levies for such purposes and each state government does so according to its priorities and the objectives (Serpo and Read, 2019). The NSW state government has invested $900 m over the last 9 years (2010-2020) in waste management and resource recovery sector. This investment is in light of Waste Less, Recycle More initiatives to the state re-invest levy revenue. In Vic, in 2010, the Environmental Protection Agency (EPA) enacted regulations to determine the share of levy revenue to be received by each state agency. In this state, during the 2015 financial year, the levy revenue was distributed to the following agencies: the EPA received 18 per cent, Sustainability Victoria received 12 per cent and Waste and Resource Recovery Groups (Councils) received 5 per cent. Similar to Vic, WA has a piece of primary legislation that specifies the arrangement of levies imposed and that the money collected through levies are used by the Environment Minister to (a) fund certain programmes relating to the management, reduction, reuse, recycling, monitoring or measurement of waste and (b) fund a person or body to conduct the activities mentioned in (a).

Other state governments, however, have not revealed a firm plan that determines how the levies charged at landfill sites should be distributed; in this situation, funding has been granted on a case-by-case basis and according to waste jurisdictional strategy objectives. For instance, the NT waste strategy document indicates that government will fund and support campaigns to encourage the community to generate less waste, and also to maximise use of current waste collection systems so waste going to landfill is minimised where possible and practical[494]. In SA, the waste strategy (2015-2022) declared that more than $ 80 million sourced from levy revenue had been invested into industry during the past decade; the fund allegedly was used by Zero Waste to build capacity and improve industry competitiveness[495]. This strategy also indicated that 50 per cent of the levy is transferred to the Waste to Resources Fund under the Zero Waste Act 2004, is to be spent on in accordance with the Zero Waste SA Business Plan. In Qld, In 2019-20 it is estimated that of the $1.54 billion in funds raised, around $569 million or 37 per cent will be reinvested into waste and recycling activities (Serpo and Read, 2019).

In Australia, state and territory governments have a pivotal role in the management of C&D waste, including design, implementation and monitoring of landfill levy. Government agencies who are

[494] ACT Waste Management Strategy (2011-2025). Towards a sustainable Canberra. ACT.
[495] South Australia's Waste Strategy, 2015-2020, p. 10.

responsible for the imposition of the landfill levy should carefully consider several factors in the design of the landfill levy regime to avoid potential issues. One study in Qld showed that how unprecedented state government decision in introducing and revoking of landfill levy significantly impacted the recycling rate of C&D waste in this state (Forghani et al., 2017).

State and territory government responsibility is to provide financial support for waste management and resource recovery activities. The typical source of these supports are known to be the revenue derived from landfill levy imposition. Serpo and Read (2019) suggested the following reforms to maximise the benefit of revenue investment in the waste related industries:

- Maintain a separate waste levy trust account from which all levies collected are managed,
- The Trust Account should have clear rules on how the funds are to be allocated and reported on including objectives that link to the State's waste avoidance, resource recovery plans,
- Levies raised are only invested in activities consistent with the Trust Account's rules and objectives,
- Guaranteeing a minimum percentage of levies be spent annually on activities to implement the jurisdiction's waste avoidance and resource recovery strategies, resource recovery and remanufacturing industry development plans, market development initiatives and infrastructure plans;

Particularly the federal government can take leadership in the development of a national waste levy policy that enables consistent imposition of waste across states and territories. Despite the prohibiting impact of landfill levy on waste disposal, market incentives were found to be a useful tool in management C&D waste space. Development of the domestic market for recycled materials is an effective market incentive-based strategy knowing that overseas waste destinations are no longer available to Australian industries (Shooshtarian et al., 2020). The successful development of a C&D waste material market hinges on several factors. Shooshtarian et al. (2019) identified seven main factors that include regulatory support, extended producer responsibility, the establishment of the effective supply chain, sustainable procurement, investments in technology and infrastructure, research and development and landfill levy imposition. Caldera et al. (2020) stated that market-based policy instruments could be developed through taxes, subsidies and other incentives, to encourage waste diversion from landfills, recycle and create a second life for waste material. To market the recycled material as a substitute for natural raw materials, it is essential to increase awareness and carry out promotional activities. Then a continuous supply of clean waste streams is necessary to produce high-quality recycled content that satisfies the given technical specifications and be economically competitive.

11.3.5 Economic barriers

Participants were asked to indicate factors they perceive to be the main barriers to effective C&D waste management from the list provided to them. Responses from participants suggest that there is a wide array of barriers that can negatively impact the Australian waste management system. To further analyse these factors, they are categorised into 19 major groups. Figure 91 displays the frequency distribution of these major groups of barriers identified by the participants. The results showed that the most frequently referenced factors include "overregulation, recycled materials acceptance criteria set by government agencies and increased testing" (13.4 per cent), "lack of local market" (9.8 per cent) and "culture, poor education (attitude and behaviour) and acceptance" (8.5 per cent).

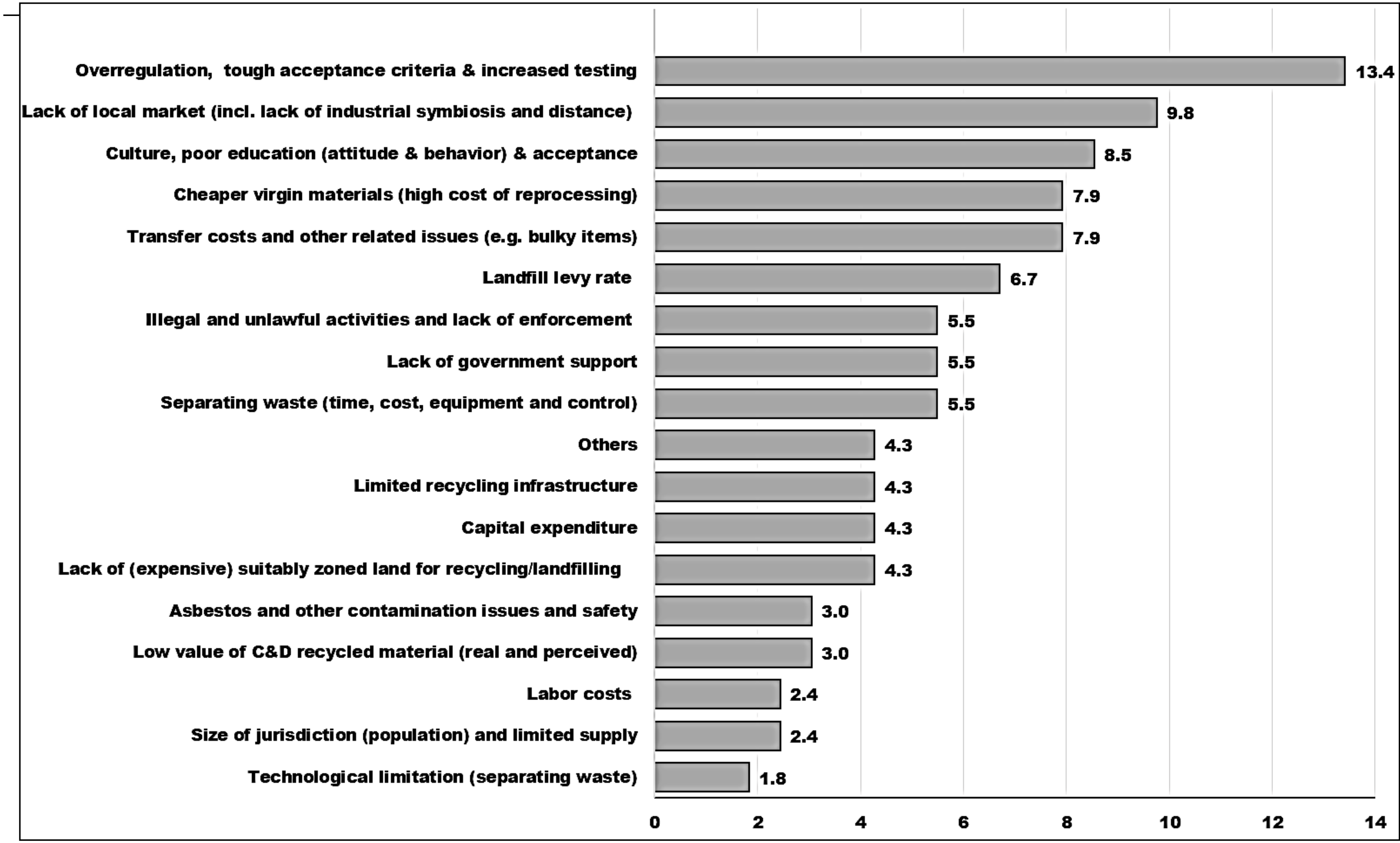


Figure 91. Frequency distribution of the main barriers towards successful implantation of effective C&D waste management in Australia

11.3.6 Role of the federal government

The federal government plays a critical role in the planning and implementation of an integrated waste management system. Despite the statutory duty of the Australian jurisdiction, the federal government has powerful tools to coordinate the disjointed efforts across states and territories. Therefore, participants were asked to express their level of agreement about some of the potential federal government roles to improve waste management. The proposed contributions have been extracted from desktop research and C&D waste expert opinions (Figure 92). The results show that, except for "providing GST subsidy for recycled materials", survey participants agreed that the rest of government contributions enhance the effective management of C&D waste (Figure 92). The most supported potential impacts of the federal government were identified to be "building confidence in C&D salvaged and recycled materials in the market" (97.5 per cent) "providing national leadership and coordination of C&D waste efforts" (93.8 per cent) and "investment in technology and waste facility" (93.7 per cent).

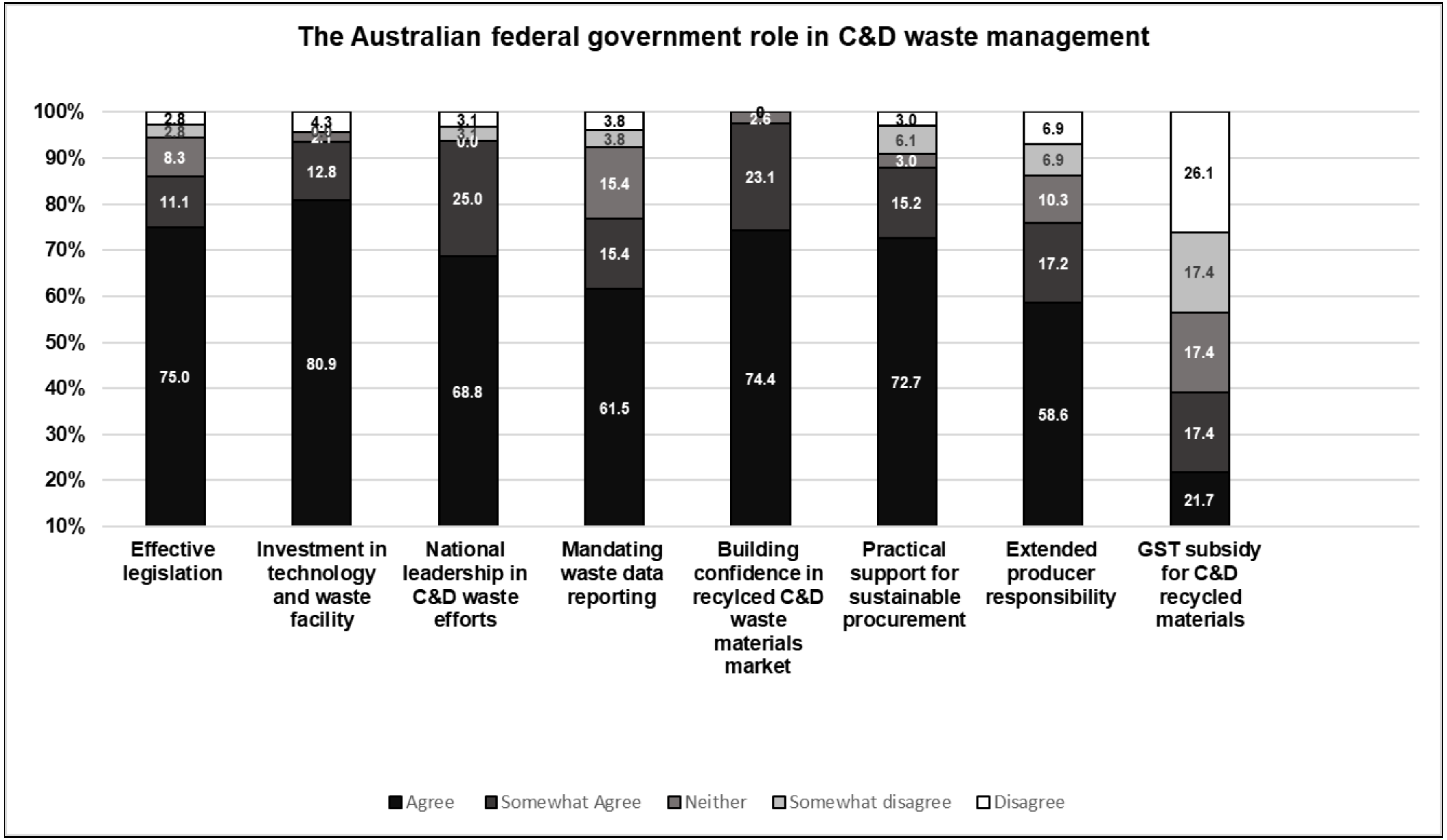


Figure 92. The role of the Australian federal government in the C&D waste management framework

11.3.7 C&D waste legislation

Legislation has a substantial impact on the way C&D waste is managed. Among the various reasons why legislation is particularly important is the lack of consensus about the adequacy of current regulations in Australian jurisdictions. Participants were asked to indicate if the current legislation supports or discourages C&D waste reduction, reuse and recycling in their State or Territory jurisdiction. More than 45 per cent of participants consider that the current regulations are not in favour of more recycling and waste minimisation activities (Figure 93). To obtain more appropriate categories to describe the issues with the current regulations, and to make sure there was an awareness of the issues identified from desktop research at the time of the survey, participants were provided with a range of options. As depicted in Figure 93, the three main issues were found to be "illegal dumping and stockpiling" (18.9 per cent), "definition and classification of C&D waste" (16.5 per cent) and 'extended producer responsibility" (13.4 per cent).

