Optimising the Use of Recycled C&D Waste Material in Civil Construction Projects

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STUDENT DECLARATION

The author certifies that this thesis titled:

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ABSTRACT

The substantial growth in infrastructure developments has resulted in an increase in the quantity of Construction and Demolition (C&D) waste, and the need to find effective waste management options. Although recycling C&D waste is becoming the preferred option for maintaining sustainable waste management practices, the adoption of recycling within the building industry is still very slow, with some C&D waste material still going to landfill. There are many drivers and barriers to the effective recycling and use of C&D waste materials. As many C&D companies strive to be considered as having sustainable practices, it has become necessary to overcome the existing barriers, as the demand for C&D recycled materials remains low.

This study investigated the recycling of Reinforced Concrete (RC) and brick waste materials as a substitute for virgin gravel, compared to landfill disposal. Case-studies from six construction sites and a recycling plant were analysed, using the Triple Bottom Line + 1 (TBL+1) concept to discuss the environmental, social, economic, and governance impacts. The methods of data analysis applied were 'End-of-Life-Cycle Assessment' (ELCA), 'investigating construction site practices', 'End-of-Life-Cycle Cost' (ELCC), and 'review of waste legislation'.

Environmentally, four impact categories were considered for the ELCA study, namely, global warming (CO_2), water use, solid waste and embodied energy. The recycling results indicated that benefits of not producing virgin gravel or steel were significant in reducing the overall environmental impact, especially in energy and transport use. However, sustainable fuel options for transport and energy could further improve the environmental recycling benefits realised. The environmental impact of recycling RC and bricks was comparatively lower than landfill disposal.

Socially, the study of the six construction sites highlighted best practices, and some barriers to recycling that had been gradually adopted at construction sites. The study findings indicated that the potential to recycle relied on effective waste management practices at C&D sites, and hence there was the need for a broader application of waste management practices across the building industry.

Economically, ELCC calculations revealed cheaper RC and brick recycling costs compared to landfill disposal and virgin gravel production, when avoided production of steel and virgin gravel were considered. Conclusions from the cost calculations indicated that fuel tax costs and sustainable cheaper fuel options could further reduce recycling cost. However, 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.

The governance aspect of the study reviewed seven organisational contributions to waste legislation. The review revealed that although there were several environmentally certified recycled materials on the market, the majority of them were not C&D recycled materials. The review of legislation highlighted the need to promote the endorsement of C&D recycled materials, as a critical step to the improvement of product quality, and increased demand.

The overall results indicated that the optimisation of demand for recycled C&D waste materials could not be solely improved by considering environmental impacts. The social, economic, and governance impacts were very important aspects to consider. This study successfully addressed the interrelated factors needed to improve current recycling practices, with recommendations to increase demand for C&D recycled products such as RC and bricks.

ABBREVIATIONS

AFG – Alex Fraser Group

C&D – Construction and Demolition

CBD – Central Business District

CPRS – Carbon Pollution Reduction Scheme

ELCA – End-of-Life-Cycle Assessment

ELCC – End-of-Life-Cycle Cost

ESD – Ecological Sustainable Development

R&D – Research and Development

RC – Reinforce Concrete

RCB – Recycled Crushed Bricks

RCC – Recycled Crushed Concrete

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1 INTRODUCTION

1.1 Background to study and study area

In sustainably managing waste, all aspects should be environmentally, economically and socially acceptable. Construction and Demolition (C&D) activities usually create waste that needs to be disposed. Waste disposal affects the environment, disposal costs and waste management. For the purpose of this study, the term 'civil construction' refers to building and civil infrastructure construction.

Most countries have begun to understand the need for a waste minimisation strategy due to the increase in waste from human causes, especially in the form of C&D activities. Figures reported most often show the total quantities recycled, for example, Denmark, Germany and Holland recycled more than 80% of the C&D waste produced in 2002; Finland, Ireland and Italy recycled between 30% and 50%, and Luxembourg only 10% (Nunes et al., 2006). However, not much consideration has been given to the various aspects of C&D waste management that could increase recycling, and the demand of C&D recycled materials. Materials that end up in the waste stream include concrete, bricks, glass, metals, cardboard, paper and wood (timber). The percentage not recycled is usually sent to landfill[1].

The eventual filling of landfill sites and the increase in C&D waste levels has necessitated quick solutions. Strategies such as deconstruction, re-use, and recycling have been measures that are slowly helping to curb the waste problem. Currently, some C&D waste still goes to landfill, despite reported recycling figures. The traditional means of waste disposal in landfill is uneconomical, not environmentally friendly, and not sustainable in the future. In the United States (Florida), a report by the state showed that only 9% of the C&D waste for 2000 was recycled out of 91% that was recyclable (Cochran et al. 2006). In Australia, 43% of C&D waste went to landfill, with the state

[1] A site used for disposal of solid material by burial in the ground that is licensed as a landfill under the *Environmental Protection Act 1986*. (Department of Environment, 2005)

of Victoria having the third largest of 39% from 2002-03 (Australian Bureau of Statistics - ABS, 2008). Landfill fees are yet to discourage the C&D industry from disposing of materials in landfill as a convenient alternative.

Costs to communities for operating and maintaining landfill sites are high, and availability of suitable land is limited. Re-use options for old landfill sites are extremely limited, due to potential health hazards from waste disposal. Remedial action is often prohibitively expensive. Studies by the Green House (2005) have revealed that emissions and leaching from landfill sites can be highly toxic, due to concentrations of heavy metals and toxic chemicals. These toxins find their way into the water table and/or waterways, often with disastrous consequences.

Recycling has therefore become a necessity for a sustainable waste management plan. In 1992, Australia adopted the 'National Waste Minimisation Act', to assist in establishing waste reduction targets. The SoE[2] (2001) reported that of the 95% of waste generated, C&D waste formed 40-50%, and although waste recovery and recycling rates had improved in all jurisdictions, these fell well short of the 1992 national target of 50% reduction by 2000. Groups such as the Australian Reusable Recovery Network (ARRN), operating in New South Wales (NSW), Queensland (QLD) and the Australian Capital Territory (ACT), made efforts to facilitate the sale and purchase of salvaged and recycled materials (Green House, 2005).

Developed countries like Australia are striving to improve their C&D materials recycling practices. Victoria's capital, Melbourne, is fast developing, and has seen an increase in high-rise green offices and refurbishments. Currently, some construction companies in Melbourne have gradually embraced the recycling idea, especially with C&D waste from commercial building sites. In Melbourne, plans are also underway to set up more waste sorting and recycling sites. Victoria's waste quantities recovered and recycled steadily increased from 1.4 million tonnes in 1993, to 3.2 million tonnes in 1998–1999, and waste recovery in 2006–07 continued the strong growth trend as

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[2] The Australian State of the Environment (SoE) report (2001). This was an independent report to the Commonwealth Minister for the Environment and Heritage. Written by the Australian State of the Environment Committee Authors

displayed over recent years. This was facilitated by the continued growth and establishment of suburban collection points for municipal waste collection, growth in recovery through increased processing capacity, and demand (Sustainability Victoria, 2008a). However, this increase in recycling has not been fully extended to the commercial C&D sector.

Various questions like 'Are there any associated problems from the use of some C&D recycled materials?', 'Are there enough C&D waste materials recovered for recycling?' and 'Is there enough awareness of C&D recycled materials?' remain unanswered.

The Department of Environment and Water Resources (DEWR) 2007, has stated that "*growth in the use of recycled materials is often constrained by specifiers' insufficient knowledge of material performance, low awareness of benefits and perceived risks*". To this effect, a guide[3] was developed and introduced for the C&D industry. Advocating for increased recycling of C&D waste means its supply should match demand. Further research is needed in this area. This chapter outlines the research questions and provides an overview of the background, methodology, scope and limitations of the study.

1.2 Problem Statement

Although recycling awareness began in the early 1990s, consistent documentation of the impact of recycling C&D waste materials began around 2004 in Australia. This stemmed from lack of data on what could or could not be recycled, why and how, the quantity of waste resources recycled, the cost of C&D recycled materials, and the quantity of recycled materials purchased by the construction companies. These past data monitoring issues have shown inconsistencies in record collection within the C&D industry. Data on past C&D waste recycling studies focused mainly on the environmental aspects such as depletion of resources, ignoring other contributory

[3] The guide to the use of recycled concrete and masonry materials attempts to consolidate available information to provide the tools required for conventional design using graded recycled concrete construction and demolition waste material. This is the first publication that brings together the 'state of the art' for concrete and masonry recycling, incorporating materials specification at a national level (DEWR, 2007)

aspects. This has hindered the correct analysis of environmental, social, economic and governance impacts (the four aspects) affecting C&D materials recycling, and the use of C&D recycled materials within the building industry. To increase the use of C&D recycled materials, a focus on all four aspects affecting recycling is required.

This study focuses on Reinforced Concrete (RC) and bricks, which are two of the most common C&D waste materials in Victoria. Coles (2007) reveals that concrete and brick still remain on the priority materials list for the Metropolitan plan for Victoria. This plan aims to improve:

- current and projected disposal quantities in landfill
- adequacy of current systems for recycling
- expand capacity for recovery of priority materials
- environmental impacts arising out of disposal, including toxicity
- cost to community and industry

Coles (2007) highlights some of the factors that require improvements, to achieve an increased awareness of C&D recycled waste material benefits. Currently, some construction and demolition companies keep records of waste recovered, recycled, disposed to landfill, and the correct accounting of expenses incurred. Highlighting the drivers and barriers to recycling C&D waste materials will depend on effectively keeping record of improvements. The persistent use of virgin alternatives, like virgin gravel in construction, highlights the need to increase awareness of C&D recycled materials.

Past efforts have fallen short of considerably increasing the use of C&D recycled materials. It is crucial to consider the environmental, social, economic, and governance aspects, to identify the factors that affect increased recycling. Though most C&D materials are recovered for recycling (Section 1.1), there is still a gap between the amount recycled and the actual quantity of C&D recycled materials used in the building industry. This research attempts to find avenues for bridging this gap.

1.3 Aim of Study

The aim of this study is to identify the major drivers and barriers in the environmental, social, economic, and governance aspects that influence the recycling of C&D waste materials in the building industry. The drivers and barriers focus on the following:

- Environmental aspect – investigates the environmental effects of recycling RC and bricks as an alternative to landfill disposal, and virgin alternatives such as virgin gravel production
- Social aspect – it establishes certain behavioural patterns of C&D waste management that affect recycling practices, and create additional overall cost to construction projects
- Economic aspect – analyses the costs and benefits of recycling. The cost study focuses on activities associated with waste collection, and the recycling of RC and bricks
- Governance aspect – identifies waste legislation, that influences C&D waste recycling and C&D recycled materials use

1.4 Research Questions

To achieve the outlined aim, the thesis answers the following questions:

Question 1

"What are the major factors that could increase recycling of C&D waste materials?"

To answer the first question, some major site practices influencing C&D waste recycling at six construction sites involved in C&D waste management were identified. The study highlighted major focus areas of C&D waste management that were drivers or barriers to effectively recycling C&D waste materials. This initial study did not focus on any particular C&D waste material.

Question 2

"How best can these factors be incorporated into existing practices to facilitate increased demand for RC and brick recycled materials?"

To incorporate findings from question 1 into existing practices, a follow-up case-study of a recycling plant narrowed the study to include only RC and bricks. The RC and brick study showed processes carried out during recycling, the costs involved, and their implications for recycling compared to landfill disposal. The research outcome for this investigation could assist in identifying a good system of monitoring, that broadens the scope of awareness associated with waste management and recycling, to optimise use of C&D recycled materials within the building industry.

The scope of the study attempts to answer the research questions by discussing the following four aspects:

- Environmental (Energy, Location & Transport, and Carbon emissions)
- Social (Industry practices & preferences, and Landfill)
- Economic (Cost, and Demand & Supply)
- Governance (Waste legislation and Product endorsements)

1.5 Overview of Study

This section outlines the various chapters that make up this research.

Chapter 2 reviews various literature on trends of carbon emissions, past waste efforts within the C&D recycling sector, identifies cost areas in the industry (especially for landfill), and related organisational contributions to the industry. This chapter uses the Triple Bottom Line + 1 (TBL+1) and sustainability review, to scope out the four aspects of this study; namely, the environmental, social, economic and governance aspects, which aim at answering the two research questions. The TBL+1 measurement techniques applied, and the two building materials (RC and bricks) are introduced. Exclusions to the study are outlined.

Chapter 3 outlines the intended research design. Methodology used in the data collection from the six construction sites and recycling plant is explained. The methods of data analysis used are the End-of-Life-Cycle Assessment (ELCA), analysis of questionnaire on social impacts, End-of-Life-Cycle Cost (ELCC), and review of legislation. The TBL+1 principles applied to the study are also discussed.

Chapters 4 and 5 present the ELCA impact assessment results for the chosen RC and bricks recycling and landfill disposal scenarios. In Chapter 4, a previous preliminary LCA study comparing crushed concrete to crushed rock (virgin gravel) is discussed, with a brief discussion on virgin gravel. Similarly, Chapter 5 discusses the ELCA impact assessment results for bricks. Both Chapters 4 and 5 outline data inputs and outputs for the ELCA study, as well as the sensitivity and uncertainty analysis of the study. These two chapters conclude the environmental analysis aspect of the study.

Chapter 6 discusses the social aspect of the study. This analysis chapter discusses the results from the study of the six construction sites. Certain vital behavioural patterns on-site affecting recycling are established, whilst recommendations are discussed. This chapter focuses on C&D waste materials in general.

Chapter 7 discusses the cost and benefits of recycling RC and brick materials. An outline of the capital and operational cost is used to determine the possible costs and benefits. A comparative cost study for recycling RC and bricks, landfill disposal of RC and bricks, and virgin gravel production is carried out. This forms the economic aspect of this study.

Chapter 8 reviews waste legislation affecting the recycling and use of C&D waste materials. The review focuses on seven organisations; namely, the Green Building Council of Australia, Environmental Protection Agency Victoria, Building Commission, Australian Building Codes Board, Australian Greenhouse Office, Australian Green

Procurement and VicRoads. This chapter forms the governance aspect of this study and concludes the analysis chapters.

Chapter 9 discusses the research findings from Chapters 4, 5, 6, 7, and 8, using principles of the TBL+1 framework outlined in Chapter 3.

Conclusions are drawn and recommendations are presented in Chapter 10. Further recommendations for future research are also outlined in Chapter 10.

2 REVIEW OF C&D WASTE MANAGEMENT STRATEGIES

This chapter reviews the past and current trends in waste management strategies. The TBL+1 framework (environmental, social, economic, and governance), is used to explain the developments that affect sustainable waste management practices such as recycling, within the C&D industry. The review of previous studies highlights areas that need to be improved. The identified areas form the scope of the study used to answer the two research questions.

2.1 Triple Bottom Line (TBL) + 1 and Sustainability

Encarta (2008) defines TBL as *"environmental sustainability and social responsibility used as criteria when judging the overall performance of a company, in addition to purely financial considerations."* Created by John Elkington in the late 1990's, TBL encompasses the environmental, economic and social aspects.

The TBL+1 was coined recently by the Doorways to Global Sustainability group at RMIT University, where the governance element (+1) was added. The use of TBL+1 involves the adoption of its framework, and some of the principles of the framework. The TBL+1 framework is used to highlight the scope of the study, and summarize the discussion of the research findings in this study.