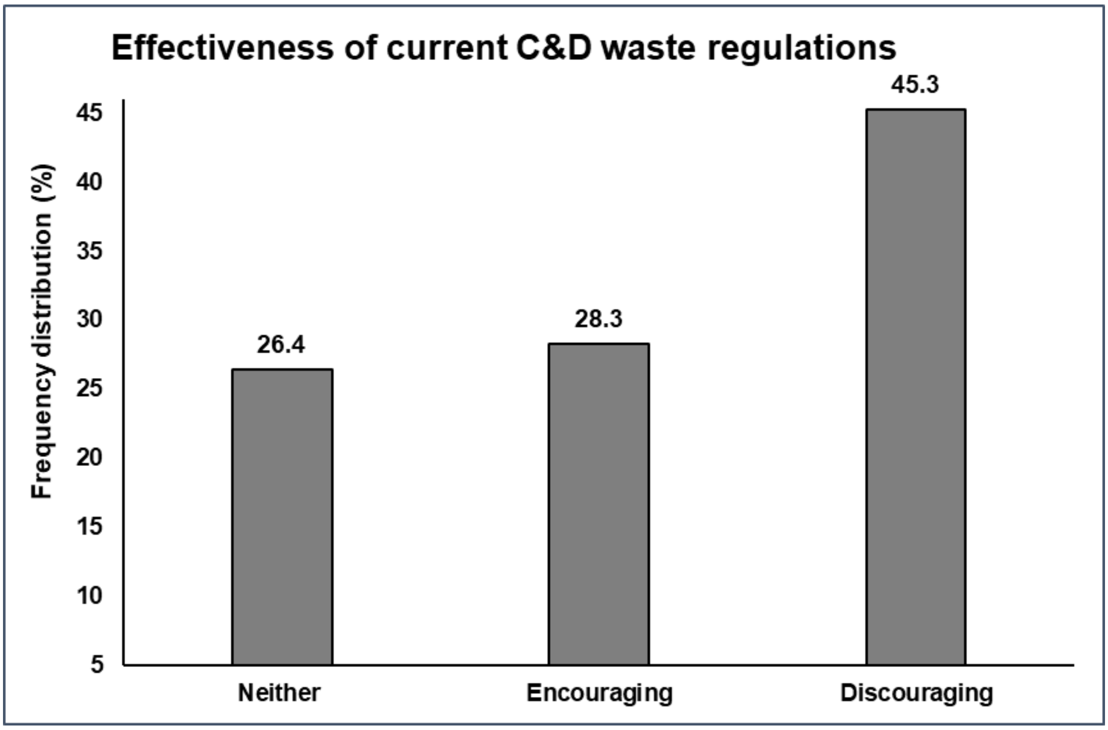


Figure 93. Participants' opinion about the effectiveness of the current C&D waste regulations in discouraging further waste recovery

To further understand how current legislation operates in favour of or against the successful planning and implementation of effective waste management, participants requested to provide a reason for their choice and possible suggestions to modify the system. These issues were reported based on the inconsistencies perceived by respondents from C&D waste regulation. Three key categories (i.e. reasons) emerged through the thematic analysis of open-ended responses are: 1) varying jurisdictional systems; 2) different testing criteria; and 3) limited market opportunities for recycled products. Varying levies within jurisdictions was raised as a major reason for their choice, including 'variable levies", 'different expectations and targets" and 'nuances in the waste definitions". A national standard for C&D waste management, standard levy rates across the country, more legal action for illegal dumping and more capacity for innovation were proposed as possible future opportunities.

Different testing criteria was also highlighted as a major issue by the respondents. Factors such as 'variations in allowable parameter limits", 'aggregates reuse specification", 'additional testing requirements", 'allowable contamination levels" were identified as factors affecting the different testing criteria. The respondents highlighted the urgent need for opportunities for business to use secondary material and exemptions to encourage movement in that direction. Limited market opportunities for recycled products was the third key issue emphasized by the respondents. For example, 'additional costs", 'limited product demand", 'lack of infrastructure", 'inconsistencies in the product quality standard" and 'existing cheaper alternatives" were indicated as factors affecting limited market opportunities for recycled products. Respondents emphasised more focus on research and development to investigate how businesses could benefit recycling products and implementation of effective product stewardship schemes. Table 114 provides a summary of selected participant qualitative responses to support the three key categories.

Table 114. Participants' responses to the inconsistencies in the current C&D waste regulations

Category	Sub-category	Example quotes (open ended responses)
Varying jurisdictional systems	Variable levies	*Cross state border differences in regulation,* *Waste levy costs appear inconsistent and this appears to drive the wrong behaviour ie. we truck waste to another jurisdiction where levy costs are lower* *Does not flow from National to State to Local government* *Cross state border differences in return of landfill levy revenue* *In QLD* [Queensland] *the levy is so low that it takes mixed C&D waste from potential markets in* [New South Wales] *NSW.*
	Different expectations and targets	*In WA* [Western Australia] *we have overwritten specifications that we cant match in [the] manufacture* *Different recycling targets* *In NSW, it is very difficult to use C&D wood waste as fuel. In other states, it is widely used as a fuel*
	Nuances in the waste definitions	*In NSW a recycled waste product is still defined as waste even when it meets an Australian Standard equivalent to a natural product. In Victoria, it is no longer a waste once it is recycled into an approved product.* *In NSW waste is always defined as waste even after its recycled. In Victoria, it is no longer a waste if it meets a suitable standard or specification.* *No requirement to be a mandatory activity*
Different testing criteria and reuse specifications	Variations in allowable parameter limits	*Allowable asbestos limits in Victoria and WA however no allowable limit in NSW* *Asbestos has a very low allowable limit in most states except NSW. In NSW one fibre of asbestos in a stockpile of crushed concrete makes it a stockpile of asbestos waste.*
	Aggregates reuse specification	*In SA* [South Australia] *they have the sustainable aggregates association for testing costs reduction and brand development of C&D materials.* *Inconsistent reporting requirements*
	Additional testing requirements	*- why does recycled content have to be tested so much & virgin not when the same risks are involved especially for companies that blend virgin product with recycled & don't have to test*
	Contamination levels	*Acceptable contaminant levels in recovered C&D materials*
Limited market opportunities for recycled products	Additional costs	*Transportation costs for some local councils away from the CBD* [Central Business District] *The regulations, licensing costs and application processes for reprocesses are too onerous* *Expensive to process recycled materials* *Costs associated with sorting the C&D waste*
	Product demand	*Procurement - recyclables are generally not allowed in construction projects (not included in Tenders)*
	Lack of infrastructure	*DWER [Department of Water, Environment and Regulation, WA] imposes a restriction on locations and uses* *Driving recycling when there is no infrastructure*
	Inconsistencies in the product quality standard	*there should be a consistent set of national standards for recycled C&D products and end-uses to provide confidence to the market* *Lack of strong guidance from EPA [Environmental Protection Authority] on use of recycled materials*
	Cheaper alternatives	*Cheaper to landfill* *Cheaper to import virgin materials*

To obtain more uniform categories of the issues with the current regulations, and to make sure that they are aware of the issues that are identified from desktop research at the time of the survey, participants were provided with a range of options to choose three from. The result, as depicted in

Figure 93 the main three issues were found to be ‘extended producer responsibility” (13.4 per cent), ‘definition of waste as opposed to resource” (10 per cent) and ‘waste data management and reporting” (10 per cent).

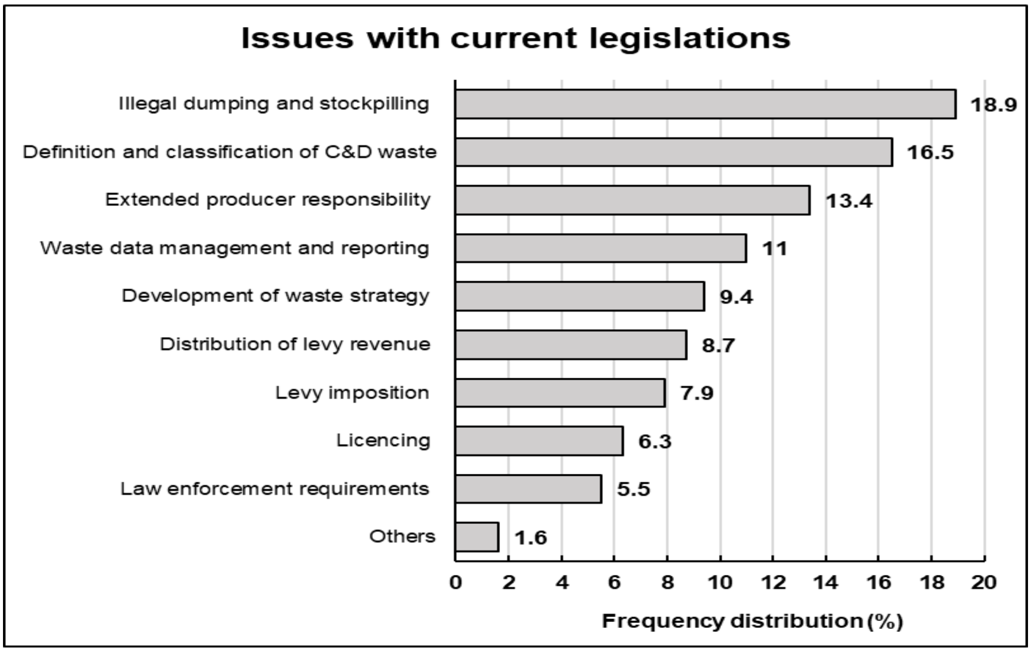


Figure 94. The main three issues in current legislations

For each of the issue mentioned above, several reforming strategies provided by the respondents. Table 115 summarises these recommendations.

Table 115. Participants' input about the main issues in the current C&D waste regulations

Issue	Explanations	Issue	Explanations
Ambiguity in the definition and classification of C&D waste	• very unclear and soil is not defined • no enforcement by regulators • need clearer and simpler guidelines • inert C&D waste normally being reported separately to C&D, which in occasions gets missed in the reporting from landfills. • have a national standard • End of waste guidelines have only just come out for review after missing for 5 years due to legal action between the state and a large C&D landfill company. very poor offering with no innovation. just a question of which of the other states we could copy...! • Definitions of waste should be homogenised across Australia • Create standardisation and harmonisation	**Definition of waste versus resource**	• This is a critical issue for all states • This is a barrier and it's complex to solve unless we have greater regulation. Once processed, a waste should be considered a resource but the amount of processing and who monitors this for quality is the issue from an engineering perspective. • liaise with best-practice industry to set strict definitions • In NSW recycled products made from waste is still defined as waste. This causes lots of issues when trying to separate it from regulations to deal with waste that's not been recycled. The regulation states that 'Asbestos waste can not be recycled and the definition of asbestos waste is any waste that contains asbestos". So is a recycled crushed concrete road base that meets the RMS standards has one asbestos fibre in it then the entire stockpile is defined as asbestos waste. In other states in Australia its not defined as waste and therefore doesn't have the same problem. • Important to provide clarity to both recyclers and purchasers • If a waste material can be reprocessed into a 2nd life capability then there ought to be exemptions to entice that direction • Clarify • C&D should not be classed as a waste, it is a resource (like so much other material) • A recycled product should no longer be a waste once it complies with a standard or specification. A national legislative framework would be highly beneficial. That developed by Queensland appears to be the most appropriate of the three developed to date.
Levy imposition	• reduce the levy rate for commercial operators, this will help to maintain local business • Pls see earlier comments re applying the levy efficiently and effectively to provide a level playing field in which the disposal and recycling industry operates. • None- impose one • must be consistent • Greater consistency in application cross different jurisdictions would help	**Illegal dumping and stockpiling**	• yes • Use levy to fund more active investigation and monitoring of sites, with greater penalties for illegal dumping. • see licensing • No way to prevent this in remote communities. • Minimising illegal dumping and stockpiling is the key managing this waste stream. Illegal dumping clearly requires more compliance and enforcement actions (and perhaps greater tracking of waste, more stringent licence conditions), while stockpiling (which may be legal) should be more tightly controlled so as to avoid unintended consequences (such as stockpiling on rented land which is then vacated leaving a liability with the landholder or government). • increase penalty and enforcement • Improve ease of prosecution • Cost needs to be added to point of purchase, with no cost incurred for disposal • Control better through tracking and reporting at all stages • Big issue, even with no landfill levy C&D wastes and others are routinely dumped as part of the widely accepted business model • Authorities need the power to stop "pop-up" waste dumps opening without licences/approvals and no staff or machinery to operate - It took 3 months to close a site here in Perth that just opened. Now there is 100,000m3 of waste dumped and DWER and council couldn't act fast enough.