Sustainability in waste management is a key area of sustainable development. The earliest definition of 'sustainable development' was coined from the Brundtland report in 1987, which states *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Department of Sustainability and Environment - DSE, 2010). Over three decades, several other committees and legislation that have been introduced include the Rio Earth Summit (1992), Agenda 21, and the Johannesburg Plan of Implementation (2002). In 1992, the Commission on Sustainable Development (CSD) was set up in Australia to address the concerns raised at the Rio Earth Summit. Other definitions of particular interest and relevance to this study include:

- *The sustainable development concept constitutes a further elaboration of the close links between economic activity and the conservation of environmental resources. It implies a partnership between the environment and the economy, within which a key element is the legacy of environmental resources, which is not "unduly" diminished* (Organisation for Economic Co-operation and Development - OECD, 1990)
- *Sustainable development means basing developmental and environmental policies on a comparison of costs and benefits, and on careful economic analysis, that will strengthen environmental protection, and lead to rising and sustainable levels of welfare* (World Bank, 1992)
- *Sustainability results from activities which:*
    - *Enhance the planet's ability to maintain and renew the viability of the biosphere, and protect all living species*
    - *Enhance society's ability to maintain itself to solve its major problems*
    - *Maintain a decent level of welfare for present and future generations of humanity*
    - *Extend the productive life of organisations, and maintain high levels of corporate performance* (Dunphy et al., 2000)

In the last decade, the drive towards sustainable developments has motivated various governments to apply the TBL to various sectors of the economy, to clearly define the crucial aspects that need to be addressed. Sustainability in waste management is becoming an emerging trend that seeks to promote sustainable development through sustainable cities. In 1992, the Melbourne principles for sustainable cities were also outlined, but the initial sustainability initiatives in Australia focused on the environmental issues (Department of Sustainability Environment, Water, Population and Communication - DSEWPC, 2010). The adoption of sustainability in the other aspects of TBL (economic and social) has been very slow, and the governance aspect has still not been considered as part of a waste management framework. Thus, the TBL+1 has not been fully utilized as part of a sustainable waste management strategy, to analyse the impacts of recycling, and optimise the use of C&D recycled materials. Sustainability in waste management is defined by the 3Rs, which are to Reduce (avoidance), Re-use, or Recycle in the waste management hierarchy[4]. Since its introduction in the 1970s, the waste management hierarchy is yet to produce the desired outcome of waste minimisation, although organisations like the Environmental Protection Agency (EPA) Victoria have adopted the hierarchy. The continuous increase in waste generation has therefore necessitated recycling, which is considered the next best option after waste reduction (avoidance) and re-use.

Recycling, together with re-use, are the middle-of-the-road options in the hierarchy of best practice in waste management shown in Figure 2.1. Clearly, preventing waste is the most preferred option, but in the building and construction industry, it will not always be possible as building purposes change, and structures must be altered to suit. Recycling is therefore, the most practical and accessible way of reducing the amount of C&D waste going to landfill. It thereby minimises harmful impact on the environment, while at the same time, saving money on waste-related costs.

[4] The wastes management hierarchy is one of eleven environment protection principles in the Environment Protection Act 1970. It is an order of preference, and states that waste should be managed in accordance with the hierarchy, with avoidance being the most preferred option, and disposal being the least. EPA is committed to reducing the amount of waste generated in Victoria, and uses the wastes hierarchy, in conjunction with the other 10 environment protection principles in the Act, to achieve this aim (EPA, Victoria, 2009).

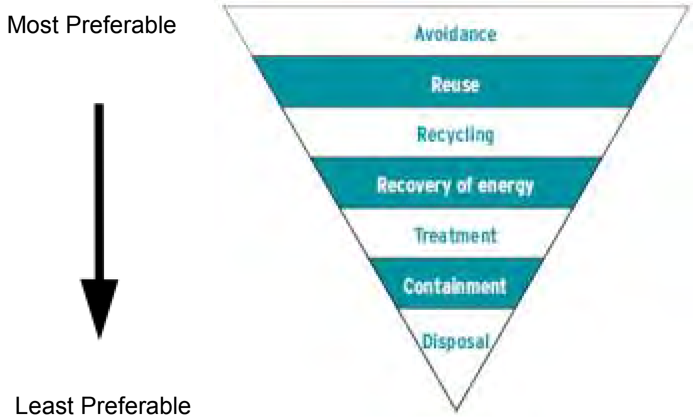

Figure 2.1: The waste management hierarchy
(Source: EPA Victoria 2009)

There is no doubt that the waste management hierarchy is a good start towards sustainability. However, various studies have suggested that the waste management hierarchy needs to be reviewed, to incorporate the changing demands in sustainability. A study in Australia by Gertsakis & Lewis (2003) has identified that the current waste management strategies are still unsustainable, due to the absence of the major stakeholders that influence waste management decisions. In Europe, there has been a call to rethink the European Union (EU) policy on waste disposal, which is currently determined by the waste management hierarchy. An EU study by Rasmussen et al., (2005) identified that the waste management hierarchy was environmentally-oriented, and did not take into account social and economic aspects. Rasmussen et al. (2005) outlined several problems, which were important reasons for policy-makers and decision-makers to rethink the use of the principles in the waste hierarchy. These included:

- Social cost-benefit studies cast doubts on the validity of the waste hierarchy as the sole ranking principle in waste management strategies
- There are inefficiencies of the fixed recycling targets in the European Union
- European legislation on waste move towards more economic regulation, such as green taxes or tradable quotas, which are price-based policies

Due to the continuous generation of C&D waste in Australia, it is crucial to rethink waste management strategies, regardless of the adoption of the hierarchy in most waste legislation. Although recycling remains the preferred option in many countries, several factors such as recycling costs, recycling benefits, recycling targets and waste regulations, affect waste management, and need to be reviewed. The subsequent sections of this chapter review waste management strategies, based on the TBL+1 framework.

2.1.1 Environmental Trends – Carbon emissions and embodied energy impacts

There is currently a major focus on Green House Gases (GHG), especially with the rising concern about carbon emissions worldwide. These emission concerns have also been raised in the recycling sector. The assessment of embodied energy is crucial to determine the benefits or impacts of waste management. The use of alternative renewable energy sources has been considered for various sectors of the economy. However, the option of alternative renewable energy is yet to be fully extended to waste management, particularly recycling. This section discusses the effects of waste on carbon emission and energy use.

2.1.1.1 Carbon Emissions impacts

While Australia only accounts for around 1.4 % of global emissions of CO_2, its emissions per person are relatively high compared with other OECD countries. In 2007, 18.75 tonnes of CO_2 were emitted for every Australian, compared with an OECD country average of 10.97 tonnes per person. Many large economies, including Japan (9.68 tonnes/person) and the United Kingdom (8.6 tonnes/person), had significantly lower per capita CO_2 emissions than Australia in 2007 (ABS, 2010). The Australian Greenhouse Office (AGO) 2007, released a report on emissions from states and territories from 1999-2007. Seven sectors were identified as the main avenues for emissions. These included energy (stationary energy[5], transport, and fugitive

[5] **Stationary energy** includes emissions from electricity generation and from fuels consumed in the manufacturing, construction and commercial sectors, and emissions from other sources like domestic heating (Origin Energy, 2008)

emissions[6]), industrial processes, agriculture, Land Use Land Use Change and Forestry (LULUCF) and waste[7].

Table 2.1 shows that energy had the most significant change. Waste emissions figures appear comparatively insignificant, but waste management requires the use of energy, and therefore has the potential to influence the higher figures realised in the stationary energy and transport sectors. Also, although carbon emission from the waste sector is minimal (Table 2.1), the use of virgin materials like gravel could increase the carbon emission figures for stationary energy and transport. For example, brick production requires more energy use compared to brick recycling.

Table 2.1: Emissions by Sectors in Victoria 1990 - 2007

Sectors	1990 (base year) (MtCO2-e)	1990-2005 Per cent change (%)	1990-2006 Per cent change (%)	1990-2007 Per cent change (%)
Energy - Stationary Energy, Transport and Fugitive emissions	79	23	40	44.2
Industrial processes	4	-33	17.7	21.5
Agriculture	14	7	3.8	-1.1
Land Use Land Use Change and Forestry (LULUCF)	5	-	-53.9	-70.6
Waste	5	-25	-11.4	-9.8
Total for base year	**107**			

(Source: AGO, 2007 & Department of Climate Change - DCC, 2008d) – Million Tonnes Carbon dioxide equivalent (MtCO2-e)

The percentage change for energy shows a steady increase from 2005-2007. Waste, on the other hand, had less impacts, and decreased in percentage change from 2005-2007. According to the AGO (2007) report on emissions, stationary energy and transport contributed the most impact to the energy sector. Table 2.2 shows the percentage contribution of stationary energy and transport figures to the national total CO_2 emissions for all sectors of Australian states in 2005. Emissions contributions from

[6] The 'Fugitive Emissions from Fuels' sector is comprised of the greenhouse gas emissions from the extraction and distribution of coal, oil and natural gas.
[7] Waste in the AGO report included Municipal Solid Waste (MSW), Commercial and Industrial waste (C&I) and C&D waste.

energy were higher than for transport. Victoria's energy (80.5MtCO_2-e) and transport (20.6MtCO_2-e) emissions were amongst the highest in Australia for 2005. In Victoria, the stationary energy and transport figures dominated those of the other states.

Table 2.2: State and Territories Stationary Energy, Transport and total emissions 2005

State and Territories	Stationary Energy MtCO_2-e	Stationary Energy %	Transport Mt CO_2-e	Transport %	All sectors MtCO_2-e	All sectors %
New South Wales	76.0	27	21.6	27	158.2	28
Queensland	64.6	23	18.7	23	157.0	28
Victoria	80.5	30	20.6	26	121.9	22
Western Australia	36.3	13	9.5	12	66.6	12
South Australia	14.2	5	5.9	7	28.1	5
Northern Territory	3.7	1	1.4	2	13.5	2
Tasmania	2.4	1	1.8	2	11.0	2
ACT	-	-	0.9	1	1.1	0.2
Australia (Total)	**277.7**	**100**	**80.4**	**100**	**557.4**	**99.2**

(Source: AGO, 2007) – Million Tonnes Carbon dioxide equivalent (MtCO_2-e)

To reduce carbon emissions, the Australian Government initially proposed the Carbon Pollution Reduction Scheme (CPRS) [8], which has been superseded by the carbon tax scheduled for implementation in July 2012. The Department of Climate Change and Energy Efficiency (DCCEE, 2010a) explains the CPRS cap as an upper limit on Australia's carbon pollution that will be lowered annually, until carbon emissions are reduced, to achieve the targeted environmental outcome. The ability to trade emissions ensures that pollution reduction opportunities are harnessed throughout the economy, to

[8] The CPRS is an emissions trading scheme, which will use a cap and trade mechanism.

reduce the economic cost of meeting ambitious carbon pollution reduction targets. The CPRS puts a price on carbon pollution, and ensures that all businesses include the carbon pricing in business decisions. In April 2010, the Australian Government announced a delay in the implementation of the CPRS, to focus efforts on the current commitment period of the Kyoto Protocol. The government has also stated that the CPRS will be implemented, when there is greater clarity in relation to the action of other major carbon emitting countries such as the United States, China and India (DCCEE, 2010a). The CPRS will cover the six GHGs in the Kyoto Protocol (Section 2.1.4.2), and the emission sources include stationary energy (which includes electricity production), transport, fugitive sources (oil and gas production), industrial processes (such as cement and aluminium production), and waste. When introduced, the CPRS will be an avenue for the transport, energy and waste emissions to be monitored.

2.1.1.2 Embodied Energy

Embodied Energy (EE) is the energy consumed by all of the processes associated with the production of a building, from the acquisition of natural resources to product delivery. This includes the mining and manufacturing of materials and equipment, transportation of the materials and the administrative functions (Green house, 2005). This research analyses the embodied energy involved in the disposal and recycling of buildings materials. The EE of materials and environmental impacts are only known when the LCA is fully applied. EE is a significant component of Life-Cycle impact, which also extends to the study of disposal and recycling energy.

The two types of EE include the ***Initial Embodied Energy*** (IEE)[9] and the ***Recurring Embodied Energy*** (REE)[10]. The IEE and REE have two components, namely, Direct[11] and Indirect[12] energy. The electricity and fuel used during the waste disposal and recycling stages can be classified as indirect energy. In Figure 2.2, it is assumed that

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[9] IEE in buildings represents the non-renewable energy consumed in the acquisition of raw materials, their processing, manufacturing, transportation to site, and construction (Canadian Architects, 2007).

[10] The REE in buildings represents the non-renewable energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the life of the building (Canadian Architects, 2007).

[11] *Direct energy* is the energy used to transport building products to the site, and then to construct the building.

[12] *Indirect energy* is the energy used to acquire, process, and manufacture the building materials, including any transportation related to these activities.

energy is the main component used in the initial processing of construction materials to the point of disposal. The disposal stage offers two options: landfill and recycling. Recycling and landfill of C&D waste materials usually involves some amounts of energy use.

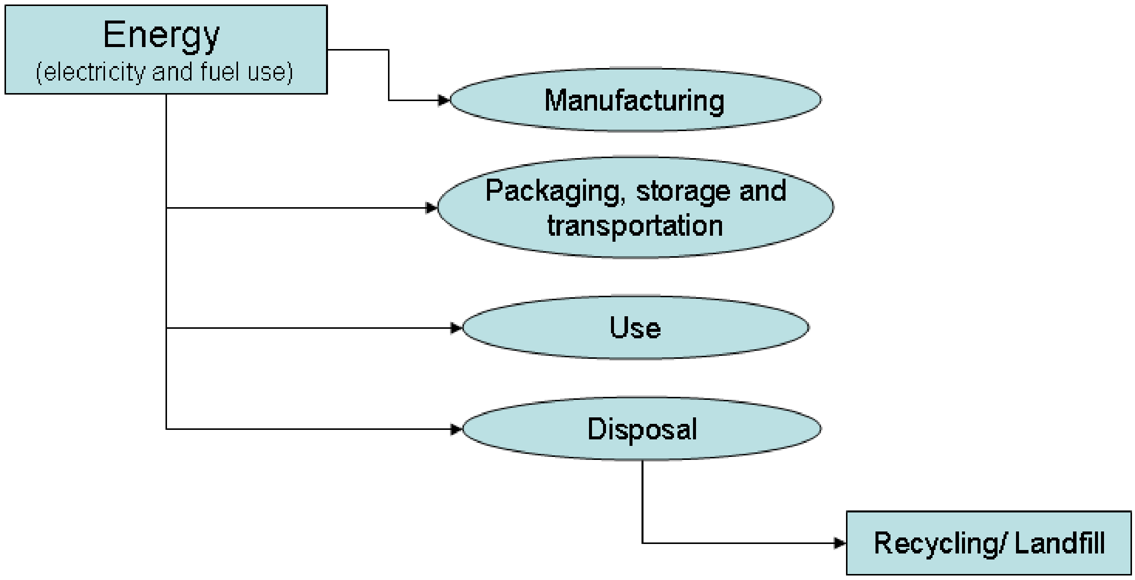

Figure 2.2: Initial production phases involving energy use
(Source: Adapted from Institute of Lifecycle Environmental Assessment - ILEA, 2004)

Processes found during the initial production of construction materials are sometimes repeated in the recycling phase; for example, similarities exist in the crushing process of quarry rock (gravel) and concrete recycling. Recycling utilises energy in much the same way as illustrated in Figure 2.2, with the differences of remanufacturing instead of manufacturing shown in Figure 2.3. Energy use in recycling is believed to be less than the amount required during the initial production, as construction materials have previously undergone a rigorous transformation. This study investigates the effects of energy and carbon emissions on the RC and bricks recycling process, compared to RC and brick landfill disposal, and virgin gravel.