			as the rates go up more likely but rouge element always there and goes back to licencing
Law enforcement requirements	• should monitor the illegal disposal of C&D waste • see licensing • Planning take no action for illegal filling or reclamation with C7D wastes. • Need level playing field as smaller operators can declare bankruptcy and escape • must be consistent • Inconsistent in application and in interpretation • licensed premises are targeted more than illegal	**Distribution of levy revenue**	• What revenue? Never seen it here in Perth - not a penny. Get's spent all on compliance and they can't even close illegal sites - they get the local council to do it for them. • Use Levy income for initiatives • Should not go back into consolidated revenue. Needs to be reinvested in the industry and in compliance activities • Should be a national prescription so everybody is under the same umbrella • Required more use of funds raised to increase resource recovery markets & infrastructure • only <25% of the levy is distributed in grants. most of this is to local governments and non viable programmes that wouldn't survive without the grants. better choices from non political positions (similar to Arena for the renewables market) is needed on a national scale and in each state • ONE- Provide funding for new sites • must benefit end user • More grant funding for industry and investment in project trials, innovation and new technology • Greater funding for research into product performance definitely
Waste data management and reporting	• Yes • yes • There should be an industry standard for waste measurement. • There is currently no reporting. If we could introduce reporting, we could quantify the issue and start finding solutions. • see licensing - data obtained currently in any state is only 50% of what is actually happening • register at point of drop off, so other business can see uses • One uniform way to report data by ALL facilities so that it can be collated together and utilised. Everyone at the moment has their own method - digital, software, spreadsheets, manual (book entry) and there is no way to validate the information. • must be audited • Mandatory tracking and reporting across all areas • Mandatory reporting of C&I and C&D waste - the same as MSW • mandate tracking of waste vehicles • landfills only report the C&D waste stream when they service a population higher than 1000 people • lack of governance around data collection therefore data is not very useful for planning purposes • In NSW the EPA collect the waste data about volumes of waste and how much is being recycled however they won't supply the data in summary form to industry. • There is no consistent state-wide reporting on C&D waste.	**Extended producer responsibility**	• yes • work more with the producers of this source of waste, perhaps solutions could be developed to reduce certain materials that are hard to recycle. • Transition • This is extremely difficult in construction due to the long design lives of materials making a manufacturer payment today grossly inadequate in 50 years time • The producer of the waste should pay for repurposing that waste back into a usable resource. This reflects the true cost of the product to being in with and takes away the incentive to illegally dump waste. • should imposed the extended producer responsibility • Producer of the waste in remote communities takes no responsibility (no paying of fees / illegal dumping / etc.) • Not likley to be an effective approach given the conditions required for effective product stewardship schemes. • Needs more commitment from government and construction sector to by recycled. • Needs greater focus and government willing to pass regulation rather than toothless initiatives like the NPC • More Stewardship programs • do not exist but would be useful to help drive change if it did exist • chain of custody procedures t be adopted • C&D product/sales have little cost placed on them for the processing of their product at its end of life. this should be explored as it would put more onus on producers and R&D to make better products and products that can easily be recycled. • Agreed. • Agree - increase the likelihood of it being recycled

	This needs to be rectified by establishing state-wide data collection systems. • The differences in states can be overlooked by managers that move with work. National approach. • The data collected should be shared with industry. • standard reporting protocols required • see licensing • One software system, one program, one report. • Need to have a baseline on current behaviour, practices and opinions • Less focus on recycling rates and more emphasis on overall generation. Standard waste classification and lower thresholds for weighbridges • Desperately needed.		
Extend the legal liability of illegal dumping activities to those who transport, accept and allow waste to be illegally disposed of anywhere	• yes this is supposedly in the current legislation but seems never enforced • Yes • yes • Sounds good • needed • Make people personally responsible for waste dumping, stockpiling and utilising illegal sites. Transporters will go to the cheapest site even if that site is not licenced and is purely a dump and run site. • I thought this was already the case in NSW • I have been stating this for years - if i went to a pub & bought a TV for $50 i would get charged for receiving stolen goods. Why the hell is there no chain of responsibility for builders etc who screw the price down to what is the known cost for disposal? they should be charged for illegal waste disposal as they know it is not going to a legitimate facility • have a national standard • Create chain of responsibility • as above • agreed	**Licensing**	• yes • no licencing exists for C&D waste stream handling • No 1 issue - needs quicker timing and less requirements to achieve approvals for resource recovery facilities • Make licensing mandatory and at different levels • in western Australia you need a license to catch a fish, be a plumber or electrician or even hang wallpaper but anyone can transport waste without a background check or license. there is criminal activity in our industry & large amounts of waste being transported illegally for cash payment. this can be stopped nationally easily by mandating that every vehicle capable of transporting waste (tipper or bincar) be licensed by the relevant state authority & have standard GPS tracking fitted. known tipping spots can have geofences for alerts & waste can be tracked. Auditors can do spot checks of operators - say on 9 Feb abc bobcat GPS shows you stopping in 6 locations please document where the waste went,. Same applies for landfills showing incoming waste (no cash payments) all of a sudden the waste levy income doubles & the market place is on a level field. • improve enforcement • Any company and vehicle associated with transporting or handling waste ought to be licenced. All vehicles and skip bins should be clearly marked with company name and licence number. there are too many anonymous waste transport trucks on the road. Again, tighter budgets (due to the levy not working) means they don't visit sites and have no understanding of how C&D recycling actually works and needs to be controlled.
Development of waste strategy	• Develop educate and encourage across industry including producers and end users • Critically missing as outlined by the VAGO report. • community strategy required	**Others (please specify)**	• Ultimately, the user must pay for the true cost of the product and that includes reprocessing the waste back into a usable resource. No resources (staff and site) to be able to offer C&D segregation from landfill and recycling opportunities

Non-legislative policies and guidelines are an important source of information and guidance for the stakeholders of waste management in Australia. Hence, participants were asked to indicate the main five areas of improvement that can be facilitated through policy development. The results of their responses are provided in Figure 95. The main five areas were found to be 'Providing a guideline that determines the accepted level of contamination for reusing C&D waste" (61.4 per cent), 'Preparation of guidelines on requirements of using recycled C&D materials in different industries" (59 per cent), 'setting target for reduction, reusing and recycling C&D waste (54.5 per cent) sustainable procurement guideline" (43.2 per cent) and the development of a statewide waste resource recovery infrastructure plan" (43.2 per cent).

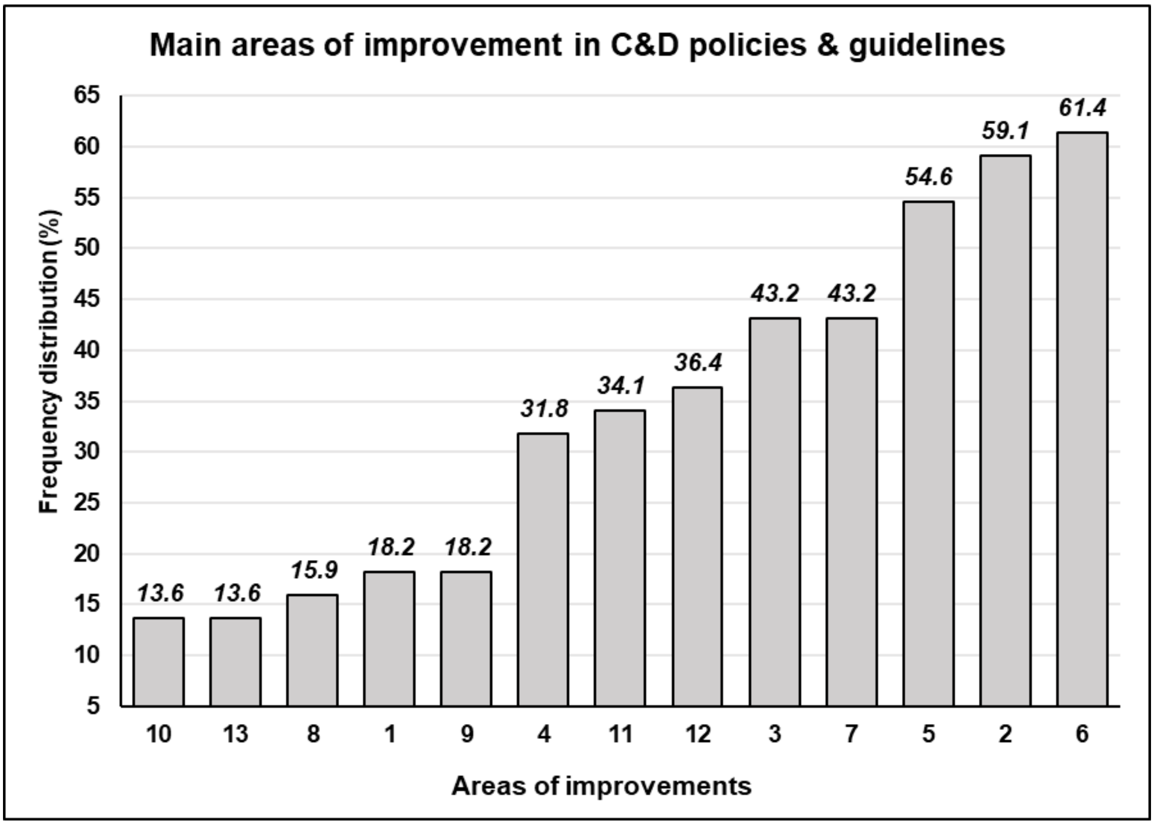


Figure 95. Areas of improvement in non-legislative C&D waste policies and guidelines

To obtain more information about other policies implemented in other parts of the world that participants might have been aware of, a question was posed. The question sought to understand if there is any foreign policy that can be considered in participants' jurisdictions. A large proportion of the responses suggested the policies that are in place in European nations, particularly Germany, are suitable for the Australian context. Table 116 presents these responses.

Table 116. Participants' insight into the best practice management in other countries

No	Explanation	No	Explanation
1	Whatever happens in Europe is always worth considering.	15	Need to move from waste = a resource. Building sites required to have recycling plans lodged with building applications to separate waste on large projects or commit to all waste going to a resource recovery facility.
2	we have been lobbying for GPS trackers in trucks under their registration details for years. this would make it so easy for the regulators to police the companies that are doing the wrong thing with their waste and lowering their prices because they can avoid paying a levy on their residuals that arnt even getting recycled in the regional areas of Western Australia. rewards on licencing fees for those that have GPS trackers would have a carrot not stick approach. in the UK we have a Basic Raw Materials Tax to help balance the cost of virgin material and recycled materials.	16	more waste streams that can be added to products EG ash into road base glass into road base and asphalt
3	waste to energy, this would help to reduce products that would normally go to landfill and that are hard to reuse/recycle	17	Many European nations mandate more C&D recycling, mandatory procurement of recyclables and fund essential industry infrastructure along with well-defined waste and recycling precincts.
4	unsure by I would suggest the response to Q5.5 would be the same	18	Look at waste from other streams that work within Australia.
5	unsure	19	Japanese waste policy
6	Unknown	20	It is almost impossible to eliminate asbestos in C&D materials and there needs to be a practical level permitted depending on the use of the recovered material. Re sampling of C&D recovered stockpiles after asbestos is found needs to be allowed otherwise the loss of a complete stockpile can financially destroy a C&D recycler
7	UK and Germany	21	Germany/Japan
8	UK and Europe have a number	22	Germany currently the best practice, Australia just needs to adopt this model with a policy that allows continual improvement
9	Sweden	23	Don't know
10	Other countries have an agency that is in charge of recycling waste. In NSW its the same agency that manages licencing of waste facilities and enforcement of the regulation is their only priority. Encouraging more recycling is a low priority. There used to be an agency the looked after recycling, but they were merged together i.e. the EPA.	24	Circular economy in the Netherlands
11	Not to my knowledge	25	Change to all levels of Government procurement policies
12	not that I am aware of	26	C&D reuse should be mandated as the first choice material before extraction of new materials is allowed,
13	Not aware of any	27	Any countries that mandate separation at the source
14	No	28	An allowable limit for asbestos in recycled products of 0.01%

According to the desktop research terminologies used in regulations are believed to have tangible implications on waste management. In particular, the definition of waste versus resource is a source of confusion and may impede activities that contribute to a successful waste management system. Participants were asked to share their experience with this sometimes-misleading definition (Table 117). Almost 27 per cent of participants noted that this definition had not impacted their activities, or they were not aware of any implications. Others, however, provided a wide range of solutions to this lasting issue. Among which, adding a clear definition for a reusable waste as a resource was highly suggested. On this note, one of the respondents stated that *'Only apply the word waste to those materials that cannot be reused - i.e. very few materials are a waste, waste is a verb, and that we do very well".*

Table 117. Participants opinion about the waste definition in various jurisdictions