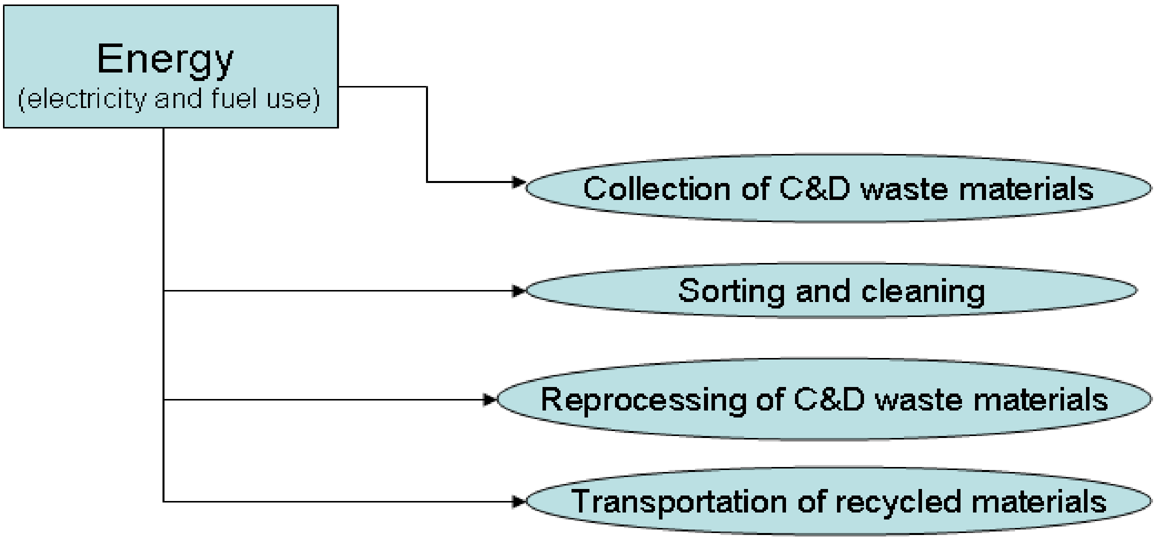

Figure 2.3: Recycling phases involving energy use
(Source: Adapted from ILEA, 2004)

2.1.2 Social Trends – Earlier waste recycling efforts

This section discusses earlier recycling efforts and practices in the C&D industry. The review identifies the measures that have shaped the social aspects of recycling, and where further changes are needed.

Earlier recycling efforts have shaped current recycling trends and developments in Victoria. A number of construction companies undertook waste management initiatives that spear-headed the awareness of recycling over a decade ago.

ANZECC[13] specifically targeted construction and demolition waste because it constitutes a high percentage of the waste going to landfill. One of the more successful national programmes was the Waste Wise Construction Programme[14], initiated by the Federal Government in 1995, as a partnership with five major building and participating

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[13] In 1992 the Australian and New Zealand Environment and Conservation Council (ANZECC) set a target of reducing 1990 per capita levels of waste going to landfill by 50 per cent by the year 2000 (Sustainability Victoria, 2006b).

[14] ANZECC developed the Waste Wise Construction Programme, a co operative programme with five leading Australian construction companies. Currently, the waste wise programme is managed by Sustainability Victoria and delivered by experienced Waste Wise facilitators from within Sustainability Victoria and Regional Waste Management Groups around Victoria (Sustainability Victoria, 2006b).

construction companies and associations. Waste Wise aimed at providing a national demonstration through case-study activities of participating companies, and the potential to reduce waste through effective waste management strategies.

Following the success of the initial 3-year Waste Wise programme, a second phase of the programme began in 1998, with an expanded membership of 14 organisations (refer to Appendix A1). Waste Wise Phase II officially concluded in December 2001. The final phase of Waste Wise involved fourteen partners, made up of industry associations (7), construction companies (6), and an architecture firm (Department of Water Resources - DEWR, 2005a). In 2001, the year Waste Wise concluded as a national initiative, the programme reported that construction companies were recycling an average of 87% of their waste, with recycling ranging from 66% to 94% (DEWR, 2005b). Waste Wise delivered a financial return to businesses through cost-effective waste reduction and recycling systems for solid, non-hazardous wastes. Certification was also available for businesses that made significant achievements in waste reduction (Sustainability Victoria, 2006b).

The 6 construction companies that made up the Waste Wise programme applied various strategies. Some of the strategies that were adopted by the companies to reduce waste were waste audit, waste minimisation plans, management and training, site arrangements, contracts and purchasing. Figures 2.4 and 2.5 show how two of these companies implemented their waste minimisation strategies. Figure 2.4 shows how RECON-Fletcher measured the company's waste produced. Figure 2.5 outlines the Environmental Management System (EMS) for the John Holland Company. Waste Wise assisted businesses to reduce waste, as well as costs, through improving material efficiency. Waste Wise is now operating on a state level under Sustainability Victoria.

Although the Waste Wise strategies were introduced, waste generation continued to increase, and projections by Coles (2007), has confirmed the waste increase. Waste minimisation strategies and recycling at C&D sites need to be improved. Chapter 6 highlights some drivers and barriers to waste minimisation strategies and recycling of C&D waste materials.

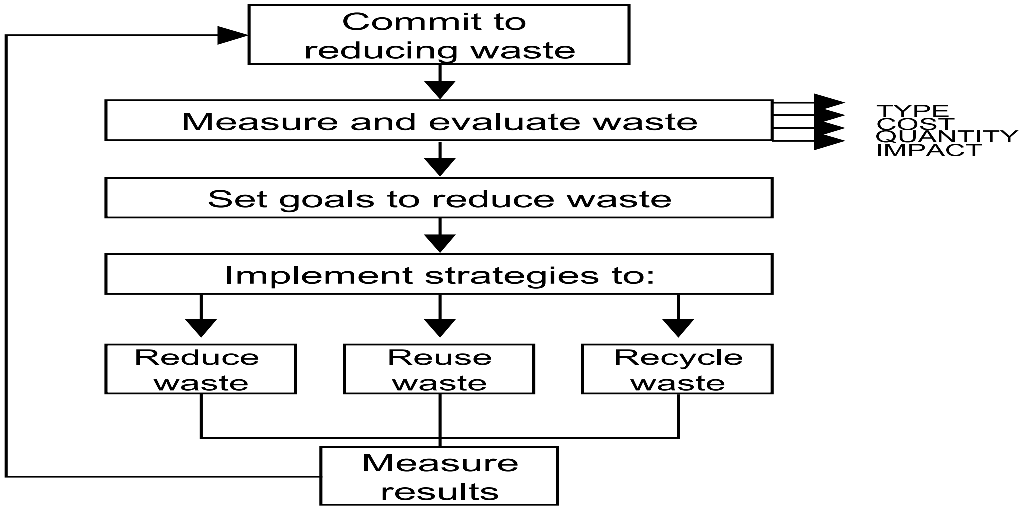

Figure 2.4: Waste minimisation & recycling programme for RECON- Fletcher construction Australia

(Source: DEWR, 2005b)

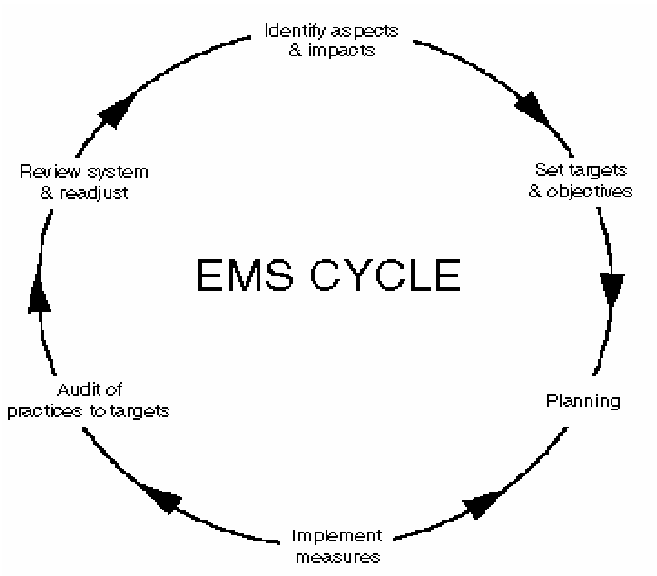

Figure 2.5: The flow chart for the John Holland Company on waste minimisation practices

(Source: DEWR, 2005b)

2.1.3 Economic Trends – Waste management costs

This section discusses some of the cost factors that influence waste management strategies such as waste minimisation, recycling, and landfill disposal of C&D waste materials.

There are immediate benefits, which can be achieved by tracking waste costs more closely, and modifying basic 'housekeeping' practices. Such information is essential to improve efficiency, minimise waste, and to give individuals an understanding of their role in identifying specific actions[15].

According to EcoRecycle[16] (2002), the haulage of waste involves some hidden costs, such as the value of lost raw materials, labour costs associated with internal management, energy costs, capital costs, on-site treatment and storage, administration, and lost opportunity cost (from loss of income from generating waste instead of product). Increasing haulage cost, and new recycling requirements have made C&D waste disposal a significant cost component of projects. These costs result from waste generation, and are not easily known during the initial planning of the project. Australia's long run of economic growth has been fuelling strong growth in construction activities across the country. As a result, less landfill capacity has in turn put upward pressure on tipping fees. This is providing strong impetus for companies to implement enhanced waste minimisation and recycling strategies.

The Victorian State Government has estimated that the landfill levies would raise about $30 million in the next four years, and over $53 million by 2014-15, which is estimated to increase resource efficiency and recycling by up to 33% (State of Victoria, 2007; Environment Victoria, 2010). In Victoria, landfill levies remained at $15 per tonne until July 2010, when the levies were increased to $30, and this is scheduled to increase to

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15 The Monash Centre for Environmental Management in partnership with academics, organisations and accountants, released a publication on the *"Accounting for waste as a business management tool- A best practice guideline"* (Sustainability Victoria, 2006b)

16 EcoRecycle Victoria is a government body and agency responsible for waste minimisation and recycling in Victoria. EcoRecycle Victoria is not a legislative body, but attempts to achieve its goals through co-operation with local government and private industry. EcoRecycle Victoria is now a part of Sustainability Victoria, and funds a number of activities with construction and demolition industry relevance. (Crowther, 2000)

$53 by 2014-15 (EPA Victoria, 2007c; Environment Victoria, 2010). Increased landfill charges were also evident in other states; for example, since 2001 in New South Wales (NSW), landfill fees have gradually increased from $17 (increases by $1 each year) to $25 in 2009. The charge will be maintained until 2014, when additional charges will be applied (EPA NSW, 2001). NSW has over the years, maintained a higher level of recycling, which correlates with its higher landfill charges. It is yet to be seen if Victoria's increase in landfill prices will also increase recycling.

The correlation between landfill charges and levels of recycling suggests that as tipping fees increase, the level of recycling can be expected to grow as well. This begs the question as to whether industry change can simply be achieved by increasing these fees, and leaving the issue to the market. Also, if recycling truly increases with tipping fees, can there be a guarantee of demand for the recycled C&D products? This will undoubtedly be part of the solution, as landfill sites become harder to find, and are sited further from commercial centres. The fees are likely to increase. However, simply increasing fees faster may not deliver the best overall outcomes, because of the usual difficulties in pricing environmental impacts. It is not in the interest of the economy to overburden the building sector with charges, because these will flow through to construction costs, and will find their way to almost all other sectors of the economy, and ultimately, to consumer costs.

Contracts and purchasing involves the acquisition of the right amount of materials needed, and complying with the waste management plans that have been set up for every project. Individual attitudes and purchasing habits influence the purchasing and disposal of building materials. It would be better to ensure rapid diffusion of best practice, and to optimise the demand for recycled C&D building materials across the whole industry. An informed market is an efficient one, and the challenge is to help markets function more efficiently, without undue price penalties.

The cost analysis in Chapter 7 attempts to highlight some cost and benefit areas for recycling and landfill disposal of RC and bricks, compared to virgin gravel production. Recycling C&D waste is associated with cost impacts, rather than cost savings, within the building industry. The correct analysis of the costs and benefits is needed to increase awareness of C&D waste recycling and C&D recycled materials use.

2.1.4 Governance Trends – Waste and carbon emissions legislation

The Victorian State Government is responsible for the legislation and policies in various areas of the environment, waste minimisation, recycling, construction and demolition. The state government empowers the local government and councils to enforce the state level decisions at the local levels. The Victorian State Government, in 2005, released the '*Towards Zero Waste' (TZW)* Strategy report[17]. Waste management strategies implemented at the state level in Victoria, account for a section of the national waste figures. Similarly in NSW, legislation on the economies of waste minimisation has been applied as a strategy for implementing project management tools such as waste management (Brown & West, 2003). At the international level, Australia, like many other countries, has sought to use various legislative approaches in dealing with the impacts of waste and carbon emissions. This section discusses some international waste and carbon emissions legislation that affects Australia.

2.1.4.1 Waste legislation

According to the OECD (2004), most of its member countries have policies and legislation that encourage the recovery and reduction of C&D waste, but admits that not many of these countries have policies regarding the prevention of waste. As at 2005, Netherlands and Finland were the only two countries that had set a target of waste prevention at 10% and 15% respectively. In recent times, the prevention of C&D waste has become as inevitable as it is important. The upgrade of most existing buildings to sustainable standards requires parts to be replaced, generating waste. Being part of the OECD, Australia is no exception, as green offices and other infrastructure are in high demand. The OECD (2004) however, advises member countries on various waste prevention or minimisation strategies. For example, in Japan, the Construction Material Recycling Act requires the people in charge of demolitions to separate certain construction materials (concrete, wood, etc.) for re-use and recycling. The Netherlands legislation on landfill involves a ban on all recoverable C&D waste materials. Others

[17] The TZW report was introduced by the State Government of Victoria in April 2005. The vision was for the state of Victoria to be a low waste society by 2014 (DSE 2005).

have used landfill taxes; for example, in Austria, where there is a specific landfill tax for C&D waste.

Australia's minimisation measures involve the enforcement of landfill levies. Various laws and regulations concerning waste management strategies and recycling have been implemented within the last decade. State and local governments are tasked to meet set targets and achieve set goals. Government organisations, such as the Environmental Protection Agency (EPA) and Sustainability Victoria, have a mandate to set up regulations that influence waste management. Two such regulations include the TZW (set up in 2005), and the Metropolitan Waste and Resource Recovery Strategic Plan (April-May 2008). The main purpose of the strategic plan was to outline measures to improve recycling, and the gradual shut down of existing landfill sites in metropolitan Melbourne. Chapter 8 discusses some organisational efforts for C&D recycling and materials use in Australia.

2.1.4.2 Carbon Emissions legislation

As the world faces a rise in emission levels, most developed countries have been subjected to a binding contract that targets the reduction of Green House Gas (GHG) emissions. The Kyoto Protocol is one such avenue that seeks to impress on countries the need to reduce their GHG emissions. The Kyoto Protocol was adopted under the United Nations Framework Convention on Climate Change (UNFCCC)[18]. The Protocol requires developed countries to reduce their GHG emissions below levels specified in the Treaty. The emissions reduction targets must be met within a five-year time frame between 2008 and 2012, and add up to a total cut in GHG emissions of at least 5% against the baseline of 1990. Australia's ratification of the Kyoto Protocol came into effect on the 11th of March 2008, amongst other countries listed in the Table 2.3, except the United States. Other bilateral partners on climate change action include China, New Zealand, South Africa, Japan, the European Union, and the United States (DCC, 2008a).

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[18] The Kyoto Protocol was adopted at the third Conference of the Parties to the UNFCCC (COP 3) in Kyoto, Japan, on 11 December 1997. The major distinction between the Kyoto Protocol and the UNFCCC, however, is that while the Convention **encouraged** developed countries to stabilize GHG emissions, the Protocol **commits** them to do so. The Kyoto Protocol entered into force on 16 February 2005 (UNFCCC, 2008).

There are six main GHGs under the Kyoto Protocol adopted for the emissions reduction scheme; namely, Carbon dioxide (CO_2); Methane (CH4); Nitrous oxide (N_2O), Hydro Fluorocarbons (HFCs), Per Fluorocarbons (PFCs), and Sulphur hexafluoride (SF_6). The GHG emissions sources such as energy, industrial processing, agriculture and waste form the Annex A, whilst transportation, manufacturing industries and construction, solid waste disposal on land, and waste incineration were some of the sub-sections considered under Annex A of the Protocol. Annex B, shown in Table 2.3, focuses on the emission targets for various countries.