No	Explanation	No	Explanation
1	we lobbied for changes to the uncontaminated fill guidelines in WA as they increased the cost of manufacturing to levels above the cost of sourcing virgin material. didn't make any difference. The government didn't listen to our feedback after it was even raised in the state parliament as not complaint. (just offered lip service to the problems of poor specification by government causing stockpiles of C&D materials). [We] suggest an approach where industry self-regulate rather than government meddle where they don't understand. Also adopt procurement policies that force the use of recycled materials in D&C contracts (rather than the lip service offered to the C&D recycled road base by the Western Australian Government and MRWA who haven't purchased anywhere near the tonnage advertised in the media when patting themselves on the back for not fixing the problem.	16	It is currently still confusing in WA. It's better than it was, but still confusing. When is a waste a 'waste'. There are too many different guidelines in separate documents.
2	waste is only waste when there is no further use for the product or it is unwanted. I can throw an aluminium can in a bin as waste & i have finished using it for my purpose but it is retrieved as a wanted product as a recycling centre. the bin was a recycling bin i placed it in............ so was it waste or resource?? waste is the end of the road where no one wants the product. it is a resource until then.	17	It does not impede a lot as the recycling rates are high in my jurisdiction as well as the recycled products made from waste have been promoted adequately.
3	very little	18	It confuses people. They would rather send things to a landfill than face the EPA.
4	Use resource terminology across the supply chain	19	It can impede bonafide recovery of resources however the exemption process in NSW helps balance compliance red tape with best resource recovery outcomes. The current definitions are needed to protect the environment and communities from real risks posed by illegal dumping.
5	Unsure	20	In NSW the EPA who manage waste are more interested in enforcement and increasing their powers to regulate the lowest common denominator than they are in promoting recycling and solving the issues that increase recycling.
6	this is not a barrier	21	If there is such a problem, I'm not aware of the details
7	The regulators are always correctly trying to stop the shonky waste operators. In NSW there are very few of them. Regulations get changed regularly to keep up with these bad operators. In doing this they put unnecessary burden and costs on the good operators. Simple put if our recycled products meet an agreed standard then we should no longer be defined as waste and be captured by these regulations.	22	Everybody agrees that if there is a market it is resource
8	The definition does not impede C&D management. The lack of a state-wide policy and regulatory mechanisms to encourage C&D recovery are the biggest issues in Tasmania.	23	eliminate the term waste and identify everything as a resource
9	The definition does not impact regulation. The lack of legislation that enforces regulation of C&D stream is the main problem, associated with the remoteness of the NT.	24	Don't know
10	Take recycled products out of the waste classification	25	confirm a proper definition of waste
11	Regulations ought to be raised to allow the use of recycles	26	Clear guidance of when a waste ceases to become a

	especially in non-critical areas and perhaps these could be insentively classed as GST free		waste (and is instead considered a product) is critical. This is generally difficult to do in legislation (because waste often requires a broad definition) but is suited to regulatory policy or guidance.
12	Quantify and categorise all potential materials in an industry, build this category, expected yield (waste), timeline expectancy into building plans, work method statements so that 'waste' can be well defined, where as resource potential can be maximised	27	because of a court ruling here in WA regarding a landfill site that refuse to pay the levy as they were arguing their usage was for sequential land use, DWER have changed the definition to an almost unworkable description. For WA because of the DWER total risk avoidance approach, the onus of ensuring materials are fit for purpose and free of contaminants needs to be put on the owner/developer from where these materials are coming from. For example, if a developer is removing sand from a site, this is actually classed as a waste from when it leaves the site and the emphasis falls on the receiver to ensure it is fit for purpose. In WA the regulations and testing compliance fall only on licensed recyclers because the DWER only have the resources to keep them compliant. Unfortunately, this only accounts for about 20% of the 'waste' being moved. The remainder moves from site to site or unregistered operations and doesn't get checked. The materials should be tested prior to extraction and a then a decision can be made on location it must go to i.e. suitable for reuse of not. Much easier to control and maintain compliance
13	Only apply the word waste to those materials that cannot be reused - ie very few materials are a waste, waste is a verb, and that we do very well	28	Access to a list of companies that utilise certain waste streams
14	Once C&D waste has been processed into a saleable product it should not be considered a waste.	29	a reduced levy on C&D would help to reduce the impact on small business, as well as having a positive impact on potential recycling of these materials, also reduce the possibility of illegal dumping.
15	Need to move from waste = a resource. Building sites required to have recycling plans lodged with building applications to separate waste on large projects or commit to all waste going to a resource recovery facility.	30	We have people filling sites and not paying a levy because the fill they are using is classified as "engineered fill" which is just a fancy word for "mixed waste that is now so small due to crushing you can't see the bottle caps and wood chips unless you bend over and look close" yet they are allowed to use it and fill land and avoid paying a levy. This financially impacts how other recycling facilities operate that cannot simply fill the backyard they are situated on and have to properly sort their C&D waste and have to pay levies when depositing by-product to landfill.

11.3.8 Waste management schemes

Seven waste management schemes (advisory/mandatory) identified in the desktop research were presented to participants, in order to understand their views on effectiveness (Figure 96). The survey results show that 'manufacturer's shared responsibility of waste generation" (86.4 per cent), 'subsidy for C&D waste recycled materials" (81.4 per cent) and 'proximity principle" (78.6 per cent) received the highest rates of agreement by the respondents. In the case of manufacture's shared responsibility, many responses (n= 8) highlighted that the scheme encourages producers to design and produce a readily recyclable material.

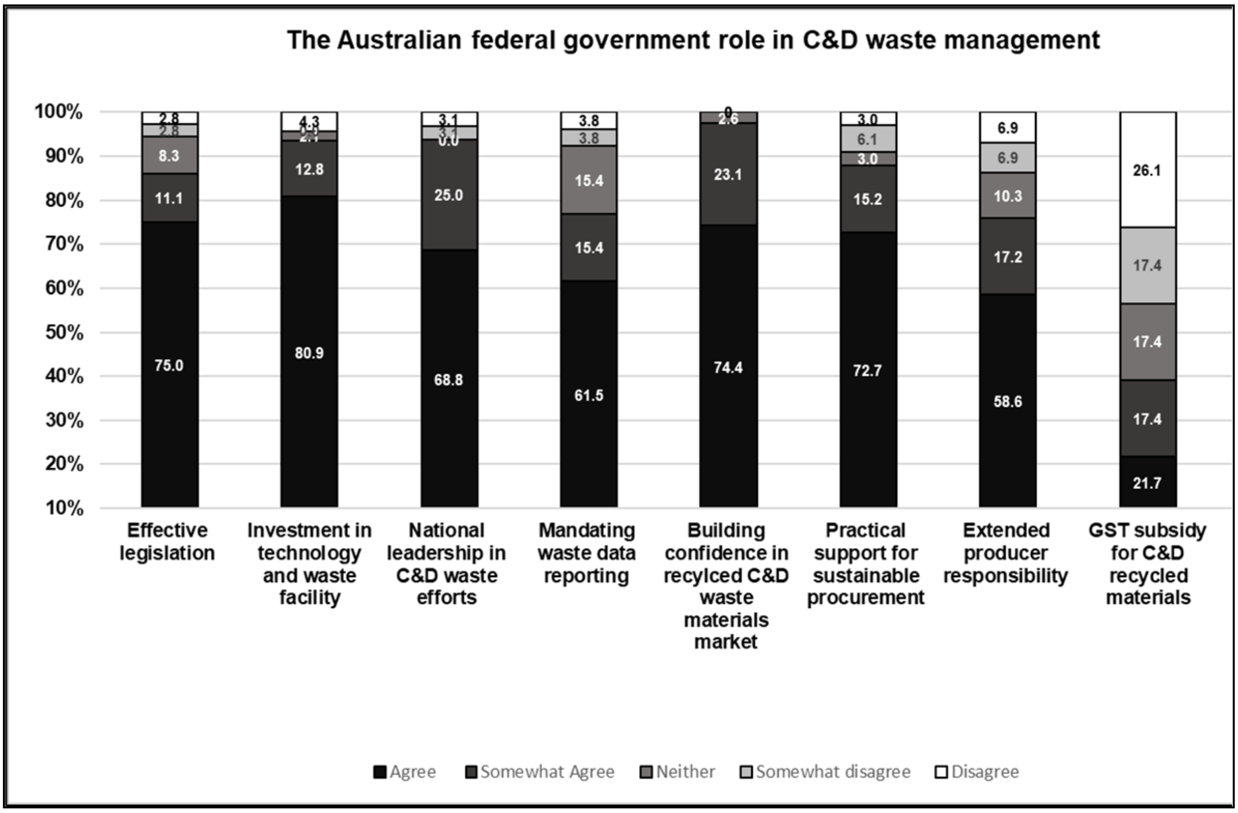


Figure 96. Participants' agreement level with various (advisory/mandatory) schemes

Furthermore, for each of the schemes mentioned above, participants shared their views and indicated how they think these schemes can be helpful for better management of C&D waste in Australia.

Table 118. Participants explanation about various (advisory/mandatory) schemes

Scheme	Explanation	Scheme	Explanation
Manufacturer's shared responsibility of waste generation	•Yes. Producers feel better as they follow through •Yes, they reap the convenient benefits, now there should be as many convenient ways to reclaim waste. •Yes - it will encourage manufacturers to create products that can be readily recycled. •the waste creator should be responsible for ensuring their waste is treated appropriately. •no sure how it would be practicable. •many manufacturers can reuse their products if recycled correctly but choose not to due to new infrastructure required •majority of C&D Waste being concrete, bricks, rubble, sand has reuse capabilities that would provide near zero waste •local gov need to assist with alternate uses •Its important that we are using products in construction that can be recycled at end of life of the structure. EG we don't want the issue of asbestos or treated timbers to continue to happen •Good conceptually but very challenging and needs to be targeted to select waste streams. Global supply chains are challenging. •Forces them to consider waste •Encourages them to think about how they can	**Sustainable Infrastructure rating scheme**	•the same above •As above •Only useful if mandated •Yes •Creates a standard •Yes, as above •See above

	make products differently so they can more easily be disposed •Encourages minimization •designing out waste •Demolition waste is usually mixed. Sorting stations can process the materials into products for reuse. No need to share responsibility with the manufacturer who is long gone. •Creates responsibility		
Imposition of tax on virgin materials	•YES. It will even the playing field for materials with RC •Virgin materials already have road levies imposed. •Overcomes lack of proper accounting in way of environmental costs •Not the best idea when in very remote locations. Need to consider emissions from haulage •Money talks louder than anything else •it fosters the recycling; reusing protecting the environment eventually •In Sydney there is no natural resources, so the transport is a tax. •Hard one, some materials are specific, and risking poor quality may not be acceptable so some should be exempt •Good but only where a recycled alternative raw material supply exists and only is tax is reinvested in recycling industry / recycled product development. •doesn't address issue •Creates value	**Emission trading scheme**	•recycling is more ecofriendly than landfilling •As long as emissions from landfill are incorporated and an equitable CO2 factor is placed on landfill waste (eg typical C&D waste not putrescible and therefore not as high in GHG emissions. •Allows unresponsive polluters to continue without finding alternatives - easy way out •virgin concrete is excessively greenhouse gas intensive. •Is a contributing factor •Unsure how that works •Less acute for C&D sector. Would help but indirect.
Providing subsidy for salvaged and recycled C&D waste derived products	•Yes any incentive will help. •the same above •Recycled products require all the incentives possible. Need to breakthrough conservative business as usual practices. •Promotes reuse and recycling •Not sure how this would be applied. Levy exception is possibly an existing and easier way to subsidies. •Not necessary •Maybe, but product needs to stand on its own •landfill reduction •If virgins are properly accounted in triple bottom line, subsidy should not be required •Creates initiate •agree but a mandate is better - proven in Victoria	**Proximity principle**	•It can reduce the redundant transportations •Important to minimize transport emissions but also to encourage a domestic recycling and market for RC products •Cuts on unnecessary transport •Aligning levies would help. •The cheapest option is what should be looked at. •Transport costs and fuel is expensive. •Life cycle assessment •Yes, provides economic potential and bolsters a local marketplace •European policy to stop cross border importation of C&D waste. Is important but mode of transport is important - we need more move of waste on rail, proximity to end market / remanufacture is equally important so efficient networks are a better measure. •reduce transport impact
Green Star rating scheme	•it can promote sustainable material management •Yes, encourages waste tracking to a fairly high degree •Only useful if mandated •Need to quantify the true credentials of a development •Yes, more support on this.	**Sustainable Infrastructure rating scheme**	•the same above •As above •Only useful if mandated •Yes •Creates a standard •Yes, as above

	• Other schemes available • Yes, awards and preference should be afforded to higher rated performers • Green Star has done nothing, just driven a lot of reports which do not change / shift the market. There are bigger regulator and economic forces that drive the market and outcomes.		• See above

11.3.9 Domestic market development

The development of a domestic market for recyclables is a sustainable method within the circular economy context. However, as discussed before the development of such a market needs to be carefully done. Various factors can impact market development negatively or otherwise. The choices included investment in technology and infrastructure, virgin material tax, product stewardship, employment, sustainable procurement, an adequate supply chain system, penalty for illegal dumping, green star and sustainable infrastructure rating scheme, national approach, landfill levy, and waste data collection & reporting. As depicted in Figure 97, respondents indicated that investment in technology and infrastructure and sustainable procurement are two major influential factors that have a significant impact on market development.