Table 2.3: Annex B emission targets

Annex I Parties	**Emissions target (expressed in relation to emissions in the base year or period*)**
Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom of Great Britain and Northern Ireland	–8%
United States of America**	–7%
Canada, Hungary, Japan, Poland	–6%
Croatia	–5%
New Zealand, Russian Federation, Ukraine	0
Norway	+1%
Australia** (Before 11th March 2008)	+8%
Iceland	+10%

(Source: UNFCCC, 2007) * This base year is flexible in the case of countries with economies in transition. ** Countries which have declared their intention not to ratify the Protocol

According to the United Nations Environment Programme Sustainable Buildings and Construction Initiative (UNEP SBCI,[19] 2007), the built environment contributed to solid waste generation (30-40%) and global GHG emissions (30-40%). As part of its efforts to reduce carbon emissions in 2003, Australia joined the Carbon Sequestration Leadership Forum (CSLF), which seeks to capture and store CO_2 (CSLF, 2008). Carbon emissions in every production process are inevitable, but the process of reducing the emissions determines its impact on the environment. The carbon emission produced should be channeled to other avenues of use, through an effective waste management plan (where applicable), as shown in Figure 2.6. This study focuses on the CO_2 emission impact from recycling and landfill disposal for RC and bricks.

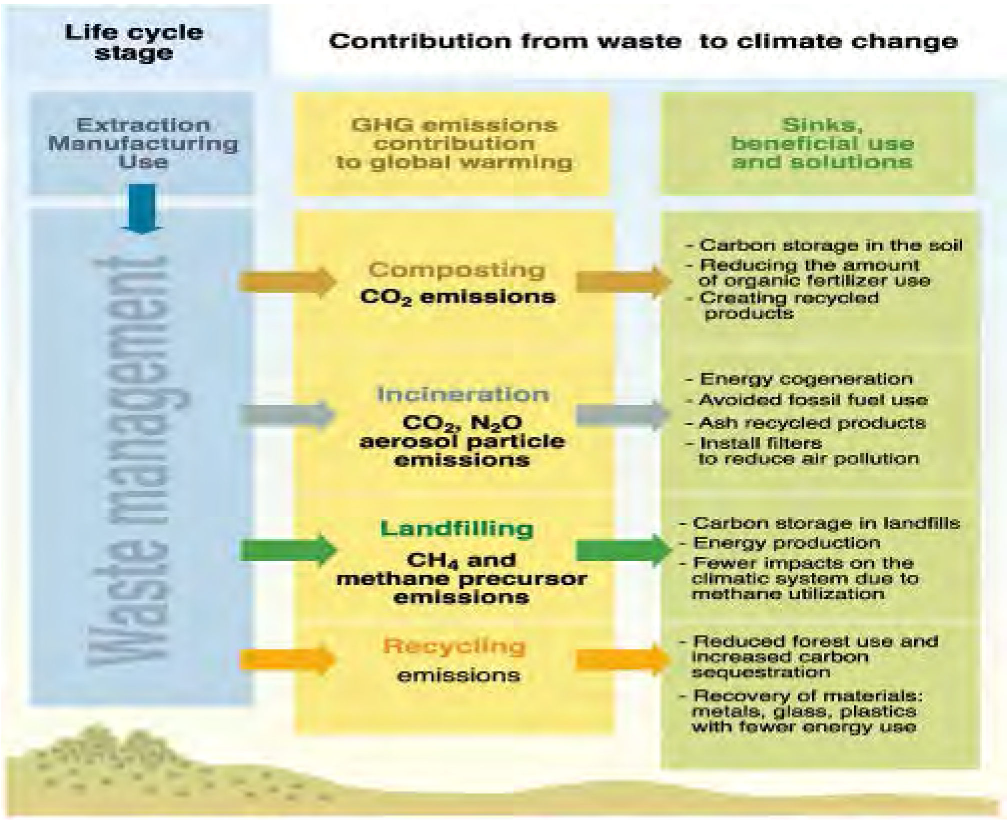

Figure 2.6: Waste and GHG emissions

(Source: UNEP/GRID-Arendal Maps and Graphics Library, 2004)

[19] UNEP SBCI focuses on key areas such as energy use, production of building materials, use and recycling (UNEP, 2007a).

In 2005, CO_2 emission for Australia was 73.4%, as opposed to methane, which was at 20.9% (DCC, 2008b). Australia's national inventory report to the UNFCCC, in accordance with international guidelines, revealed that energy and transport contributed most to CO_2 emissions. Table 2.4 outlines some waste minimisation, re-use, and recovery processes that affect GHG and related regulatory instruments.

Recycling might not offer a zero emissions solution, but could contribute towards CO_2 reduction, through the adoption of alternatives such as carbon sequestration (storage of CO_2), carbon trading and carbon taxing. There has been little discussion on the recycling impact and benefits of C&D materials, such as concrete and bricks, on CO_2 emissions. This study investigates the effects of product endorsement, as an avenue that ensures environmental impacts, such as CO_2, are reduced as a requirement for product certification. Most OECD countries use Eco-labelling[20] as a tool for product endorsement. Australia, Canada and New Zealand all have the same Eco-labelling programme called the "Environmental Choice". This study reviews some of the legislation that advocates for product endorsement in Chapter 8.

[20] Eco-labelling is a voluntary method of environmental performance certification, and labelling that is practiced around the world. An eco-label is a label which identifies the overall environmental preference of a product or service, within a specific product/service category, based on Life-Cycle considerations (OECD, 2004).

Table 2.4: Promoting waste minimisation, re-use and recovery

Policies and Measures	Activity affected	GHG affected	Type of Instruments
Extended Producer Responsibility (EPR)	Manufacture of products Recovery of used products Disposal of waste	CO_2 CH4 Fluorinated gases	Regulation Voluntary
Unit pricing / Variable rate pricing / Pay-as-you-throw (PAYT)	Recovery of used products Disposal of waste	CO_2 CH4	Economic incentive
Landfill tax	Recovery of used products Disposal of waste	CO_2 CH4	Regulation
Separate collection and recovery of specific waste fractions	Recovery of used products Disposal of waste	CO_2 CH4	Subsidy
Promotion of use of recycled products	Manufacturing of products	CO_2 CH4	Regulation Voluntary

(Source: Bogner et al., 2007)

The review of trends in Section 2.1 of this chapter has identified a number of environmental, social, economic and governance factors that could influence recycling and use of C&D materials. Based on this review, the scope of the thesis has been limited to selected key factors that seek to answer the two research questions. These key factors are discussed in the next section.

2.2 Scope of the Study

According to Seadon (2006), waste management issues are inter-related, and therefore need to be treated in a more integrated manner. Turner & Powell (1991) and Korhonen et al. (2004), reveal that integrated waste management in its simplest sense incorporates the waste management hierarchy, by considering direct impacts (transportation, collection, treatment and disposal of waste), and indirect impacts (use of waste materials and energy outside the waste management system). This section discusses the various factors affecting the direct impacts of waste management with recycling and landfill disposal.

The scope of the study includes the TBL+1 framework to highlight the areas identified in Section 2.1 in need of further investigation. These include:

- Environmental (Energy, Location & Transport, and Carbon emissions)
- Social (Industry practices & preferences, and Landfill)
- Economic (Cost, and Demand & Supply)
- Governance (Waste legislation and Product endorsements)

2.2.1 Environmental Scope

In Section 2.1.1, energy, transport and carbon emissions were identified as the major environmental factors to consider.

2.2.1.1 Energy

Energy plays an important role in waste management. Energy is saved when materials are recycled, and energy is also used in the whole recycling process. LCA modelling has shown that by substituting secondary-use materials for virgin materials in 2004–05, Victoria saved enough energy to power every household in the state for 8 months (Sustainability Victoria, 2006a).

This study focuses on the impact of embodied energy on recycling RC and bricks, compared to landfill disposal and virgin gravel production. The energy impacts on the environment were calculated for transport (fuel) and production processes (fuel and electricity), shown in Figure 2.3. Tables 2.1 and 2.2 showed the impact of energy was the most significant for Victoria in 2005. In this study, fuel and electricity were the two energy sources considered during the recycling process. The significance of energy impact in recycling and landfill disposal for RC and bricks is investigated in Chapters 4 and 5. Energy used in the initial production of RC and brick materials was excluded from this research, although references were made to other studies where necessary, for the purpose of comparison.

2.2.1.2 Transport and Location

The location of recycling plants and landfill sites should be considered when mapping out an effective waste management strategy. Decisions on the establishment of recycling plants and locations are determined by the land area needed for both stockpiling and recycling, noise and air pollution. Contractors are mainly concerned about the most cost-effective option for every project's waste management. The production of bulk materials such as virgin gravel, concrete or bricks, is best sited close to the raw material source. However, waste creation points such as C&D sites are usually further away from most recycling plants hence, the issue of transporting waste over a longer distance becomes a problem. Tables 2.1 and 2.2 showed the impact of transport for Victoria in 2005.

Although recyclers might offer attractive prices for waste dumping, contractors also consider the distance traveled. Distances traveled are likely to influence the waste quantities sent to the recyclers, especially if the distance to a landfill site is shorter. The distances traveled affect time and cost factors, which are critical to most projects, as they have set completion periods and budgets.

This study examines the effects of transport and location on quantities received for recycling, compared to landfill disposal related environmental impacts, which ultimately influences the recycled quantities available for purchasing. Transport and location data covered fuel use, distances traveled, number of trips to waste recycling plants and landfill sites.

2.2.1.3 Carbon emissions

So far, little is known about the carbon emissions (especially CO_2) impact from recycling RC and bricks as aggregate, compared to sending the waste into landfill, or virgin gravel production from quarried stone.

Embodied energy and transport have been identified as two major factors influencing CO_2 emissions. Transport activity is one of the major sources of emissions related to the combustion of fossil fuels, with transport contributing 78.8MtCO_2-e (13%) of Australia's net emissions in 2007. Emissions from this sector were 26.9% higher in 2007 than in 1990. Road transport was the main source of transport emissions in 2007, accounting for 68.5MtCO_2-e (11.5%) of national emissions (ABS, 2010). With frequent use in road transport such as trucks, this could increase further. In 2007, electricity generation accounted for 199.5MtCO_2-e (68.4% of stationary energy emissions, and 33% of Australia's net emissions). Stationary energy emissions increased by 49.5% between 1990 and 2007, and electricity generation emissions increased by 54% (ABS, 2010).

As Marland (2008) suggests, the accurate accounting of CO_2 depends on the boundaries set out for the research in question, which in this study cover the recycling process. Chapters 4 and 5 seek to identify the extent of carbon emissions (CO_2) from the recycling process, compared to landfill disposal. The implications of the carbon emissions (CO_2) results for RC and bricks recycling, and landfilling compared to virgin gravel production, are discussed in Chapter 9.

2.2.2 Social Scope

Section 2.1.2 discussed some earlier efforts made at recycling. Australians generated approximately 43.8 million tonnes of waste (approximately 2,080 kilograms of waste per person) in 2006–07. The states responsible for the largest proportions of the country's waste generation in 2006–07 were the three most populous states: NSW (35%), Victoria (23%) and Queensland (18%). Of the 43.8 million tonnes of waste generated in Australia in 2006–07, 38% came from the construction and demolition sector (ABS, 2010). With waste generation set to significantly increase, the current recycling practices in the building industry are not likely to decrease the waste generation figure hence, increased recycling is needed. The social scope of the study identifies some drivers of waste generation increase, whilst proposed improvements to increase C&D waste recycling are discussed in Chapter 9.

2.2.2.1 Industry practices and preferences

Though industry practices are governed by legislation and regulations, human behaviours, attitudes and perceptions, have the potential to influence waste management practices at C&D sites. Site workers, project managers, contractors, site and environmental managers were some of the stakeholders targeted for the six construction sites study. The waste management choices of these stakeholders played a major role in recycling, and the use of C&D recycled materials.

Contractors, building owners and developers have the mandate to approve the building materials used and the waste management options in construction projects. However, non-recyclable building material choices, and attitudes towards recycling, could influence the need to recycle. The waste management plan for waste disposal is often based on the demand for certain building material types over others, which determines the C&D waste materials that get recycled. Section 2.1.2 discussed efforts made by some construction companies to recycle during the Waste Wise programme. Increased knowledge of building materials recovered is required, to create the awareness needed for the recycling and patronage of C&D recycled materials. The study of the six construction sites in Chapter 6, seeks to tease out the reasons behind such construction material choices and decisions to recycle.

2.2.2.2 Landfill

Landfill disposal has become increasingly difficult, with pressure on most contractors to account for the disposal of their C&D waste. In Clause 19 of the Waste Management Policy, it states "*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*" (Victorian Government Gazette, 2004). The above statement implies that C&D waste materials such as RC and bricks have a "higher waste management option (recycling) that is practicably available" however, they are still sent to landfill. Others may argue that RC and bricks do not "pose an unacceptable risk to the environment", compared to say plastics or other hazardous materials. Victoria saw 59% of C&D waste material going to landfill in 2005 (Sustainability Victoria, 2008a). During 2006–07, nearly half (48%) of all waste was disposed to landfill. Approximately 43% of C&D waste went into landfill in 2006–07 (ABS, 2010). The pertinent issue does not only relate to landfill disposal risks, but simply goes beyond the risk, to incorporate good disposal practices.

Waste such as RC and bricks, used as cover materials at landfill sites attract a 15% rebate for every tonne of waste disposed to landfill, in accordance with the *Environment*

Protection Act 1970 (Sustainability Victoria, 2008a). Although the cover material use option is financially beneficial to landfill owners, the worth of the cover material is devalued, compared to recycled materials. More C&D waste materials disposed to landfill means fewer quantities recycled, and less C&D recycled materials available on demand. Landfill has been included in this study to establish the extent of environmental impacts for RC and brick waste disposed to landfill. Section 2.1.3 discussed the effects of landfill levies on the patterns of landfill disposal for NSW compared to Victoria. Undoubtedly, waste management practices on-site will determine if C&D projects incur the landfill levies. Chapter 6 investigates the barriers to effectively managing waste at the six construction sites, and identifies the drivers of best practices. Chapter 9 suggests some improvements to increase recycling.

2.2.3 Economic Scope

Section 2.1.3 identified factors such as recycling costs, landfill costs, as well as demand and supply of C&D recycled materials, as important to maintain the business viability of recycling.

2.2.3.1 Cost

Cost is an important part of recycling. Cost is incurred at every stage of the recycling process; for example, tipping, haulage, and the capital cost of the crusher, all add to the cost of recycling.

Whilst recyclers incur these costs, there are avenues for income generation, when recycled materials are sold. The pricing of C&D recycled materials is determined by the cost of the inputs needed to recycle. Stakeholders may choose to compare the price of C&D recycled materials with virgin alternatives. In major projects, the use of recycled material content is usually advised where there is a cost difference of less than 5% (DSE, 2004). However, there is an ongoing debate as to how much is too much for pricing C&D recycled materials. Whilst some people agree that the minimisation of environmental impacts come at a price, others argue that processed waste should be cheaper. Consequently, consumers who pay more for C&D recycled materials are less likely to patronise C&D recycled materials. The cost study in Chapter 7 highlights costs and benefits for recycling and landfilling RC and bricks, compared to virgin gravel production.

2.2.3.2 Demand and Supply

A supply chain involves more than just the receipt of goods. There are various factors that affect the process. Ayers (2001) states *"supply chain is Life-Cycle processes comprising physical, information, financial and knowledge flows whose purpose is to satisfy end-user requirements with products and services from multiple linked suppliers".* Ayers explain that these processes are carried out through sourcing, manufacturing, transporting, and selling physical products. The supply chain is a very important aspect of the recycling process because without the ready-market or demand for recycled goods, there is no need to recycle. To fully understand the supply chain of a product, it is important to look at the demand driving it. Buying C&D recycled materials 'closes the loop', as there is a continuous cycle of demand and supply for recycled materials.

Recycling is not a viable business if recyclables cannot be sold. C&D companies as well as recyclers, like any business, are interested in the financial returns of C&D waste recycling and C&D recycled materials. However, it is crucial that the returns are comparable with options such as landfill disposal cost, and the cost of virgin building materials. A comparison would identify cost savings needed to mount a persuasive case towards market demand for C&D recycled materials.

Chapter 7 calculates the costs and benefits of recycling RC and bricks, compared to landfilling and virgin gravel production. The cost analysis will provide a better understanding of the C&D recycled materials' demand, and supply patterns within the building industry.

2.2.4 Governance Scope

In Victoria, targets such as the Towards Zero Waste (TZW) are geared towards waste generation reduction and increased recycling. Product endorsements have been used to create awareness, through the promotion of other recycled products. Product endorsements ensure that materials meet specific environmental requirements, and could be an avenue in which optimal demand for C&D recycled materials could be ensured. Section 2.1. 4 discussed Australia's legislative responsibility on waste and carbon emissions.

2.2.4.1 Waste legislation – 'Towards Zero Waste' Legislation

In the TZW business sector, the C&D waste "Target 7" is geared towards achieving a recovery rate of 80% (by weight) of C&D solid waste for re-use and recycling by 2014. An interim target of 65% established for 2008-09 was exceeded, with the C&D sector resource recovery rate being 6% above the target in 2006-07 (71%). This equated to 2.9 million tonnes, and an increase of 127,000 tonnes of recovered material, compared to the 2005 -06 period (Sustainability Victoria, 2007a & 2008b). It is important to emphasize that these are recovery rate targets, and not recycling rates, and that not all the recovered materials are necessarily recycled. There is the need for waste legislation, which allows for the accurate accounting of waste streams. Australia, and particularly Victoria's ability to effectively reach targets of plans such as the TZW, will require that waste recovered is recycled. With the increasing demand for building infrastructure across Australia, recycling targets, rather than recovery targets, are needed.

2.2.4.2 Product endorsements

Product endorsements highlight the environmental benefits of certified products, and serve as an avenue for informing consumer choices. An endorsed product should satisfy the requirement that the product Life-Cycle had the least amount of impact on the environment. With the recent emphasis on global warming and carbon emissions, product endorsement could ensure the effective measures are put in place to address environmental impacts. In Australia, authorised or regulatory bodies include the GBCA, EPA, Building Commission, and Waste Management Association of Australia, as well as other government departments and organisations responsible (Chapter 8). Chapter 8 discusses the efforts by seven organisations to endorse recycled products. However, some of these products are not C&D recycled materials. The effective use of the product endorsement system for other recycled materials should be applied to C&D recycled products to optimise their use.

2.3 Techniques used to measure the TBL+1 aspects

The following were used to analyse the four TB+1 aspects previously discussed. Chapter 3 explains the use of these techniques in this study.

- LCA – Environmental impact
- Social impact analysis for C&D waste recovery and recycling – Social impact
- LCC – Economic impact
- Review of waste legislation – Governance impact

2.3.1 Life-Cycle Assessment (LCA)

The International Organisation for Standardization (ISO, 2006) defines ***Life-Cycle Assessment (LCA)*** as the "compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its Life-Cycle" (Prokopy, 2007). The Life-Cycle impact of every product, starts from the harvesting of raw materials, and goes through to the disposal stage.

Internationally, the idea of LCA was previously raised at the Earth Summit in Rio (1992), Kyoto Protocol (1997), United Nations Environment Programme (1998) and the Earth Summit in Johannesburg (2002). Some countries well-known for their LCA programmes in building include ATHENA (Canada), BEES (United States), SIMAPRO and Eco Quantum (The Netherlands) and ENVEST (United Kingdom) (Electrical & Mechanical Services Department - EMSD, 2007).

LCA involves four steps, according to the ISO; namely, goal and scope definition, inventory analysis, impact assessment, and the interpretation of results (Grant et al., 2003). The four steps are applied in the End-of-Life-Cycle Assessment (ELCA) data analysis in Chapters 4 & 5, according to the international standards (ISO 14044, 2006). In this study, the ELCA has been coined to clearly define the systems boundary under which the LCA was carried out. The ELCA is used in assessing the environment impacts of recycling and landfilling of RC and bricks (Section 3.2.1). The ELCA applies the four steps in the same way as LCA. Figure 2.7 is a model of LCA, as proposed by ISO 14040 standards.

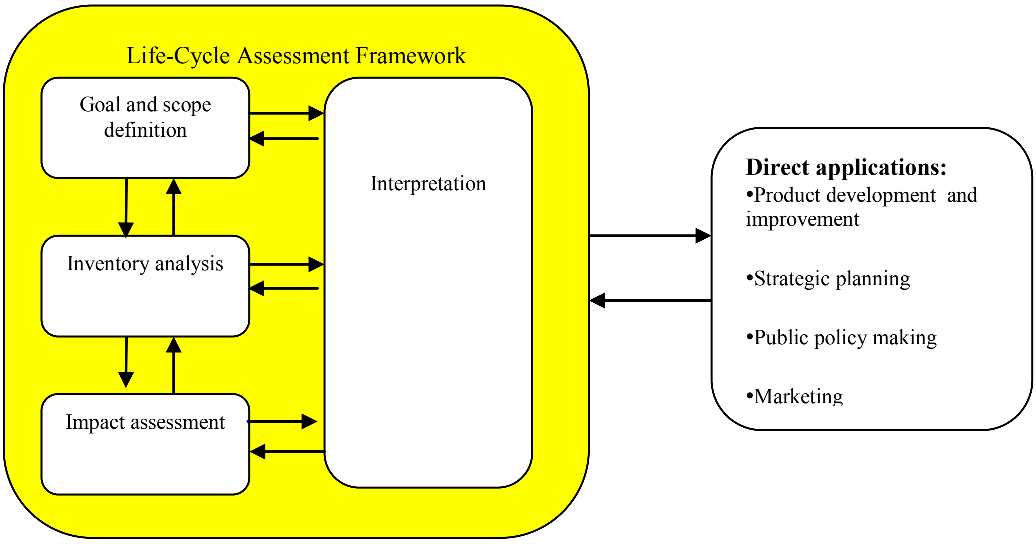

Figure 2.7: The interaction of the four steps of LCA, according to ISO

(Source: Royal Melbourne Institute of Technology - RMIT, 1999b)

LCA methodology is adopted as an objective process, to evaluate the environmental burdens associated with building development, by identifying and quantifying energy, material uses, and releases to the environment, to evaluate, implement opportunities, and achieve environmental improvements (EMSD, 2007). LCA provides a conceptual framework for a detailed, comprehensive, and comparative evaluation of potential environmental impacts. Traditional LCA involves a complete inventory of resource inputs and outputs, in all steps of production, and can incorporate indirect emissions (Bertel & Fraser, 2002).

This study uses the Systems for Integrated Environmental Assessment of Products (SIMAPRO) software. There are 3 versions of SIMAPRO, namely the SIMAPRO compact, the Analyst and the Developer. The Analyst educational version called SIMAPRO PhD was used in this study. SIMAPRO covers all the four LCA steps, as shown in the user interface screen (Figure 2.8).

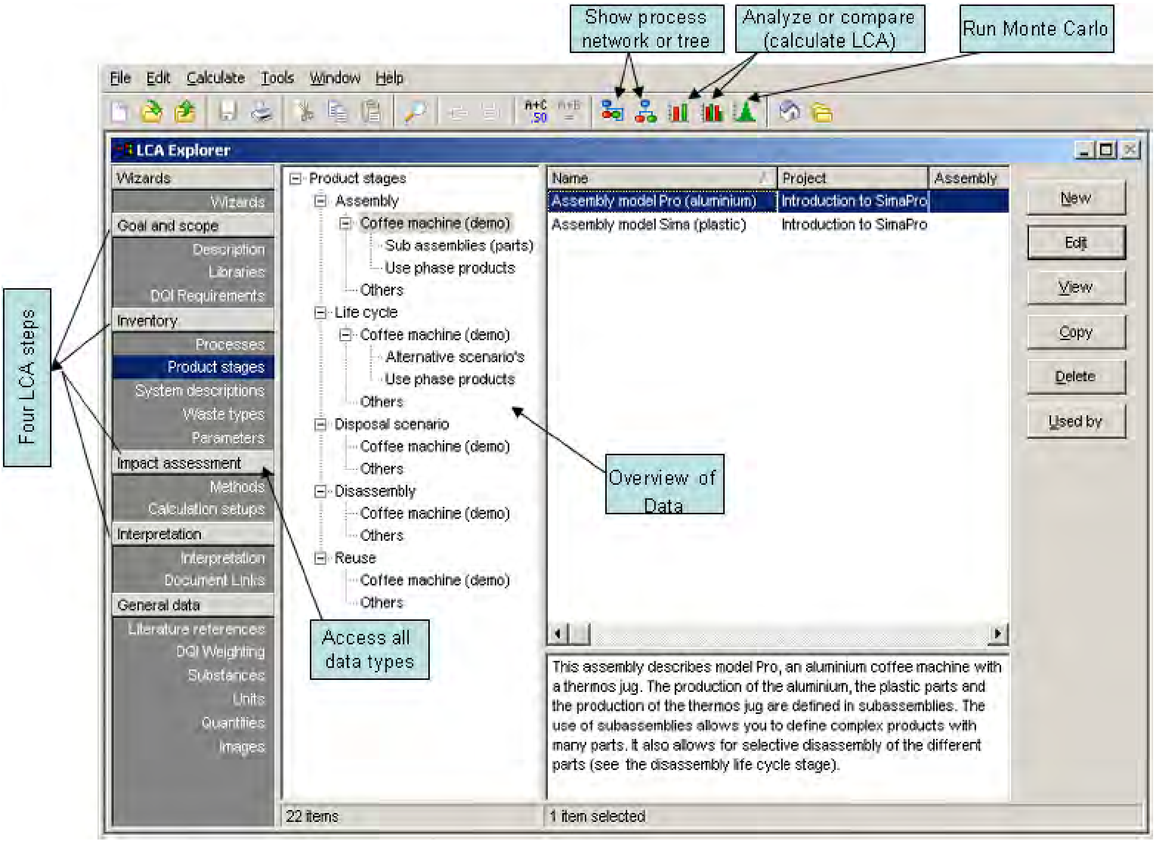

Figure 2.8: The user interface in SIMAPRO

(Source: PRe, 2006)

The application of the four LCA steps is further outlined in Chapter 3. The two steps used to present the results for interpretation are the inventory analysis and impact assessments. The inventory analysis is made up of Life-Cycle inventories, and in SIMAPRO, these are presented as ‘processes’ and ‘product stages’ (Figure 2.8). In the SIMAPRO inventory section, the ‘systems description’ provides additional data on unit processes, whilst ‘waste types’ provides information on waste materials. The impact assessment section of SIMAPRO allows for several analysis runs to be conducted, to compare the various Life-Cycle scenarios and processes (PRe, 2008b). SIMAPRO analyses the impacts of input and output processes, by using the ‘calculation setups’ and ‘methods’ of analysis in the impact assessment category, as shown in Figure 2.8. Figure 2.9 illustrates the inventory and impacts assessments using a proprietary example.

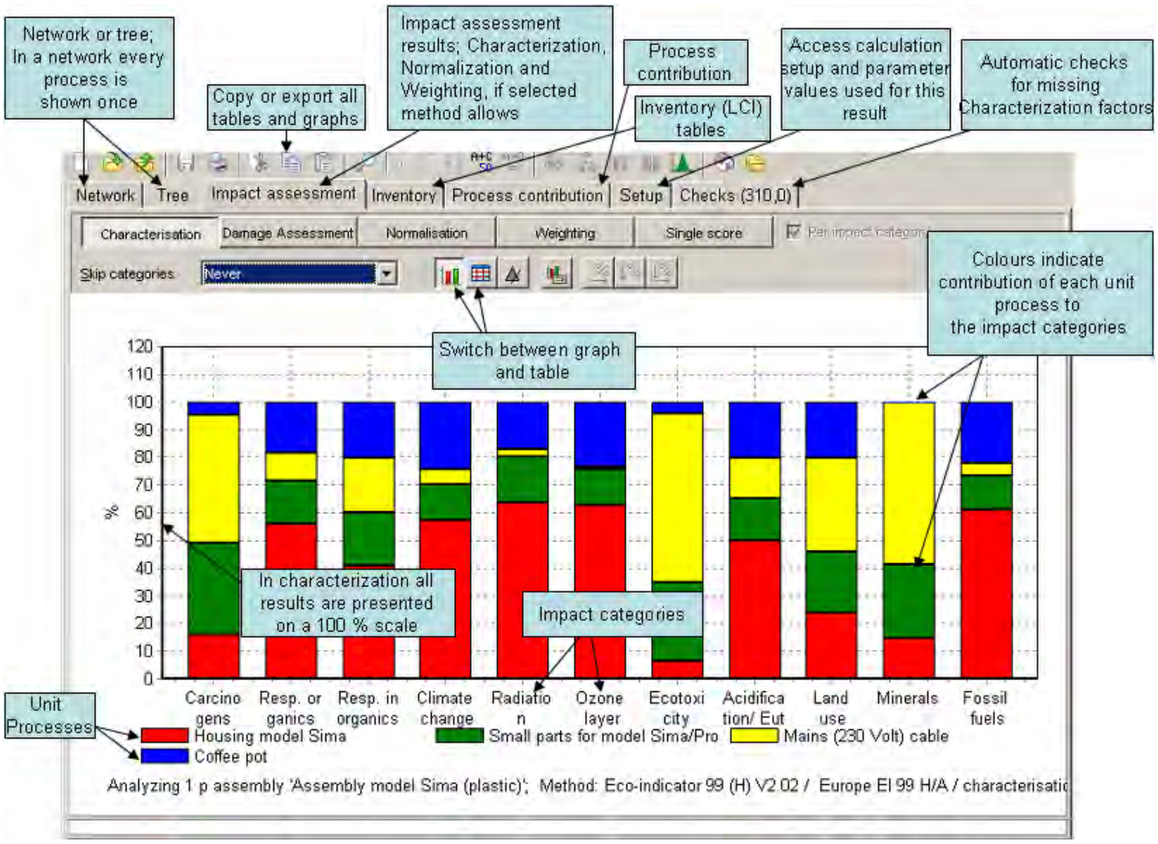

Figure 2.9: An illustration of process contributions, inventory, and impact assessment results in SIMAPRO

(Source: PRe, 2006)

Similar bar charts are used to present the results in this study. In Figure 2.9, the unit processes are colour-coded to show the level of contribution for each process. The illustration is represented on a percentage (100%) scale, which in this case means that the processes had only environmental impacts, and no benefits to the environment. However, in SIMAPRO, processes with environmental benefits are represented as negative percentage figures on the percentage scale. In instances where environmental impacts and benefits results were realised, the percentage scale is represented with both positive (impacts) and negative (benefits) percentage figures. All impact categories have different metric units (such as kilograms), and consequently, the results are plotted on a percentage scale (if applicable to the study), to uniformly compare impact category results. In Figure 2.10, the main process (main blue assembly) indicates the relative contribution from the four sub-assemblies (blue). The housing sub-assembly (thick red arrow) shows a major contribution to the main process (assembly), compared to the other three sub-assemblies. Figure 2. 10 shows an example of the characterization results, using a SIMAPRO process tree. It should be noted that results presented using process trees in this study, do not show processes that have an impact of less than 1% environmental significance, based on the cut-off criteria for the systems boundary (Appendix A9, Table A9.4).