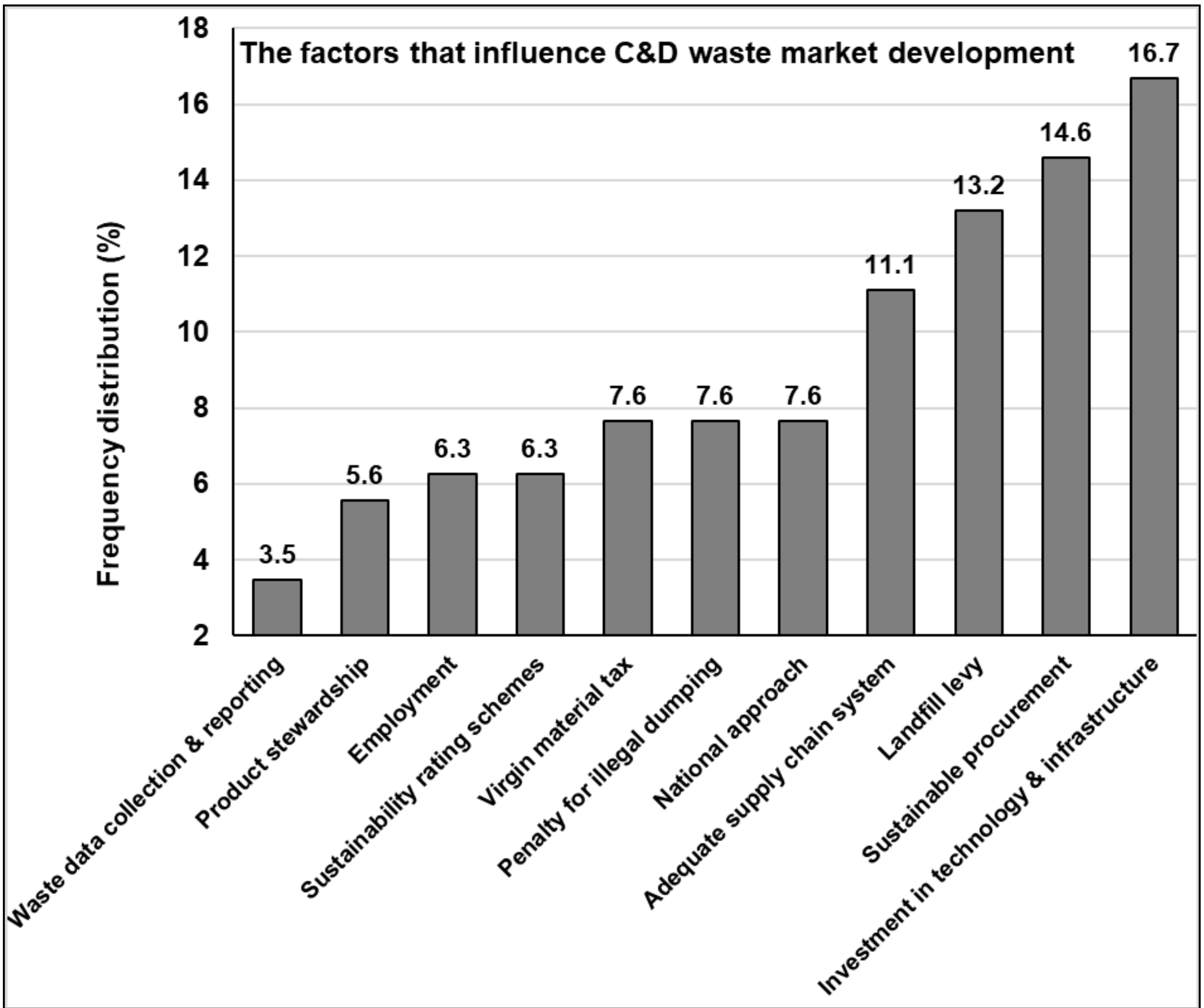


Figure 97. Participants' selection of factors that influence the establishment of C&D waste market.

11.3.10 Validity of test

A number of questions were designed to test the validity of the survey from participants' perspectives. These questions aimed to evaluate the participant's views on the number of questions, clarity and understandability of questions, the expectation of the time spent for the survey, success in extracting information in this survey, and finding new perspective for C&D waste management in Australia. The participants' responses are presented in Figure 98 and Figure 99. In the first part, findings showed that only 35 per cent of the participants believed that the survey had a proper number of questions (Figure 98). About 55 per cent agreed that the number of questions was about right. The second validity question referred to clarity and understandability of the questions. A very little portion of participants (12.5 per cent) reported the questions to be unclear/understandable. 77.5 per cent of them agreed that the questions were clear and understandable.

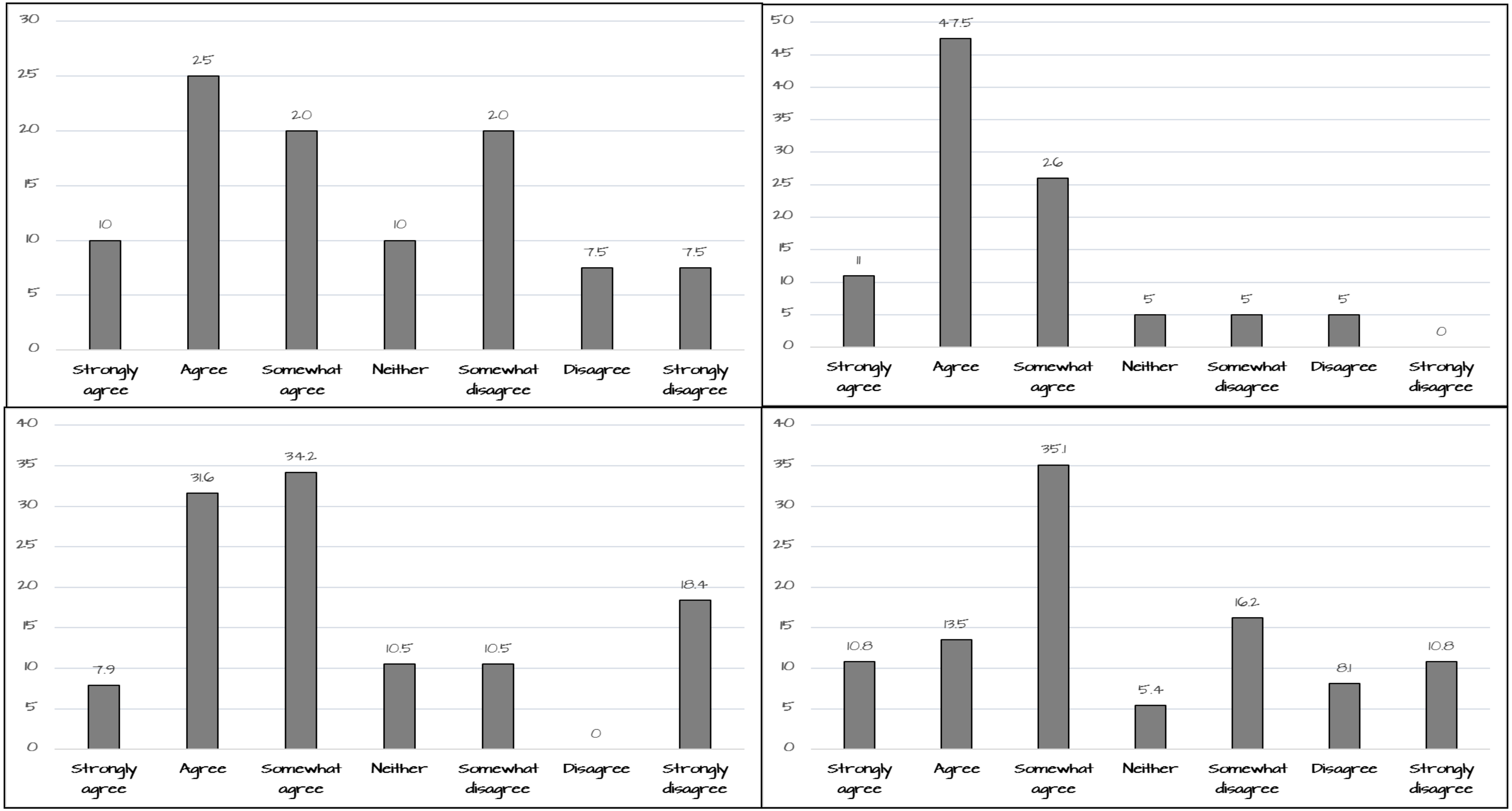


Figure 98. Participants' response distribution about the level of suitability of question number (top left), comprehensiveness (top right), clarity (bottom left) and completion time (bottom right)

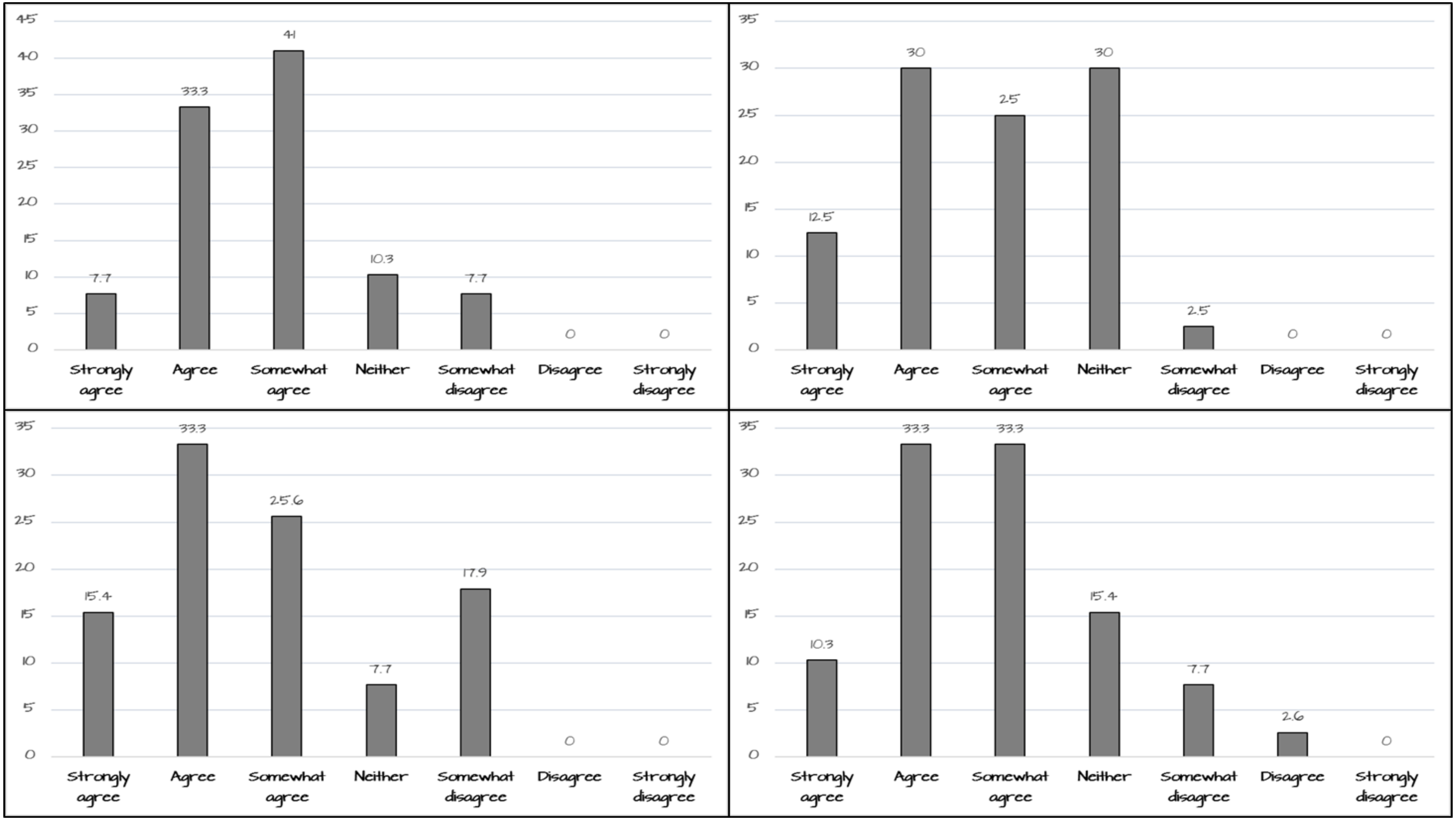


Figure 99. Participants' response distribution about the level of suitability of extracting useful information (top left), finding new perspectives on C&D waste (top right), in establishing a good interaction with participants with respects to C&D waste economic factors (bottom left) and establishing a good interaction with participants with respects to C&D waste legislation (bottom right).

12. Appendices

12.1 Survey responses

The following tables (Table A1-A4) present the participants' qualitative responses to some of the questions in the questionnaire.