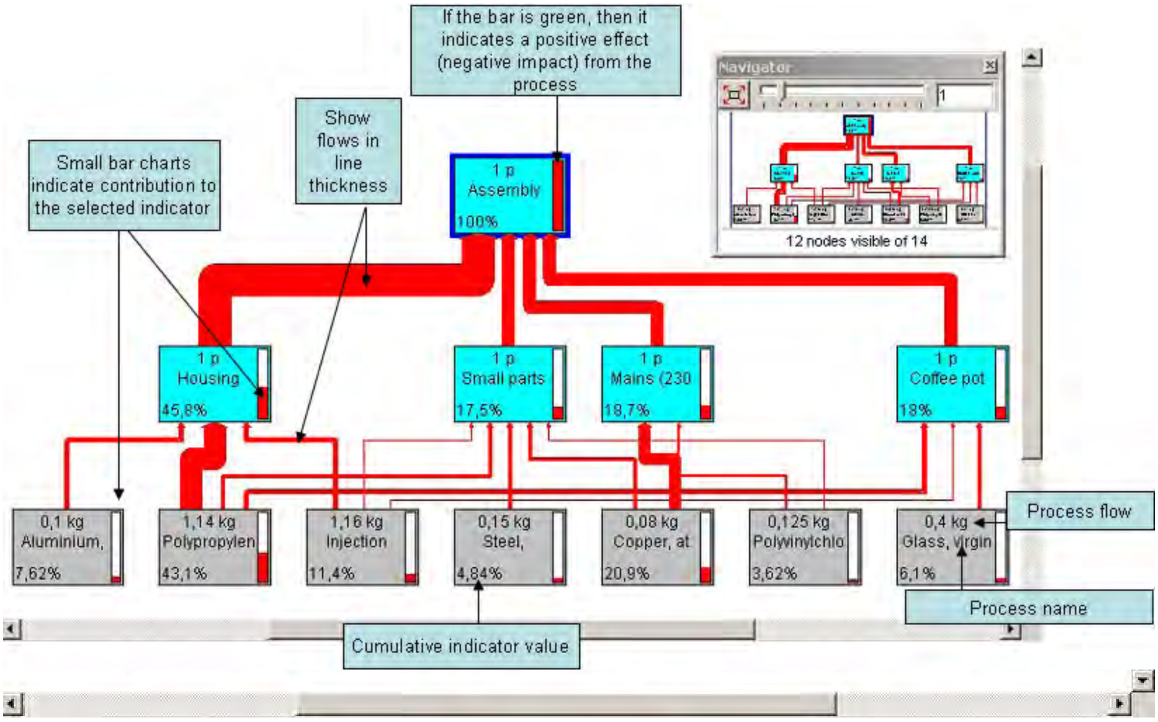

Figure 2.10: An example of characterization results using a SIMAPRO process tree (Source: PRe, 2006)

SIMAPRO illustrates process flows in various values; for example, in tonnes or mega joules, and the process name is represented by the main unit process considered (Figure 2.10). The cumulative indicator value shows the contribution of the unit process to the overall process, and could also be expressed in percentages, kilograms or carbon dioxide emission values.

2.3.1.1 LCA shortfalls

It is argued that LCA impact assessments fail to take into account the unknown health and environmental impacts of new chemicals, have no objective scale, contain many assumptions, and are very complex. In a study by Heijungs & Guinee (2007), LCA was found to be more effectively used when there were no assumptions. However, LCA users and experts are more likely to make assumptions with the use of the LCA method, especially in waste management application. Therefore, Bertel & Fraser (2002) warns that LCA should not be used as the basis for comparing widely different generating options, or as the basis for internalizing external costs. On the other hand, it is a valuable tool for systematic descriptions of resource use and environmental impact characteristics. It can be used more precisely when the production chains and technology options are all very similar, or in choosing amongst locations for the same technology option. For example, recycling in Melbourne and Sydney might produce similar results, due to similar technologies used.

2.3.2 Social impact analysis – C&D waste recovery and recycling

Solid inert wastes like concrete and bricks are defined in the Industrial Waste Management Policy (Prescribed Industrial Waste) as *"hard waste which has negligible activity or effect on the environment"*. Landfills licensed by EPA to accept only solid inert waste, usually have less stringent operating and monitoring requirements than other landfills (EPA Victoria, 2007b). These materials should not be received at landfill sites, and waste management options such as re-use and recycling should become standard practice across the building industry.

Although recycling in Australia has grown steadily over the past 20 years, it is yet to become a widely accepted part of waste management. The ability to increase waste recovery and recycling rates is reliant on C&D industry practices. The Australian Bureau of Statistics (ABS, 2006) found that in 2002–03, recycling accounted for 57% of C&D waste generated (7.8 million tonnes). Almost half of the total generated in that year was recycled. Overall, the recycling rate was about 46% in 2002-03, which represented the amount that had been reprocessed into a usable product, and not just the quantity recovered for recycling.

Reporting the amount of material recovered could inflate the amount of total materials recycled. The construction and demolition of buildings in Australia generated over 40% of waste that went into landfill, with Victoria producing the second highest amount of

C&D waste in Australia (Appendix A3, Tables A3.1-A3.3). A report[21] on the recycling trends for Victoria in 2004-05, noted that C&D waste was just over half the material received for recycling. The adoption of recycling practices has been slow, as it is easier to simply dispose of C&D waste into landfill, rather than to sort and recycle, even though the extra effort may have a good payback. The social impact analysis uses an open-ended questionnaire to assess the on-site waste management practices that influence the recovery and recycling of waste in Chapter 6. Chapter 3 explains the methodology and methods (Section 3.2.2) of analysis used for the six construction site studies.

2.3.3 Life-Cycle Cost (LCC)

Life-Cycle Cost (LCC) is a method of costing that examines a product's entire value chain from a cost perspective (Bradford, 2008). LCC focuses on costing from 'cradle to cradle', which is why it is also known as whole life costing. According to the United Kingdom Office of Government Commerce (OGC, 2008) there are four major benefits of LCC; namely, it creates an opportunity to evaluate options of purchase, it improves awareness of the overall cost, and it allows for a more accurate forecasting of cost and performance trade-off against cost. In performing an LCC, there are some basic concepts that must be followed, including, a cost breakdown structure, cost estimating, discounting, and inflation. The term End-of-Life-Cycle Cost (ELCC) has been coined from LCC, and is used to clearly define the boundary for the costing of RC and brick recycling and landfill disposal.

2.3.4 Review of Waste legislation

In Victoria's TZW, the Waste Management and Resource Recovery Framework is a channel for major government bodies like the Department of Sustainability and Environment, the Environmental Protection Agency (EPA) Victoria, and Sustainability Victoria, to outline waste management plans for Victoria. Measures implemented to ensure the effectiveness of this framework include some guiding principles and strategic

[21] From the *Annual Survey of Victorian Recycling Industries* conducted by Sustainability Victoria (2006a)

tools, such as the waste hierarchy, product stewardship[22], engagement and education, partnerships with industry and government[23], funding and support, and regulatory tools such as the Sustainability Covenant. Sustainability Covenants[24] ensure that the industry waste generators such as manufacturers, suppliers, and consumers assume a shared responsibility (Sustainability Victoria, 2005). The TZW actions[25] outlined the target to recover 80% (by weight) of C&D waste materials by 2014, include waste generation minimisation, high recycled product standard, and marketing of C&D recycled materials. To assess the Governance impacts, this study investigates and reviews efforts by seven organisations to endorse recycled products. The concerns about the quality and market for C&D recycled materials have not been fully addressed thus far and hence, product endorsements is an avenue to be explored. Chapter 3 (Section 3.2.4) outlines the seven companies reviewed in Chapter 8.

2.4 Building materials studied: Reinforced Concrete and Bricks

Two building materials have been chosen for the purpose of this study; RC and Brick. Concrete, steel, aluminium and brick are typically the most significant contributors to C&D waste. The rate of recovery tends to be higher for metals and other high value materials, but many materials that are recycled, such as concrete, are 'down cycled' into road base, and other low value uses due to doubts about material quality (RMIT, 2006).

Table 2.5 shows the rates of recovery over a ten-year period. The recovery rate for concrete remained fairly constant between 2005 and 2008, whilst the recovery rate for

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[22] This involves a shared responsibility between producers, users, and government to determine environmental impacts on a product's end Life-Cycle (Amendments to Victorian Environment Protection Act 1970 in 2001).

[23] This is especially with C&D waste, where the support of leading industry associations and key government agencies is required. Successful examples to date in the C&D sector include consultation and project partnerships with bodies such as the Housing Industry Association (HIA) and the Master Builders Association of Victoria (MBAV) (Coles, 2005).

[24] In June 2002, an amendment was made to the Victorian Environment Protection Act 1970. Sustainability Covenants were voluntary agreements made between the EPA and covenant partners, through which targets were set for post-consumer package recycling, for example, the National Packaging Covenant (NPC).

[25] Actions 15-24 in the TZW report (Sustainability Victoria, 2005).

bricks fluctuated from a 14% increase (2005/06 – 2006/07), to a 33% decrease (2006/07 – 2007/08), over a two-year period.

Table 2.5: Concrete and Brick waste material recovered in Victoria for reprocessing (1997-2008)

Year	**Brick/brick rubble** (Tonnes '000)	**Concrete** (Tonnes '000)
1997-98	126	834
1998-99	271	899
1999-00	228	577
2000-01	318	811
2001-02	293	942
2002-03	250	1,161
2003-04	425	1,525
2004-05	395	1,477
2005-06	385	1,734
2006-07	438	1,695
2007-08	293	1,717
% Change between 2005-06 and 2006-07	**14%**	**-2%**
% Change between 2006-07 and 2007-08	**-33%**	**1%**

(Source: Sustainability Victoria, 2008a & 2009)

2.4.1 Reinforced Concrete

Portland cement concrete, typically referred to as "concrete", is a mixture of Portland cement, water, fine aggregate such as sand or finely crushed rock, and coarse aggregate, such as virgin gravel or crushed rock. According to the Cement Concrete and Aggregates Australia (CCAA, 2004), aggregates form about 65-80% of the concrete mix. Normal class concrete typically has a slump of 20-120mm, and coarse aggregate, with a size of 10, 14 or 20mm.

Concrete is strong in compression, but weak in tension, and consequently steel reinforcement is added to create a composite material termed RC. Recycling RC involves the separation of concrete from steel, during the crushing process. Steel is not studied in detail in this research, since the steel recovered is sent to a steel recycler, and no follow-up study is done thereafter. However, steel is considered as a benefit to the environment during the ELCA study, where 2 approaches; namely, the Recycled

Content Approach[26] and End-of-life Recycling Approach[27], were considered. Separation of steel from RC is discussed further in Chapter 4 (Section 4.3.1), where the crushing process is explained.

Alex Fraser Group (AFG, 2008b) defines crushed concrete as "*composed rock fragments coated with cement with or without asphalt, sands and fillers produced in a controlled manner to close tolerances of grading and minimum foreign material content*". Recycled Crushed Concrete (RCC) is crushed concrete that is used in place of virgin gravel. RCC is used for various purposes, with the most popular one in Victoria being for road bases, which is similar to the United States, where a survey recently conducted by the Federal Highway Administration, showed 38 states in the United States recycled concrete to create an aggregate base material (Prokopy, 2007). Some other uses, according to Prokopy, suggest that unprocessed RCC can be used as general bulk-fill material, in bank protection, as base or backfill for drainage structures, for road construction, noise barriers, and embankments. These are basic uses and one would like to think that RCC use could extend beyond these purposes in the future.

The restricted use of RCC for some projects and not others, confirms that many builders and clients do not consider it as a good quality material. RCC can be used on its own, or mixed with virgin concrete. This study does not focus on the chemical and physical composition of concrete, however, it might hold a key to improving the quality, and increased use, of RCC. Therefore, the requirements for product quality was analysed in Chapter 8. RCC is mainly used for non-structural applications in Victoria.

Figure 2.11 summarizes the Life-Cycle of RC and shows the various inputs involved in the production of RC. The end-of-life disposal offers the options of recycling or landfilling, which are included in this study. RC environmental impacts are analysed in Chapters 4.

[26] Recycled Content Approach is based on statistics of how much is recycled but general environmental performance is not considered (SRI, 2007).
[27] End-of-life Recycling Approach traces the Life-Cycle of the material to its end use stage, the product recovery, and the recyclability (SRI, 2007).

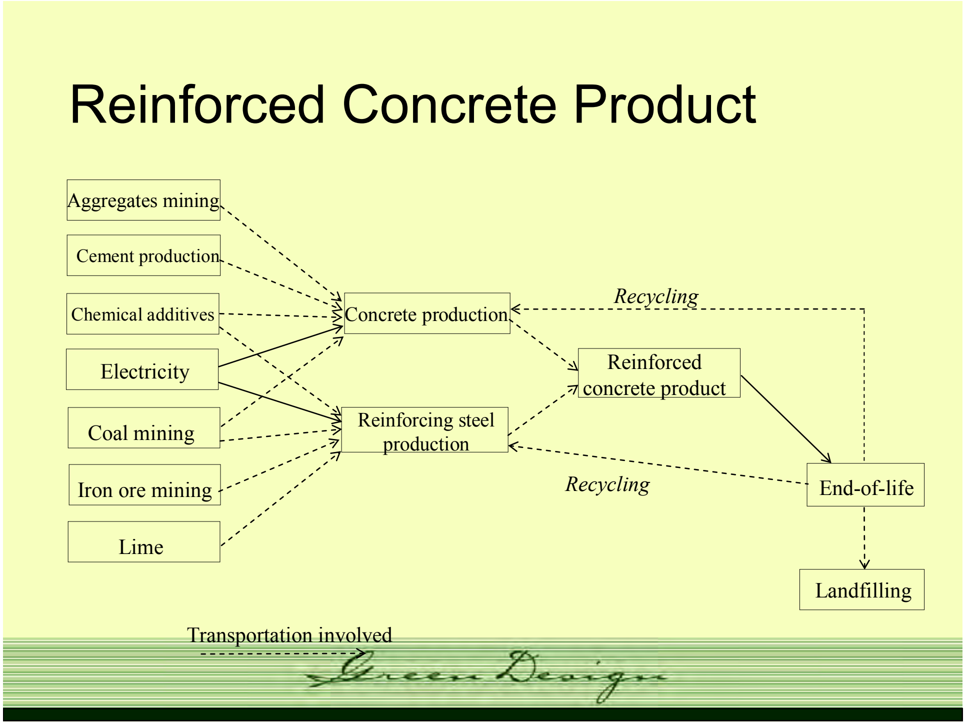


Figure 2.11: Reinforced Concrete production

(Source: Matthews, 2006)

2.4.2 Concrete production in Australia

This section provides an insight into the resources involved in concrete production. Concrete can be produced as a precast product, or ready-mix concrete (which represents about three-quarters of all concrete used annually). The composition of concrete is usually based on the type of use.

The embodied energy of concrete, excluding manufacture and delivery costs, can range between 1.1GJ/m^3 to over 3GJ/m^3 for a material with an average density of 2400kg/m^3 (RMIT, 1999a). In the past, ground granulated blast furnace slag (slag cement), fly ash, silica fume, or limestone, may be substituted for a portion of the Portland cement used in the concrete mix (BEES, 2007). Recycling of concrete has become necessary, especially due to the high energy use and carbon emissions created during the production of cement.

Cement production involves the burning of limestone and other materials under high temperatures, which emits high amounts of CO_2. The calcination process, (as this is called), produces the cement clinker, and most of the energy is used during the calcination process. In Australia, the Cement Industry Federation (CIF)[28] is a project partner of the World Business Council for Sustainable Development (WBCSD). The WBCSD, (2008) states that *"in manufacturing 1500M tonnes of Portland cement each year worldwide, an equivalent tonnage of CO_2 is released into the atmosphere. A considerable degree of mitigation can be achieved by adopting principles of sustainable waste management, not only by reducing emission of CO_2 at source, but also by reusing or recycling it where possible".*

The production of virgin resources like cement, for example, accounts for the high energy emission figures. Cement forms about 10-15% of RC (University of Virginia, 2010), and is likely to contribute to higher CO_2 impacts for RC production, compared to RCC, that uses little or no cement. Worldwide, cement production is estimated to produce approximately 5% of all CO_2 emissions from human sources (Marland et al., 2006). As can be seen from Table 2.6, Australia has steadily increased its CO_2 emissions from cement production, similar to countries like Canada and the United Kingdom, whilst Japan and the United States were the largest emitters of CO_2.

Table 2.6: CO_2 emissions by source from Cement production 1994 – 2003

Countries	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Australia	3,239	3,239	3,114	3,213	3,415	3, 712	3,737	3,737	3,763	3,986
Canada	5,272	5,203	5,774	5,987	6,042	6,295	6,284	6,471	6,833	6,690
Japan	45,657	45,082	47,086	45,815	40,528	39,923	40,410	38,146	35,794	34,266
United Kingdom	6,134	5,881	6,086	6,298	6,185	6,328	6,328	5,906	5,525	5,588
United States	38,842	38,322	39,498	41,150	41,825	42,828	43,774	44,301	44,715	46,265

(Source: Marland et al., 2006) Units: Thousand metric tons (kilo tonnes) of CO_2

[28] The CIF is a Project Partner in the Cement Sustainability Initiative (CSI), supporting the formation of common protocols for CO_2 accounting, selection of fuels and raw materials for cement manufacturing, health and safety guidelines, and community engagement and government interaction. WBCSD launched the CSI in 1999 (CIF, 2008)

According to the Environmental Literacy Council (2008), cement requires 1.7 tonnes of raw materials, mostly limestone, to make one tonne of cement. Coal or coke is typically used to fire the kilns used to burn the limestone, clay, shale, and other materials. This contributes significantly to CO_2 emissions, in addition to nitrogen oxides, sulfur oxides, and particulate matter. Concrete manufacturing is one of the most significant sources of CO_2 emissions, because of its cement content. One tonne of CO_2 is emitted per one tonne of cement produced.

Australia has adopted the principles of managing resources, energy efficiency, reducing emissions and pollution associated with cement production, in an effort to keep up with the worldwide goals and targets. Cement creates the binding strength and durability needed in concrete. Cement production contributes the highest impact to the Life-Cycle analysis of concrete. Table 2.7 shows the materials quantity and energy inputs needed to produce a tonne of cement.

Table 2.7: Input materials required for the manufacture of one tonne of Cement

Material/energy source	**Quantity**
Limestone	1.28 tonne
Clay	0.24 tonne
Iron Ore	0.08 tonne
Gypsum	0.05 tonne
Coal	800 kcal/kg clinker
Water	100 L
Electricity	100 kWh

(Source: How, 2007)

In Australia, the ready-mix concrete is mostly used. Concrete production involves the use of sand, virgin gravel and fly ash, which requires energy use. These dry materials are put through a mixer in proportions that are specified for each project, based on the intended use, and then transferred to a drum mixer, where water is added. Typical composition by volume is about 10-15% cement, 60-75% aggregates, and 15-20% water. Entrained air bubbles account for about 5-8% (University of Virginia, 2010). Using less water generally results in a higher quality concrete. Table 2.8 shows an example of energy use in one of the major Australian concrete plants. Table 2.8 and Figure 2.11 show the energy required for concrete production, and also reveals that the impact of cement is quite significant. Although concrete uses about 280kg of cement, the total energy used to produce a kilogram of cement is about six mega joules. This is obviously due to the firing of the kiln in cement production.

Table 2.8: Energy used to produce 1m^3 of concrete in selected CSR/ready-mix Concrete plants in Australia

Input Material/process	Amount used in 1m^3 of concrete (kg)	Energy type, MJ/m^3 of concrete			
		Electricity	Diesel	Coal	Total energy
Fine sand	160	2	8	0	10
CRG	1000	17	75	0	92
Coarse sand	700	12	53	0	65
Cement	280	173	12	1400	1585
Fly ash	80	0	0	0	0
Manufacture	1	20	0	0	20
Total energy		**224**	**148**	**1400**	**1772**

(Source: Padina, 1997)

In Figure 2.12, the process tree shows the percentage contributions of the cement to the overall process of making a standard ready-mix concrete in Australia. The process flow impacts are presented by the thickness of the arrows, as illustrated earlier in Figure 2.10. SIMAPRO only shows the processes that have significant effects on the manufacturing process, therefore, sand, fly ash, and water, are left out of the process tree. Energy from natural gas, coal and electricity were the main contributors to the high impact of cement and the blast furnace slag use. For virgin gravel, the main impacts were realised in the use of trucks, but with relatively less significance.

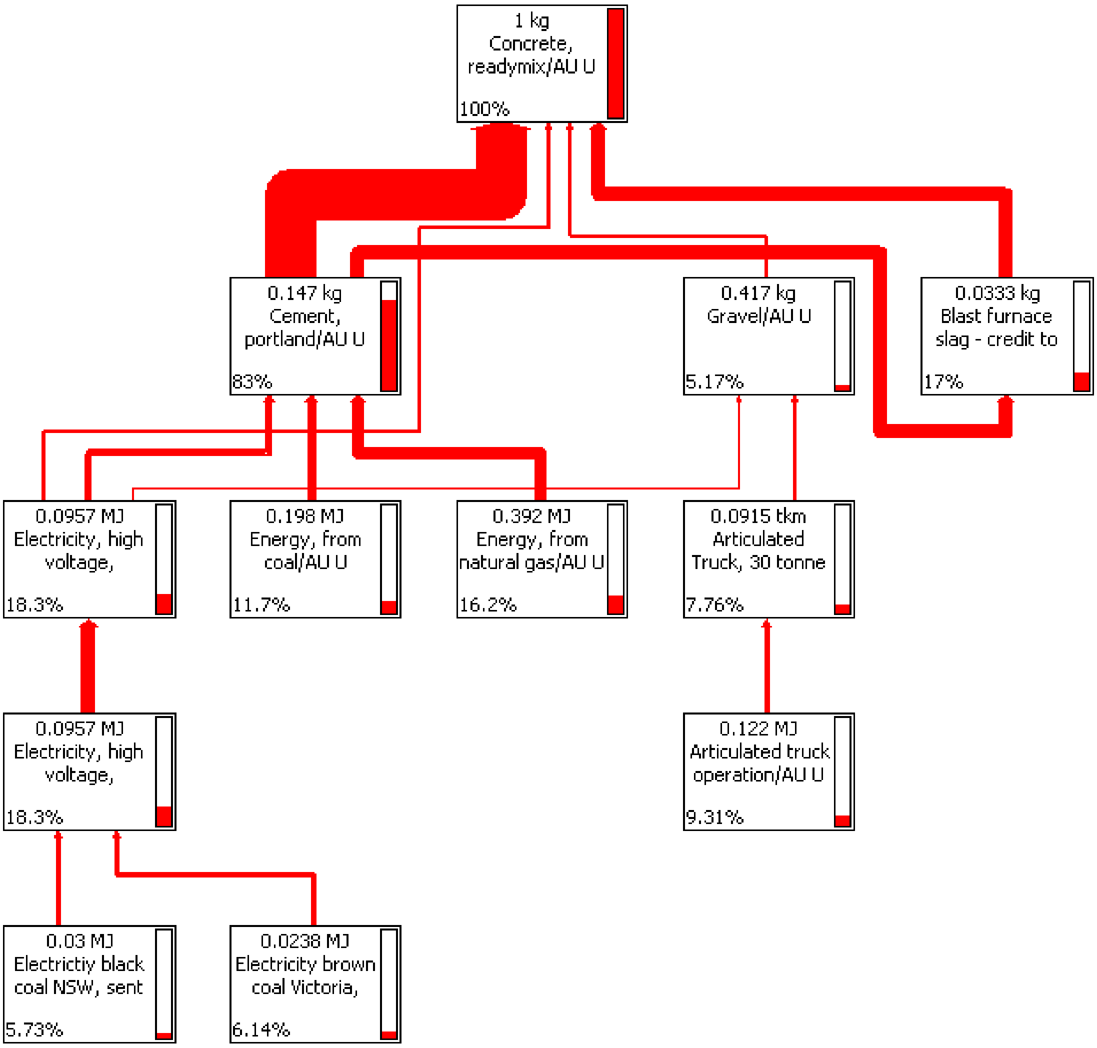


Figure 2.12: Process tree for impacts of ready-mix Concrete in Australia

Studies by RMIT (2006) have predicted there will be an increased use of concrete, bricks, and steel, by 2055. This means that cement use is also likely to increase accordingly, unless more cement substitutes are used, or recycling is increased. The initial production of concrete contributes a significant amount of emissions to the environment, as Table 2.9 summarizes the material inputs and related outputs resulting from emissions to air, water, land, and other wastes, from concrete production.

Table 2.9: Concrete product manufacturing process material inputs and pollutant outputs

Process	Material Input	Air Emissions	Water or Land Emissions	Other Wastes & Emissions
Concrete Batching and Product Manufacturing	• Cement • Sand • Limestone • Virgin gravel • Aggregate material • Acetone • Glycol ethers • Hydrochloric acid • Styrene, • Solvents in paints and clean-up	• Cement dust • sand virgin gravel dust • Constituents from fuel burning • VOCs from paint and solvent application and cleaning	• Wastewaters containing residual solvents • Other VOCs acids, and particulates	• Equipment and repair emissions and wastes • Paint sludge containing residue solvents

(Source: USEPA *Sector Notebook Project*, 1995)

2.4.3 Bricks

Bricks have undergone a transition in production technology and still remain one of the most durable materials in the building industry, as they are known for being sustainable, long lasting and possess good thermal mass properties. According to Glen-Gery (2004), brick are made using any of these three major methods; namely, handmade, machine-molded, and the extrusion method (usually with holes to speed up the firing process, and reduce the weight of the brick). There are numerous other methods classified under these three major methods. Bricks come in different colours, shapes, and sizes, and are basically made from clay or shale, depending on the manufacturing process, which determines the colour, shape, or size. Many brick workers believe that the appearance of bricks plays an important role in identifying the brick origin, method, and the time of production. Brick referred to in this study is the clay brick, and the recycled bricks are referred to as Recycled Crushed Bricks (RCB).

The technology involved in the production of bricks has improved over the years, from the use of wooden frames for shaping the bricks, to the current use of moldingmachines. The use of ordinary sun-drying techniques has been superseded by the use of special kilns.

The brick-making process involves the acquisition of the clay or shale from quarries to the processing plant, where it is crushed and grinded into fine particles. This is passed through the pug mill, where the ground clay is mixed with water (between 15-30%) and sand, molded and baked or dried, depending on any of the three major brick-making methods mentioned earlier. Glen-Gery (2004) summarizes the process of making bricks as gathering, crushing, grinding, screening, and mixing the raw materials, making the brick and setting, drying, firing, and packaging.

There are two end-of-life options for brick. Brick waste can be recovered as whole bricks, or broken brick pieces. Whole bricks can be re-used without any recycling (crushing). On the other hand, broken bricks can be crushed, and used in projects such as road bases or pedestrian walkways.

2.4.4 Brick production in Australia

In Australia, the use of bricks has risen compared to about five years ago. Between 2006 and 2007, brick recycling had increased by 14%, and from 1997-2007, the amount recycled had increased from 126,000 to 438,000 tonnes, as shown in Table 2.5 (Sustainability Victoria, 2008a). A brick has a mass between 3-4 kg, with a standard size of 230(l)* 110(w)* 76(h) mm, and a density of about 2000kg/m^3 (Think Brick, 2007). In Australia, about 1.6 billion bricks are produced each year, and the brick industry is worth around $2.8bn to the Australian economy. The brick industry directly employs about 2500 people nationally, and the same number indirectly as contractors, resellers, and in supply industries (Think Brick, 2007).

Due to the bulky nature of bricks, it is important that the raw materials, water, and market for the products, are within the same location. Brick production also involves the use of a high amount of energy and fuel resources, due to its long firing duration. The various fuel sources used in firing the kiln produce emissions such as carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM10), and volatile organic compounds (VOC) (Texas Commission on Environmental Quality - TCEQ, 2002). Brick production has its associated pollutions and health risks. Fluorides released above 600°C, are emitted into the atmosphere as Hydrogen Fluoride (Environmental Technology, 1999). This is known to be harmful to human health, especially to the kidney and liver in cases of long-term exposure. Although this is not the main focus of this study, other researchers have produced a detailed study in this area.

Bricks are tough and require high embodied energy in production, which does not necessarily make it a sustainable option. However, the long-term benefits of brick production for the environment can only be realised in a Life-Cycle assessment. Some of the major Life-Cycle impact of producing brick is summarized in Table 2.10.

Table 2.10: Life-Cycle impact of producing Bricks

Impact Categories	Impact per tonne of production	Percentage of impact contribution per tonne (%)
Global Warming(kg CO2)	189	90
Water Use (kl)	0.2	99
Solid Waste (kg)	0.02	69
Embodied Energy (GJ)	2.5	92
Emissions		
Suspended Particulate Matter (SPM) (kg)	0.3	-
NOx (kg)	0.2	-
SOx (kg)	0.5	-

(Source: SimaPro database)

In Table 2.10, embodied energy (2.5GJ) and global warming (189kgCO_{2-e}) were the main environmental impacts from the firing process, during brick production. The impact of solid waste (0.02kg) was comparatively less, whilst the water use quantity per tonne was 0.2kl. Bricks do not need any special handling at landfill sites due to their clay composition, except when mortar is involved. The main reason for the diversion of bricks from landfill, include the ability to re-use the bricks, and the ability to reduce emissions that result from the quantity initially produced. The impact per tonne of bricks is quite significant as outlined in Table 2.10, when the quantity of bricks produced annually is considered. Figures 2.13 and 2.14 show the corresponding diagrams for Table 2.10.

Figure 2.13 shows the main impacts from a tonne of brick produced based on Australian standards. The main impacts from brick production were identified as brick manufacture (yellow), natural gas (green), water (orange), and truck use (blue). The brick impacts (yellow) realised in the global warming (CO_2), photochemical oxidation, and eutrophication categories, correlate with the emissions from production as outlined in Table 2.10. Water use (orange) made up about 99% of a tonne of brick produced, whilst the effects of truck use (blue) mainly affected the land use, minerals, and solid waste, with lower truck impacts for the global warming, carcinogens, and embodied energy categories. Embodied energy impacts from natural gas were significant (92%) due to the high amounts of energy required during the brick production process.

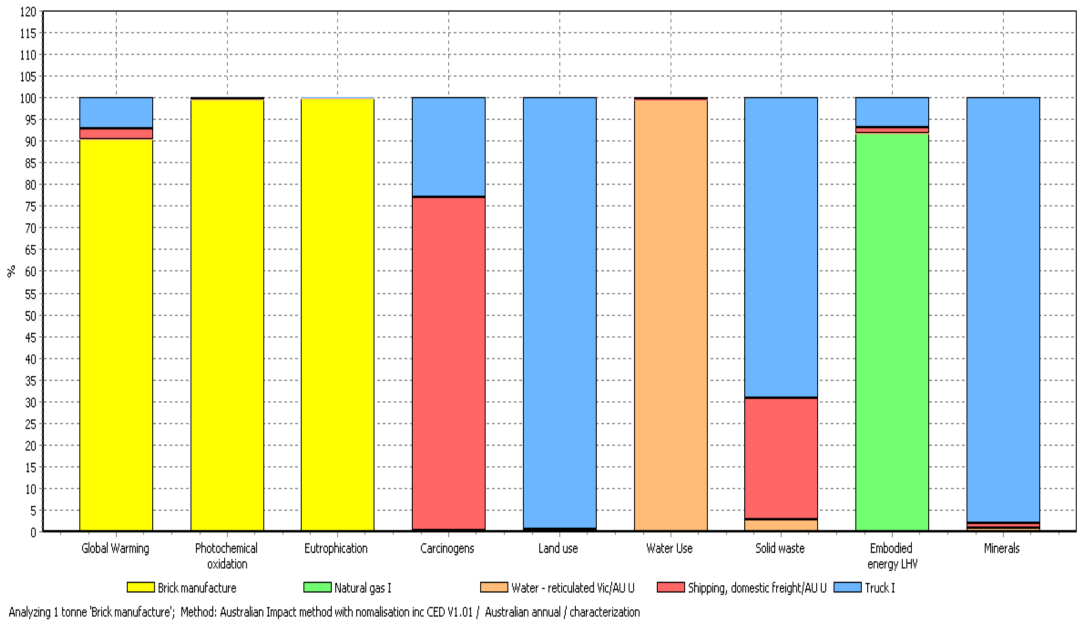


Figure 2.13: Impacts assessment of Brick production

2.5 Exclusions to Study

This brief section explains the reasons for the exclusion of other building materials and landfill activities from this study.