Table 119. Description of barriers towards effective management of C&D waste in participants' jurisdictions

No	Description	No	Description
Barrier 1			
1	Wages - Waste Award is applicable to all staff and is one of the highest rates payable	31	Lack of local processors
2	Virgin products often cheaper	32	Lack of local Markets
3	Virgin materials are too cheap, environmental costs are not applied	33	Lack of level playing field due to illegal activities (such as levy evasion) or undesirable activities (such as stockpiling). The intention of the levy is to divert material away from landfill and towards recycling. However, illegal or undesirable activities undermine the recycling industry by diverting materials from recyclers, depriving them of the volumes required (and economies of scale required) to produce recycled products which can compete with virgin materials.
4	Transport costs and relatively small volumes that can be transported	34	Lack of land in Sydney suitable for recycling facilities that are affordable or well located near the waste supply.
5	Transport costs	35	Lack of Government support for products produced from C&D
6	Transport Costs	36	Lack of economies of scale to cost effectively reprocess C&D
7	Transport costs	37	Knowledge of alternatives
8	trade relations	38	It has no value as a commodity
9	Too much testing of C&D material vs virgin product - added expense	39	Issue of asbestos contamination
10	Time to separate waste	40	illegal operators shortcutting the system
11	time to effectively separate C&D waste on site (if demoliting a building its quickly and hence more economical to just pull it all down instead of separating it)	41	government (epa)
12	The extra controls in place to minimise the risk of potential environmental contamination. This cost is not experienced by producers of virgin material	42	Finding other businesses that can utilise your waste
13	Small jurisdiction(population)	43	fear regarding asbestos in C&D products.
14	Size of jurisdiction limits feasibility of re-cycling and re-processing	44	Distance to market of any recycled product
15	remoteness and long distances for appropriate disposal	45	Disposal costs including landfill levies
16	Remoteness - too far away to transport out of communities	46	Disincentive to separate waste types
17	Prior to the introduction of the recent Qld waste levy - it was far more economical to landfill than process. We are yet to see how the levy impacts C&D recovery	47	Culture
18	Price for disposal	48	Cost of re-processing a waste back into a usable resource
19	requirement by Main Roads WA & DWER on specifications	49	Cost of levies
20	no resource recovery infrastructure - too easy to dispose illegally	50	Cost of land
21	Need more funds released from the Sustainability Fund for investment in new recycling technologies	51	Cost of labour, land and technologies to sort construction waste
22	Main Roads WA acceptance	52	Cost of labour to source separate
23	low taxes on producers	53	Cost of company
24	limited infrastructure	54	Cost
25	LIMITED financial incentives to reuse concrete it	55	cost to provide supervision at sites to segregate C&D for recycling to prevent it going to landfill

26	Levy Costs	56	Commercial in confidence arrangements that prevent data to be published
27	Levies charged	57	Cheaper to take it landfill
28	Legislation	58	Capital for plant and equipment required to reclaim wastes
29	Lack of suitably zoned land for recycling depots	59	Capital Expenditure
30	lack of site control to separation of waste	60	Building companies generally aren't providing sufficient bins for different materials, not available to them
Barrier 2			
1	Who recycled it?	27	Inability to deal with mixed waste streams
2	supply	28	Human Resources costs
3	State Government lack of support	29	High cost of land
4	State government departments increasing regulatory changes to cater for the lowest common denominator.	30	Fuel costs due to cartage/distances travelled both inbound and outbound
5	Running costs - e.g electricity	31	Fuel - transport of waste and recyclable, machinery and recycling plant costs are high
6	Poor education leads to lazy habits	32	finding businesses that will take your waste streams - i.e. plastics
7	Plant and machinery required to recycle product	33	EPA Resource recovery orders & exemptions
8	No options for timber recycling	34	EPA and varying municipal regulations in respect to cartage and disposal
9	No EPA waste transport certificate required	35	Education
10	MRWA avoidance in using recycled aggregates	36	Distance to recycling facilities
11	Main roads WA spec 501 - remove the cost impost of geotextile membrane which virgin materials dont have	37	Distance
12	Low value of recovered materials (real and perceived)	38	Disposal costs
13	Logistics	39	costs of infrastructure
14	location of landfill	40	cost to transport C&D to an end market for use
15	Lead times for federally funded infrastructure projects. Usually a lot of material is needed in a short amount of time. Given the lead time of planning, development and procurement of these projects, perhaps early procurement of C&D materials can be done prior to engagement of the main construction contractor.	41	Cost to access markets for products from diversion activities
16	Lack of uptake by local operators (no interest in separation)	42	Cost of taking material to recycling services
17	Lack of regulation/enforcement allows for levy avoidance	43	Cost of sorting waste into specific waste products for further processing
18	Lack of recycling options	44	Cost of processing C&D into a re-usable product
19	Lack of knowledge about/confidence in re-use of C&D waste	45	Cost of dumping promotes poor practice
20	Lack of infrastructure	46	Cost of alternatives
21	Lack of demand for recycled products	47	conscious market willing to pay extra to use recycled material
22	Lack of adequate resource reuse options	48	compliance costs
23	Labour cost associated with sorting and selling C&D waste	49	Community acceptance
24	its still cheaper to take to land fill than process	50	Bulkiness - too bulky to create efficiencies in transport
25	Insufficient markets	51	attitude that waste cost should be passed on to client without any responsibility
26	increased testing & QA costs not economical when compared to virgin materials	52	absence of generous incentives regarding recycling in the construction industry
Barrier 3			
1	Weight rather than volume charge calculations	18	Logistics to get to market
2	Unlicenced operators not operating on the same cost basis	19	Levys - these should be paid by the waste generator, not the waste recycler/landfill
3	transparancy of costs by builders	20	Lack of requirement of industries to use recycled product
4	Too cheap to just landfill	21	Investment in plant to process waste then find out the regulation changes that stops the waste being suitable for recycling.
5	The impact on small skip truck operators	22	Incentive for lower grade materials means companies

			skim the best (copper and metals) to recyclers, while leaving the low value (plastics) to go to landfill
6	source separation	23	inadequate planning, waste removal should be considered in planning, then how to use that waste.
7	Safety	24	Government policy and political will
8	Reuse	25	Finding other business that could ultilse the waste materials
9	Recycler is responsible for any asbestos in waste even if they don't generate the waste.	26	EPA regulations
10	Receival site no EPA control	27	End markets
11	Proximity to markets - transport costs and distances	28	DWER WA lack of prosecution for unauthorized C&D activity
12	Poor understanding of how recycled products can be used	29	DWER testing requirements for products
13	Policy constraints enforced through contract terms (all materials to be new, etc...)	30	DWER regulatory barriers
14	market value	31	Costs
15	Machinery purchase/upkeep and maintenance	32	cost to set up a recovery centre for recycling C & D
16	lowering supply of good quality clean source seperated concrete due to construction methods on-site (narrow frontages on most house builds don't allow for separation of waste streams).	33	cost of plant and equipment for recycling
17	low landfill levy	34	Building regulations make re-use of materials problematic
Barrier 4			
1	Stockpiling of C@D	11	Labour intensive recycling process
2	state & local government specifications precluding recycled product	12	Infrastructure - huge outlays are required to effectively recycle c&d waste
3	Regulatory costs	13	Industry (too much power and the unchallenged standard mantra that everything new 'risks jobs adn growth'
4	Perception recycled products are inferior to virgin products	14	Incentives for manufacturing in Australia are low
5	No requirement for reuse of materials by industry, state or local governments	15	high recycling costs
6	Need network to bolster a demand for reclaiming all materials, and allowing manafacturers access to possible resources	16	EPA is not interested in promoting recycling and helping to solve the separated issues
7	miss information by state and local government stakeholders who dont understand our market	17	DWER lack of power to stop illegal operations
8	low cost of entry to marketplace and lack of understanding of process's	18	DWER lack of enforcement on illegal operations
9	Legislative limitations to waste stockpiling of product	19	Cost
10	Legislative Compliance	20	the abundance of virgin materials

Table 120. Participants opinion on the federal government role in the sustainable management of C&D waste

No	Description	No	Description
1	The problem of extended producer responsibility lies in the longevity of design life for their product/s which may be 50 years prior to disposal	5	Mandating Recycled Content
2	Many of the above suggestions sound good in theory, but some require head powers that the Commonwealth does not have and/or are unlikely to pursue. Procurement and product standards are areas where the Commonwealth may have the most influence. EPR sounds good in theory (given the Commonwealth has powers under the Product Stewardship Act 2011), but the Act doesn't lend itself to this sort of material or sector. Export is undesirable in a circular economy that aims to manage materials locally and minimise transport costs and impacts.	6	Insist on EPA waste transport certificate for all state and territories
3	Mandating use of the recycled product in all construction - civil projects even if it is 5% it gets the ball rolling	7	Education
4	Mandating the purchase of recycled materials in public construction projects like those in VIC	8	Better working relationships with building and construction companies

Table 121. Participants opinion about the effectiveness of landfill levy

No	Description	No	Description
	The effectiveness of landfill levy		
1	We do not currently have a landfill levy in Tasmania	24	Largely effective in application but not in use of funds raised
2	Use 100% of landfill levy for landfill diversion	25	Landfill levies are effective on the mainland states as levies tend to encourage recycling of products what weigh more. Hence the relatively high resource recovery rate of C&D in NSW and Victoria
3	Unsure	26	It's certainly an incentive to find other uses for waste in major NSW construction projects.
4	To early to know effectiveness	27	It works to get the waste companies to think of alternatives, not the construction businesses.
5	The levy is high enough in NSW to promote recycling. There is no need to keep raing it.	28	is yet to be realised as it was only introduced last month in Queensland
6	the higher it goes the more we are forced into recycling	29	ineffective in WA due to DWER being unable to control illegal operations
7	Should be useful tool but governments do not spend the levy on major initiatives that have an impact.	30	Increases building costs without reducing waste
8	Not totally impacting on deterring illegal dumping	31	In Tasmania it is a pittance compared to other states
9	not sure yet as it has only been in for a month or so	32	Highly effective however comes with a level of complexity / regulation
10	not effective in WA because there are too many loopholes for avoidance	33	Highly effective as a base strategy upon which to build a more circular economy
11	None in this jurisdiction but i understand from interstate colleagues that it has driven clear improvements.	34	Good where it's high enough
12	None in NT	35	good
13	Nil	36	good
14	New Qld too early to judge, but based in other locations, not effective as the government is not reinvesting.	37	Good
15	Needs to be national	38	Fair
16	needs Australia wide consistent application and rates	39	Effective if supported by an effective compliance and enforcement regime.
17	need to be higher in WA, C&D landfill levy	40	Effective but can be circumvented due to lack of control
18	Need to adjust the levy to incentivise the identifiable recyclable content	41	effective
19	must have national not state levy to avoid cross border dumping	42	Currently no landfill levy exists in the NT, however a levy to C&D could instigate more illegal dumping
20	mostly effective -	43	The current rate is appropriate
21	Moderate	44	As yet undetermined. Further data study required
22	Levy should be homogenised across states to avoid interstate transport	45	As per findings by the Waste Authority in 2014 before the Levy was increased the cost of transport is a key factor in providing incentive to recycle rather than landfill. but if your generating waste next to a landfill its cheaper to landfill than recycle in WA.
23	As it has only been introduced in Qld, the effectiveness of the levy has not been realised.		
	Various levy rate between metropolitan and regional areas		
1	Would need very careful management to ensure that material is not transported to a neighbouring jurisdiction with more favourable levies	21	only metro areas, country areas in WA are too sparse
2	We understand why this varies, however it adds a level of complexity in being able to identify the area the waste was generated.	22	None in NT
3	we have regional levy - this is one of the loopholes	23	Nil
4	WALGA and most of private industry don't wish to extend the levy to non-metropolitan areas that only produce 25% of the waste. better to police with GPS trackers the waste within the metro area to capture loss levy	24	Needs to be higher in regional areas to promote recycling. Otherwise there is not the market for C&D material in these locations
5	WA has no regional levy which creates illegal operation taking metro waste	25	Needs further discussion
6	Very unhelpful. Levies need to be aligned across the country.	26	Needs effective monitoring to negate cross border movement between metro and regional

7	There should be a national rate set not municipality by municipality	27	Lower rates in the ERA do not help, cross border revenue leakage is an issue and opportunities to provide jobs in regional areas opportunity loss
8	There is a case for differential levies between metro & regional areas with safeguards	28	levy should be consistent
9	The regional areas are far enough away to prevent some out of area tipping. They could require a certification from the job site to confirm the waste was local.	29	Levy rates should be less in regional Qld where there is no option to recycle
10	should be standardised	30	Ineffective, levy is only in metropolitan area
11	Should be standard across all jurisdictions	31	good and justified
12	Should be set at consistent rate	32	Fair
13	should be one in place, but with a planned phase out.	33	extremely flawed - encourages waste movement vehicle accidents increased carbon emissions - just moving the issue 200Km away.
14	should be consistent	34	Encourages movement of waste to least expensive jurisdiction
15	see above	35	effective
16	Regions need to be treated the same as metropolitan	36	Don't have data to decide
17	reduced levy rate for small communities	37	all rates are currently the same for metro and regional areas. Metro create the most waste but regional areas have greater costs due to transport to metro areas for processing
18	Ridiculous.... It should be the same throughout the Nation	38	Agreed due to the remoteness conditions of the NT, which could help to prevent illegal dumping
19	rate in rural don’t work as cartage is the big problem harder to recycle less volume	39	Acceptable
20	Provides an opportunity for unintended consequences and perverse outcomes.	40	A differential levy works in mainland states because of the vast geographic size of mainland states. In Tasmania, a single levy rate across the whole island would be most effective as waste already moves from regional areas to metropolitan areas due to the small size of Tasmania and that most major landfills are located in metropolitan areas. A differential levy rate would not work in Tasmania.

The current practice in the estimation of waste quantity

1	weighbridges required at all sites	20	no comment
2	weak - DWER cannot verify the estimations given	21	Nil
3	Waste should be weighed rather than estimated eg by the truckload	22	Needs to be consistent across jurisdictions
4	Unsure	23	needs improvements as private companies don't want to give out information
5	Unsure	24	need better quantification
6	The EPA receives all waste quantities from all facilities which is good however they don't share the information about total volumes with the industry.	25	national guidelines to be adopted
7	should be shaken up with a simple gps tracker on all tipper and skip trucks. this can be audited against tipping dockets by the limited (<4) DWER inspectors.	26	Moderate
8	reasonably effective	27	Leaves a lot to be desired as much is disposed of to public requested hard fill locations
9	poor - could be improved using new tech eg machine learning	28	Lack of weighbridges in the NT impose a challenge on estimation of waste quantities
10	Poor	29	Is problematic for the C&D sector small sites should have weighbridges
11	Pointless, not accurate anyway	30	Inaccurate and troublesome
12	ok	31	I'm not familiar with detail, so can't comment
13	ok	32	governance of waste data is not good and confidence level is low in current data
14	Not sure	33	extremely flawed
15	Not particularly accurate. In the unlikely event that a site receives nothing but Styrofoam tonnage the Volumetric survey process would be skewed.	34	Easy to count material disposed of to suitable facilities; very difficult to count material managed outside of the regulated system (stockpiled, illegal disposed).

16	not effective	35	could be improved
17	not controlled	36	Ad hoc at best
18	No need for estimate - weigh all and report actual weights.	37	acceptable
19	No estimations / reporting	38	A levy in Tasmania would greatly help improve reporting on waste quantities.
Consistency of levy rate cross Australia			
1	yes	22	not an issue in WA. I can see that this might be a problem on the boarders or eastern states...
2	Would help to reduce cross boarder leakage and send right market signal	23	no opinion.
3	Waste is a national issue - levies, CDS and stewardship schemes, waste management, waste education and legislation should be consisent nationally	24	No Comment
4	WA too cheap	25	Nil
5	Very unhelpful. Levies need to be aligned across the country.	26	needs to be made consistent
6	Very important - to avoid dumping waste 'ne4xt-door' where the rates might be lower.	27	Needs further discussion
7	Too difficult, other changes could achieved before that.	28	Need to standardise bot levy and application of funds raised and their disbursement
8	This is important, however should consider the long distances needed for certain disposals	29	N/A in WA given the costs of transporting elsewhere.
9	There should be consistency across states	30	most now are about the same but without ways to stop the avoidance, ineffective in WA
10	should be standardised	31	Low
11	Should be standard across all states	32	irrelevant to overall issue
12	should be more uniform	33	I think on mainland states this is necessary to avoid cross jurisdiction transport of waste.
13	Should be done	34	I don't think this is necessarily a good idea. Each area is different. A remote town in the Kimberly should not be charge the same levy for those in major capital cities. This could encourage waste to be driven long distances (therefore high carbon emissions) to be recycled.
14	see above	35	Fair
15	regions are too diverse to be able to manage the same was as metro areas due to lack of resource availability	36	Don't have data to decide
16	Ridiculous... The levy should be the same throughout Australia	37	disagree completely
17	Queensland has an appropriate levy rate proportionate to its population.	38	Bad (none in NT)
18	Problematic - encourages road trains to QLD	39	Australia needs to establish the same levy rates across its jurisdictions
19	Precisely	40	Agree
20	Poor, it should be considered in one strategy.	41	agree
21	poor - needs addressing	42	a national level would be more effective
Distribution of levy revenue			
1	very very poor in Vic	21	N/A
2	very poor return to the industry	22	more to local councils
3	very poor in WA. promised a $10m grant to RCPP for recycled construction products procurement. only spend <$100,000 then hid the lack of spend due to poor specification that meant no product could make the specification to claim the grant. (Only 25% is hypothecated in WA. should be 100% like SA)	23	more to be returned
4	unknown	24	More needs to go towards R&D - full benefits of C&D road base materials are not understood, how can we take advantage of rehydration of cement in reuse in concrete
5	This should stay within the waste industry.	25	more needs to be returned to industry
6	this should cover the MRF cost then be distributed to assist reprocesses	26	more needs to be given back to local government to help manage recycling improvements
7	This is the key component of a landfill levy. It must go to funding better waste management not boosting government coffers	27	More levy revenue should be invested back into the industry rather than consolidated revenue
8	this is political	28	More grant funding to local government and industry
9	This could be better in most states, except for SA which seems to do it the best. Victoria has too much sitting in the Sustainability Fund and in NSW too much goes into general revenue. The levy income and	29	Moderate

	distribution needs to be transparent and be used to provide market signals on priorities for resource recovery infrastructure investment..		
10	Should be done in investment for industry on recycling and energy recovery facilities	30	make the available funds easier to access
11	Should be used exclusively to improve waste management including restoration of legacy landfill sites	31	Levy income needs to ne distributed more effectively back to the waste sector to drive improvements
12	Regional recycling and waste management solutions must be considered.	32	lack of reuse within the Waste arena in WA
13	poor	33	Ineffective - levy is a Robin Hood tax used to fund other programs or general spending
14	not to go to consolidate	34	I haven't thought about this before
15	Not sure	35	give back to the industry no government
16	No idea	36	extremely flawed - consolidated revenue not used to catch offenders or promote recycled initiatives
17	Nil	37	Don't have data to decide
18	needs to be made available with less requirements for funding applications as we do not have the staff and resources available to be doing paperwork all the time.	38	As the Queensland Government has pledged 70% of levy revenue to the waste and resource recovery sector, this would be hugely beneficial for the future of the industry.
19	Needs to be hypothecated back into compliance, incentives and recycled product market development	39	25% reinvested in waste programs. Many would like a higher level of hypothecation back into waste, however most people would like more money for all sorts of public goods and services.
20	Needs further discussion		
Others			
1	work closer with small business affected by the waste levy	6	Needs to be set at a rate which achieves the government's policy objectives; levy needs to be administered and regulated effectively and equitably.
2	waste levy collected should be returned in full to develop circular economy	7	Landfill levy is a blunt tool that acts as a broad brush. we need more detailed tools using GPS tracking and auditing by limited state government agencies that are under staffed... while we give out >$100,000 on pet projects that dont create change in the market place.
3	Taking any of the levy for state government revenue removes credibility in the system	8	clear policy and implementation plans from DELWP and SV would be useful
4	Not only need standards on application, disbursement but also on exemptions	9	can't comment on effectiveness in other states - only WA
5	Nil		

Table 122. Participants' perception of the impact of legislation to reducing, reusing, and recycling C&D waste

No	Response (Encourages)	No	Response
1	the quantum of the landfill levy is high in NSW	9	it costs more to landfill than recycle
2	The levy gives an incentive to recycle	10	it attempts to provide a level playing field
3	The current legislation encourages recycling to a degree	11	In RISP
4	Seeks to support but other factors inhibit resource recovery.	12	In NSW, the levy is high so it encourages recycling of heavies
5	recovery becomes more feasible, providing investment has been made in the infrastructure required to recycle C&D	13	From my perspective we are finding other ways to manage waste without sending to landfill on major construction projects due to levy costs.
6	Levy (if applied well) provides an incentive to divert materials from landfill	14	contractors usually divert waste from landfill because it is financially beneficial
7	levies support	15	as it provides a pathway in many locations to produce and use C&D waste
8	Jurisdictions have different facilities, different prominent industries, and must be left somewhat autonomous to manage		
Discourages			
1	when the IPWEA specification was released in 2016 most recyclers could make this spec. however the State government interfered with local gov specification and asked for concrete to be <9pH. Which wasn't going to happen. Hence nobody who applied for the $10m grant got paid for any tones to market (only policy development fees paid to consultants via local	13	Lack of State Gov Funding and Support

	gov grant submissions to the Waste Authority in WA. Now uncontaminated fill guidelines are under attack from a meddlesome state government that doesn't understand that rainwater falling on virgin soil wouldn't pass their specification.		
2	there is opportunity for many operators to act outside incentives	14	lack of standards which provide confidence to markets
3	there is not enough emphasis and support for end market use of recycled materials in Australia	15	lack of enforcement for compliance and lack of monitoring of waste movement allows avoidance
4	There is no levy	16	it is to be convoluted
5	there is no benefit to recycling over disposal, neither are there benefits for reuse over new purchase.	17	Innovations elsewhere may be very useful if access and funding was available
6	the landfill disposal costs are minuscule in Tasmania	18	inconsistencies allow for diversion to other areas for landfilling
7	the issue of asbestos in C&D recovered materials has not been satisfactorily resolved	19	Inadequacy in application of levy funding to raise resource recovery, recovered markets and circular economy initiatives.
8	Remoteness – no money available to handle C&D waste – major problem for remote communities	20	In NSW waste is always defined as waste even after it is recycled. This causes major problems with a number of recycled products.
9	recycling works on volume and close proximity to the source and EPA don't wont in the city	21	higher incentives to recycle C&D waste would help.
10	practical outcomes by industry not supervised	22	DWER imposed test regimes and MRWA practices actively discourage users
11	not enough money is allocated to illegal waste transfer & added costs over virgin materials & requirements by state government that are unjustified are in place.	23	business that can't afford to pay higher disposal fees may be inclined to illegally dump the material
12	no incentives available	24	because the cost impost on commercial operators is high and this rolls onto the customer in the community
Neither			
1	we do not have any options to reduce, reuse or recycle C&D in our regional area	8	mixed messages and policies put in place
2	Waste reduction and reuse is not supported/incentivised enough	9	lots of inconsistencies exist in the current legislation regarding C&D waste
3	waste is a result of poor planning, lack of alternatives and inadequate knowledge. Legislation does nothing to address those issues.	10	Legislation is not supported by other measures
4	There is minimal encouragement	11	it is not linked to clear polices and implementation plans
5	The Waste Management and Pollution Control Act enforcer regulation towards illegal dumping and general environmental duty, however does not support C&D stream as regulates licencing activities towards listed waste only	12	it is difficult to make C&D contractors to recycle waste when it costs more, and no legal requirement to do so. Waste processors are left to manage the issue, and more cost is incurred.
6	Some legislation supports and some discourage.	13	it does not support those that recycle C&D well and invest money into waste reduction, yet it also lets anyone get a licence and recycle C&D waste only to stockpile and go broke.
7	No data	14	In the end it is up to the industry to invest.

12.2 Recruitment of participants

INVITATION TO PARTICIPATE IN A RESEARCH PROJECT

Project title:

A National Economic Approach to Improved Management of Construction and Demolition Waste

Construction and Demolition (C&D) Waste:

Waste generated from the construction and demolition industry is growing due to the increased construction activities in different sectors (housing, building, transport infrastructure) in Australia. Poor management of C&D waste causes environmental, social and economic issues. Thus, C&D waste stream has become an emerging concern among Australians

Objectives of this survey:

This survey aims to further understand stakeholders' opinions on various dimensions of C&D waste management in Australia. The following are the objectives of this research project:

1. What discrepancies exist in regulations governing C&D waste and their application in practice in different jurisdictions and what recommendations can be made for reforms?

2. How can a consistent approach define and measure C&D waste to be developed across different jurisdictions?

3. What are the economic factors and drivers/barriers that govern the disposal and reuse/recycling of C&D waste?

4. Would be creating a marketplace to connect organisations and industries across jurisdictions for trading waste help reduce C&D waste and encourage reuse/recycle?

Ethics, confidentially and data handling:

There are no actual and perceived risks regarding participation in this survey. However, if you are unduly concerned about your responses during the survey or if you find participation in the research project distressing, please do not hesitate to contact Tayyab Maqsood or Peter Wong, contact details provided below. You will be able to discuss your concerns confidentially, including options to withdraw from the survey and suggest appropriate follow-up, if necessary. The data gathered in this survey will be handled with confidentiality according to the RMIT University Human Ethics Committee policies.

Whom should I contact if I have any questions?

Should you have clarifications and require further information regarding this research project, please get in contact via:

Assoc Professor Tayyab Maqsood,
Email: tayyab.maqsood@rmit.edu.au
Assoc Professor Peter SP Wong,
Email: peterspwong@rmit.edu.au

The project is funded by the Australian Sustainability Built Environment National Research Centre (SBEnrc).

Project Industry Partners:

BGC (WA)
Main Roads (WA)
Department of Communities (WA)
Department of Housing and Public Works (Qld)
Griffith University (QLD)
Roads and Maritime Services (NSW)

If you have any concerns about your participation in this project, which you do not wish to discuss with the researchers, then you can contact the Ethics Officer, Research Integrity, Governance and Systems, RMIT University, GPO Box 2476V, Melbourne

College Human Ethics Advisory Network (CHEAN)
College of Design and Social Context (DSC)
NHMRC Code: EC00237

17 December 2018

Associate Professor Tayyab Maqsood
School of Property, Construction and Project Management
RMIT University

Dear Associate Professor Maqsood,

RE: CHEAN A&B 21847-11/18
'A National Economic Approach to Improved Management of Construction and Demolition Waste.'

Thank you for submitting the above ethics application for consideration by the College Human Ethics Advisory Network (CHEAN) of RMIT University.

The application was considered and reviewed by the CHEAN at meeting 11/18 held Friday 14 December 2018.

Status: Low risk, Revisions required

In accordance with the requirements of the *National Statement on Ethical Conduct in Human Research, NHMRC, 2007* (NS) the CHEAN requires further information and/or clarification on the following points before approval can be granted:

Procedures/Research methods
The reviewers were unclear of the need to photograph focus groups, particularly if faces are to be blurred. Is the documentation of this activity to form research data or to inform reports to funding body? Is there another way to document the activity?

Recruitment method
Given its involvement in funding the research and distributing recruitment materials, the committee asks for more information regarding the relationship between the Sustainable Built Environment National Research Centre and the participants.

Privacy and Confidentiality
Related to the above point, the reviewers ask why transcripts will be provided to the funding agency, and whether the identity of the research participants will be discernible to the SBEnrc (even if identifying information is removed)?

Other Specific Issues
The description of the data storage protocol mentions that hardcopy data will be securely stored at the School of Global, Urban and Social Studies. Should this, instead, be the School of Property, Construction and Project Management?

PISCF
If primary research data is to be shared with the SBENRC, the committee requests that participants are informed of this in the participant information sheet.

Responding to request for revisions
Please respond to each of the above points in a summary letter or table, which includes the above points and your responses to these points, with reference to supporting documentation. Revise the application and any other relevant documentation, i.e. Participant Information Sheet and Consent Form (PISCF), recruitment materials, research instruments, etc., as required.

Email your letter/table of response along with copies of all supporting documentation to dscethics@rmit.edu.au for review.

Please note, if the committee does not receive a response to this letter within six weeks from the date of the letter, it will be assumed that you are no longer seeking approval for your project and your application will be withdrawn.

If there is anything in this letter that you are unclear about or for which you require further clarification, then please contact the CHEAN secretary, Dr David Blades.

Yours sincerely,

Associate Professor Marsha Berry
Chairperson, College Human Ethics Advisory Network (CHEAN B)
RMIT University

Dr Scott Mayson
Deputy Chairperson, College Human Ethics Advisory Network (CHEAN A)
RMIT University

cc: Dr David Blades (CHEAN secretary)
Associate Professor Peter Wong (Co-investigator)
Associate Professor Malik Khalfan (Co-investigator)
Dr Rebecca Yang (Co-investigator)
Dr Salman Shooshtarian (Co-Investigator)

Table 123. The definition of abbreviation and terms used in this report

Term	Definition
ABS	Australian Bureau of Statistics
ACOR	Australian Council of Recycling
ACT	Australia Capital Territory
ALGA	Australian Local Government Association
ALOA	Australian Landfill Owners Association
APCC	Australasian Procurement and Construction Council
Asbestos	The fibrous form of mineral silicates belonging to the serpentine and amphibole groups of rock-forming minerals, including actinolite, amosite (brown asbestos), anthophyllite, chrysotile (white asbestos), crocidolite (blue asbestos), tremolite, or any mixture containing one or more of the mineral silicates belonging to the serpentine and amphibole groups
ASBG	Australian Sustainable Business Group
AWD	Australian Waste Database
AWT facility	Advanced waste treatment facility
B2B	business-to-business
C&D waste	Construction and Demolition: Waste produced by demolition and building activities, including road and rail construction and maintenance and excavation of land associated with construction activities
C&I waste	Commercial and Industrial: the solid component of the waste stream arising from commercial, industrial, government, public or domestic premises (not collected as Municipal Solid Waste), but does not contain Listed Waste, Hazardous Waste or Radioactive Waste
Circular economy	An alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible – extracting the maximum value from them while in use, then recovering and reusing products and materials. Three core principles underpin a circular economy – design out waste and pollution; keep products and materials in use; and regenerate natural systems.
Clean (waste) fill	Raw excavated natural material (for example, clay, gravel, sand, soil or rock fines) that: (a) has been excavated or removed from the earth in areas that have not been subject to potentially contaminating land uses including industrial, commercial, mining or intensive agricultural activities; and (b) has not been processed except for the purposes of: i. achieving desired particle size distribution; and/or ii. removing naturally occurring organic materials such as roots; and (c) does not contain any acid sulphate soil; and (d) does not contain any other type of waste. This definition
Clean-up action	Action to prevent, minimise, remove, disperse, destroy or mitigate any pollution resulting or likely to result from the incident, and (b) ascertaining the nature and extent of the pollution incident and of the actual or likely resulting pollution and (c) preparing and carrying out a remedial plan of action. It also includes (without limitation) action to remove or store waste that has been disposed of on land unlawfully
COAG	Council of Australian Governments
Controlled waste	waste types listed in Schedule 1 of the Environmental Protection (Controlled Waste) Regulations 2004
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Energy from Waste (EfW)/ Waste to Energy (WtE)	is the process of generating energy in the form of electricity and/or heat from the primary treatment of waste, or the processing of waste into a fuel source. WtE is a form of energy recovery
Energy recovery facility	A facility that captures, on average, more than 20% of the embodied energy in the waste it receives for beneficial use
EPA	Environmental Protection Authority
EU	European Union
Extended Producer Responsibility	An environmental policy approach where the producers' responsibility, physical and/or financial, for a product is extended to the post-consumer stage of a product's life cycle. Producers accept their responsibility when they design their products to minimize life cycle impacts and when they accept legal, physical and/or economic responsibility for the environmental impacts that cannot be eliminated by design.

Fate	The ultimate destination of waste within the management system. The fates of waste are recycling, energy recovery, disposal and long-term storage
Focus material	According to WA waste strategy it includes eight types of waste such as C&D waste, organic waste, metals etc.
General waste	materials or products that are unwanted or have been discarded, rejected or abandoned. Includes materials or products that are recycled, converted to energy, or disposed. Materials and products that are reused (for their original or another purpose without reprocessing) are not waste because they remain in use.
Hazardous waste	means the component of the waste stream which by its characteristics poses a threat or risk to public health, safety or the environment (includes substances which are toxic, infectious, mutagenic, carcinogenic, teratogenic, explosive, flammable, corrosive, oxidising and radioactive)
Illegal dumping	is leaving waste on private or public land that is not licensed to accept such waste
Industrial symbiosis	a central part of a circular economy, a model in which resources and energy are recycled and recovered instead of moving linearly from extraction to disposal
Integrated waste management	The management of the entire waste process including generation, storage, collection, transportation, resource recovery, treatment and disposal. Integrated waste management employs several waste control methods based on the waste hierarchy including avoidance, reduction, recycling, reuse, recovery, treatment and disposal, aimed at minimising the environmental impact of waste
Level playing field	a situation in which everyone including landfill owners, waste recovery and recycling facility operator, government, and community has a fair and equal chance of succeeding
Levy	the contribution aims to reduce the amount of waste being landfilled and promote recycling and resource recovery
Listed waste	Listed wastes are defined under Schedule 2 of the Waste Management and Pollution Control (Administration) Regulations
Litter	Waste that is left in public places and not deposited into a bin.
Material environment al harm	(a) that is not trivial or negligible in nature, extent or context; or (b) that causes actual or potential loss or damage to property of an amount of, or amounts totalling, more than the threshold amount but less than the maximum amount; or (c) that results in costs of more than the threshold amount but less than the maximum amount being incurred in taking appropriate action to— (i) prevent or minimise the harm; and (ii) rehabilitate or restore the environment to its condition before the harm
MSW	Municipal Solid Waste: The solid component of the waste stream arising from domestic premises that is received directly from the public
NEPC	National Environment Protection Council
NWP	National Waste Policy
Primary legislation	These are laws Parliament has enacted. Sometimes Acts are called 'Acts of Parliament'. Less often Acts are called 'primary legislation' to distinguish them from subsidiary legislation. Usually they each have the word 'Act' in their title.
Recovery	A process that extracts materials or energy from the waste stream
Recycle/recyc ling	Set of processes (including biological) for converting recovered materials that would otherwise be disposed of as wastes into useful materials and or products
Recycled materials	Materials recovered and manufactured into products
Residual (residue) waste	means the waste from a recycling activity that is commonly disposed of to landfill after the recoverable components have been removed from material
Resource recovery	In relation to waste, means: a. reusing the waste; or b recycling waste, recovering energy and other resources from the waste
Reuse	Using a waste product again for the same or a different purpose without further manufacture
SME	small-to-medium-enterprise
Solid Waste	Any waste that is not gaseous and is not a Liquid Waste as determined by EPA Guideline, Liquid waste classification test (2003)
Storage	Accumulation of wastes in approved infrastructure such that materials are readily retrievable
Subordinate legislation	These are laws made by people using powers that Parliament, by means of its Acts, has given them. Sometimes these laws are called delegated legislation or subordinate legislation

Sustainable Procurement	A process whereby organisations meet their needs for goods, services, works and utilities in a way that achieves value for money on a whole life basis in terms of generating benefits not only to the organisation, but also to society and the economy, whilst minimising damage to the environment
SV	Sustainability Victoria
SWA	Safe Work Australia
Treatment	The removal, reduction or immobilisation of hazardous characteristics through physical, chemical or biological processing of waste to enable the waste to be sent to its final fate (i.e. disposal or reuse) or further treatment
Waste disposal	A waste fate in which no material or resource recovery use is made of the waste. Includes disposal to landfill and to incineration without energy recovery
Waste diversion	The redirection of waste from a disposal facility to a recycling or energy recovery facility
Waste diversion	The act of diverting a waste away from landfill for another purpose such as re-use or recycling.
Waste fate	The ultimate destination of waste within the management system. The fates of waste are recycling, energy recovery, disposal and long-term storage
Waste generation	The process of producing waste. For data reporting purposes, waste generation is the sum of the quantities of wastes taken to waste management facilities or added to on-site stockpiles
Waste hierarchy	The waste hierarchy is a set of priorities for the efficient use of resources. The waste hierarchy includes avoid and reduce waste, reuse waste, recycle waste, recovery energy, treat waste, dispose of waste.
Waste landfill	A waste disposal site used for the controlled deposit of solid waste onto or into land
Waste management	The activities through which a waste is dealt with, in infrastructure approved to receive it
Waste management method	waste management method, which refers to the infrastructure that receives waste – landfill, compost facility, alternative waste treatment facility, etc.
WMAA	Waste Management Association of Australia

Sources: Waste definitions- Waste Guidelines- EPA 842/09- SA

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Researchers' biographies

Associate Professor Tayyab Maqsood has been involved in the research related to C&D waste management for over 10 years. His research explores the issues of C&D waste management from a regulatory perspective as well as technical, economic, and financial perspective. He is leading the C&D waste management research group at RMIT and is a founder of Australia's first National Construction and Demolition Waste Research and Industry Portal. He is a strong proponent of the Circular economy or cradle to cradle approach. He is also Associate Dean at RMIT.

Dr Salman Shooshtarian received his PhD in the area of Built Environment from RMIT University in 2017. He is an active researcher in the fields of sustainability, environment, construction health and safety and urban ecosystem. He has published several books, journal articles and conference papers in these areas. Salman is currently a member of the WMRAA's Victoria Waste Educator working group.

Professor Wong is the Associate Dean of the School of PCPM. As at 2018 he has more than 80 publications and was awarded over AUD$1.5 Million research grants. Professor Wong is a chartered construction manager and a chartered quantity surveyor with solid industry experience. His knowledge and experience particularly in organisational and operational management in construction will provide a fundamental basis for effective operation of this activity.

Dr Khalfan is an Associate Professor in the School of Property, Construction and Project Management. Malik is an expert in the area of supply chain and his knowledge and experience can help develop a market in which currently inadequate supply chain in recovery of C & D waste management. In 2012-2014 he was a co-leader a project on developing a supply chain framework for waste minimisation for the residential sector that was funded by Sustainability Victoria.

Associate Professor Rebecca Yang is a scholar of building, construction and social practice who undertakes pure and applied research that can provide innovative solutions to the industry by integrating theories with cutting-edge technologies. Her expertise in stakeholder analysis and life cycle assessment is central to successful delivering of this activity's objective

Professor Tim Ryley is a professor of Aviation, and currently is the Head of Griffith Aviation, the largest aviation unit in Australia. He has a BSc (SocSci) Honours in Geography from the University of Bristol and a PhD (transport planning) from Edinburgh Napier University. Prof. Ryley led or co-led research projects totalling over $5 million, typically funded by Research Councils or the aviation industry. Some, such as the UK-based Engineering & Physical Sciences Research Council (EPSRC) Airports & Behavioural Change project, involved leadership across several universities and university partners.

Dr Savindi Caldera is a Research Fellow in the Cities Research institute, Griffith University (Brisbane Australia). Savindi's research serves to transform manufacturing and construction practices, creating innovative lean and green strategies that enable businesses to operate in ways that are good for both the planet and people. As a sustainability researcher she investigates the techniques of cleaner production that position sustainability in organisational processes to drive innovation, engagement and resilience.