2.5.1 Building materials

Although this study method could be applied to other C&D waste materials, only RC and bricks are analysed. RC and bricks recovery was also limited to commercial construction projects. All input and output data was collected for the end-of-life options of recycling and landfilling RC and brick materials only, and did not include the production of RC and bricks. Statistical data on virgin material inputs and outputs used in drawing comparisons, where necessary, are duly referenced.

2.5.2 Landfill site activities

Landfill activities were not included in this study; only the impacts of the trip to the landfill site and associated costs were calculated. Also, landfill scenarios for both RC and bricks ELCA calculated impacts that could occur if waste quantities were sent to landfill. Landfill study excluded landfill site activities, because differences in landfill site practices would not have allowed for an accurate assessment of the overall environmental impacts. Most landfill sites receive different kinds of C&D waste materials, which make the tracking of various incoming waste quantities, truck use impacts, and emissions data, very difficult.

2.6 Chapter summary and conclusion

Sustainability in waste management now goes beyond adopting the waste management hierarchy (3Rs). Developed countries are advocating for the use of the TBL+L framework in addressing waste management. This chapter has identified the major aspects in need of improvement through the scope of study.

Therefore, the scope of this study clearly outlined the environmental, social, economic and governance aspects, which make up the TBL+1 as the following:

- Environmental – Carbon Emissions, Location & Transport, and Energy
- Social – Industry Practices, and Landfill
- Economic – Cost, and Demand & Supply
- Government – Waste Legislation, and Product Endorsement

It is crucial that all these aspects are considered, when mapping out waste management strategies for C&D waste materials such as RC and bricks.

RC contributes significantly to the C&D waste stream, and with a predicted increase in infrastructural development across states in Australia, this is likely to grow continuously. Section 2.4.2 discussed the contribution of RC production to the environmental impacts, especially CO_2 from cement production. It reiterated the need to recycle RC instead of outright disposal in landfill.

Brick production across Australia continues to rise, as the demand increases. The main environmental impact of brick production is the emission from long-firing durations. The opportunity to re-use bricks increases environmental benefits. However, bricks that cannot be re-used must be recycled. Hence, the notion that bricks disposed to landfill have no significant impacts should not encourage the disposal of brick waste to landfill.

The production of RCC and RCB are used as an alternative to virgin gravel production, and required in an industry where resources are fast depleting. Previous sections of this chapter have discussed efforts made to recycle C&D waste. Increase in waste quantities has led to the introduction of more sustainable approaches such as the Waste Wise programme. With waste quantities predicted to increase further, there is the need to improve recycling practices across the C&D industry.

Reduction in C&D waste quantities means that a higher cost will be incurred during the waste disposal process. With comparatively low landfill prices in Victoria, there is the likelihood that cost impacts may go unnoticed, and increase waste generation within the building industry.

National and international government legislation is a key to controlling the environmental, social and economic impacts of waste management, such as recycling. The study by Brown & West (2003) also highlights legislation as a key to waste minimisation. Environmental impacts of waste on carbon emissions, and energy need to be monitored. The on-site practices and costs associated with waste management is a major determinant of how waste is disposed. Unfortunately, decisions made on waste management, affects the recyclability of materials, hence, best practice adopted on-site has the potential to improve the demand for C&D recycled materials downstream. Further opportunities could be created to develop an injection system of C&D recycled materials back into the building industry mainstream.

The next chapter discusses the methodology, and method applied in data collection and analysis, to investigate the two research questions raised in Chapter 1, namely:

- ***Question 1 -*** *"What are the major factors that could increase recycling of C&D waste materials?"*
- ***Question 2 -*** *"How best can these factors be incorporated into existing practices to facilitate increased demand for RC and brick recycled materials?"*

3 RESEARCH DESIGN

This chapter discusses the research methodology (qualitative) and methods (quantitative) used in the data collection, and analysis of this study. Nguluma (2003) explains that qualitative research provides a holistic view, whilst quantitative research is based on structured data collection and analysis. The methodology section discusses the two areas of study; namely, the six construction sites, and the recycling plant. It explains the data collection process, and gives reasons for the analysis method applied. Quantitatively, the methods applied in the analysis of data include the End-of-Life-Cycle Assessment (ELCA), the social impact analysis, End-of-Life-Cycle Cost (ELCC), and a review of waste legislation. The adopted principles of the Triple Bottom Line +1 (TBL+1) are discussed in this chapter, whilst Chapters 4, 5, 6, 7, and 8 form the analysis chapters.

3.1 Methodology

In Chapter 2, a review of other literature was undertaken to highlight some previous research findings relevant to this study. The sources of literature were books, journals, reports, conference papers, C&D databases, and newspaper articles. Issues discussed included carbon emissions, energy use, recycling and landfilling costs, and industry on-site practices, which were used to explain how the two research questions in Chapter 1 would be answered.

Nguluma (2003) states "*qualitative research views the individual or organisation in a holistic manner rather than reduced to isolated variables",* whilst Gilham (2000) has noted that qualitative research focuses on what people tell you, and what they do. Data was collected through constant consultation with industry partners. This qualitative method involves the effective assessment of human preferences, behaviours, and attitudes, using on-site participant observation and interviews. Visual imagery (pictures) is used to support the evidence of data collected in two separate studies (construction & recycling sites).

Firstly, an initial study of six construction sites in Melbourne, Victoria, was carried out to identify waste management practices that affect recycling. Interviews through structured open-ended questionnaires (Appendix A2) were used to collect information from the construction sites. Some of the stakeholders interviewed included contractors, sub-contractors, site managers, project managers, environmental managers, and some site workers. Every construction site interview involved at least three or four persons. At two of the construction sites, a building owner and developer were among the interviewed stakeholders.

The second study was a case-study of the Alex Fraser Group (AFG) recycling plant. This case-study was chosen to highlight the processes involved in the recycling of RC and brick waste materials. The study also examined the environmental impacts of recycling RC and bricks (compared to landfill and virgin gravel production), to establish how this could be used to promote the use of C&D recycled materials. This study focused on only RC and bricks. Interviews with recycling staff, participant observation at the recycling plant, and data was collected for RC and bricks. Recycling data for RC was collected from the West Gate Freeway upgrade over a six-month period in 2008, whilst data for bricks was collected from the recycling plant's (AFG) 2008 production year. Recycling and landfilling cost data was also collected for the waste quantities recovered. In all, twelve months was spent on the data collection procedures.

Though the initial quantity of bricks collected was more than RC, all figures were scaled to 1000 tonnes for convenience of comparison, and to establish a unit rate. A similar initial study carried out at the AFG recycling plant to compare recycled aggregates to quarried aggregates, is acknowledged.

3.2 Methods

According to Nguluma (2003), a quantitative research is usually concerned with measurements, and is characterized by a more structured and standardised data collection.

Life-Cycle Assessment (LCA) is used for quantitative data analysis, because it conveniently allows for a combination of the environmental aspect of this study with cost in Life-Cycle Cost (LCC). This eliminates the confusion associated with using several analysis models that produce the same results. For the purpose of this study, LCA and LCC are defined as End-of-Life-Cycle Assessment (ELCA) and End-of-Life-Cycle Cost (ELCC), to clearly outline the systems boundary under which LCA and LCC are carried out in this research. The ELCA and ELCC are used for the environmental and economic analysis respectively, whilst the other methods used are social impact analysis (Social) and review of waste legislation (Governance).

According to RMIT University (2009), a cluster of ideas have formed the TBL+1. Some of the principles used to summarize the result findings in Chapter 9 are outlined in the four methods of analysis Sections (3.2.1-3.2.4) of this chapter.

3.2.1 Environmental: End-of-Life-Cycle Assessment (ELCA)

Thormark (2000) explains that previous Life-Cycle studies of buildings tended to omit the phases after demolition. He states that "*it can be more important to design a building for recycling than to use materials which require little energy for production that the creation of effective recycling depends upon its consideration and inclusion at the design stage, that the re-use and adaptation of existing foundations is an important component of recycling*". The quality of virgin building materials produced should be good enough to be recycled, because it influences the quality of C&D recycled waste materials. Virgin building materials should be treated carefully to avoid all contaminants, and enhance the quality of C&D recycled material.

ELCA is defined by the systems boundary that focuses on only two end-of-life options - recycling and landfill. Contrary to initially encouraging a 'cradle to grave' approach, where the 'grave' referred to landfill or incineration at the end of the product's Life-Cycle, environmentalists now advocate for a 'cradle to cradle'[29] approach, where the

[29] 'Cradle to cradle' mirrors the healthy, regenerative productivity of nature, and thereby creates an industry that is continuously improving and sustaining life and growth (MBDC, 2005)

product cycle is repeated. A product-use cycle comprises of raw materials' harvesting, manufacturing, use/operation, and disposal (recycling/landfill). Every product-use-cycle stage has its own 'cradle to cradle' approach. Building materials can have an end-of-life 'cradle to cradle' approach, can be recyclable, and can be free of all contaminants. Figure 3.1 shows the 'cradle to cradle' diagram for the end-of-life stage of recycling. The ELCA will compare the environmental impacts of recycling and landfill disposal of RC and brick C&D waste materials. Figure 3.1 shows the responsibility of a contractor and recycler at the end-of-life stage of C&D waste materials. All processes will be considered, except the stage of transporting materials for use due to insufficient data on outgoing materials.

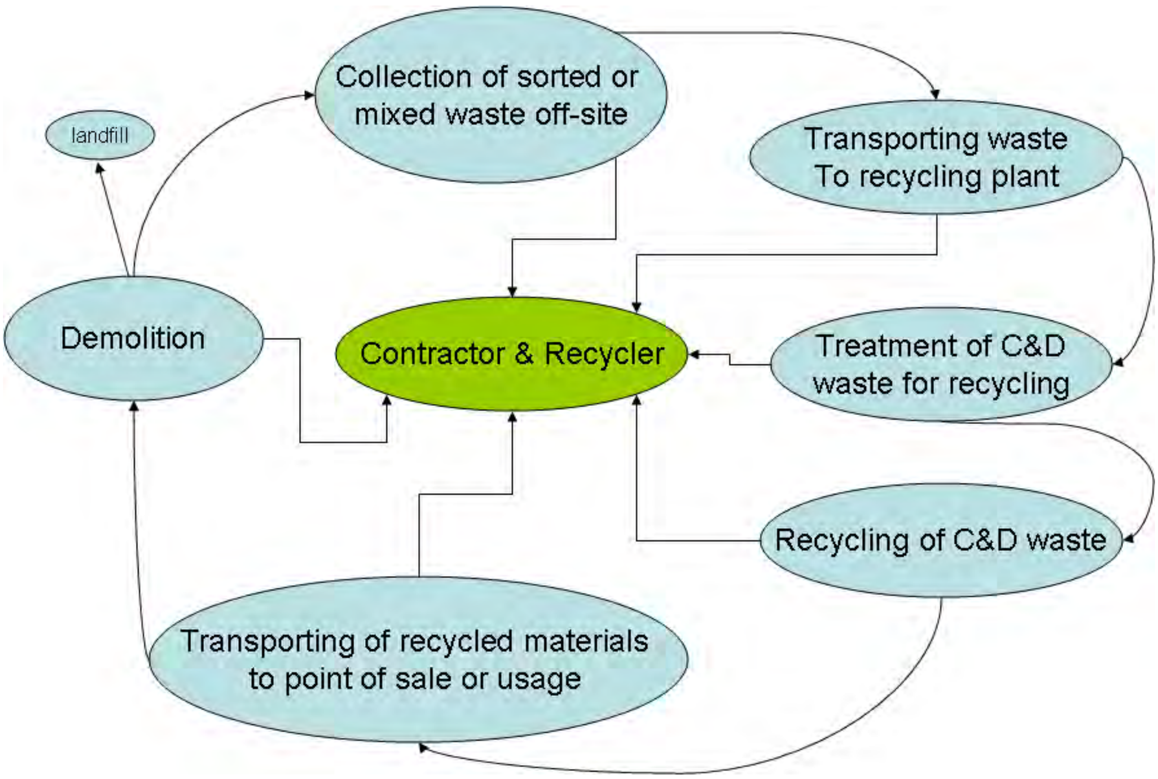


Figure 3.1: 'Cradle to cradle' end-of-life stage of recycling

To make an informed decision on which performance model is best suited for the ELCA study, it is necessary to highlight some of the tools that have been used in Australia and worldwide to rate environmental performance, as listed in Table 3.1. The table shows some of the LCA and rating tool attributes mentioned, but not necessarily included, in this study.

Table 3.2 shows the various environmental indicators that could be investigated using these tools, based on an investigation by Foliente et al. (2008). These programmes still remain competent ways of undertaking an LCA, and are effective rating tools, but every study has its individual attributes, that can be analysed by using these tools. It is therefore necessary to choose the tool that best suits the study in question. LCA tools developed for material products include Boustead & PEM (UK), GaBi (Germany), KCL-ECO (Finland), LCAiT (Sweden), SIMAPRO (Netherlands), and TEAM (France). For this study, SIMAPRO was found to cover all the attributes in an ELCA analysis.

System for Integrated Environmental Assessment of Products (SIMAPRO) was developed by a Netherlands group called the Product Ecology Consultants. SIMAPRO provides a professional tool to collect, analyse, and monitor the environmental performance of products and services. It allows for easy modelling and analysing of complex Life-Cycles in a systematic and transparent way, following the ISO 14040 series recommendations (PRe, 2008a).

Apart from LCA, there are other quantitative methods that could have been used for this research. One such method that could be used to assess environmental impacts is the Ecological Footprint method. Although it effectively assesses resource use and impacts, it did not adequately cover the 'cradle to cradle' approach and thus, it was not used.

Table 3.1: Environmental performance attributes and comparison of breadth and depth of coverage of each tool function with Energy, Materials and Transport

Tools	Environmental Performance Attributes								
	Energy				Material/Resource Use				Transport
	Embodied Energy	Operation	Efficiency	Renewable	Consumption	Recycle	Waste	Service life	
NABERS	-	√√	-	-	–	–	√√√	–	√√√
Green Star-Office Design	-	√√	√√	-	–	√√	√√	–	√√
LCAid	–	√√	–	–	√√√	–	√√√	√√	–
LCADesign	√√√	√		–	√√	–	√√√	√√√	–
LISA	√√	√√	–	–	√√√	–	–	√√	√√
EPGB	√√	√√	√√	√	√√	√√	√√	√√	√√
BASIX	-	√√	√√	√√	–	–	–	–	–
Firstrate	-	–	√√√√	–	–	–	–	–	–
Nat HERS	-	–	√√√√	–	–	–	–	–	–
AccuRate	-	√√	√√√√	√√√√	–	–	–	–	–
BERS	-	–	√√√√	–	–	–	–	–	–
ABGR	–	√√√	√√	–	–	–	–	–	–
EcoSpecifier	√√	√√	√√√	√	√√	√√√	√√√	√√√	–
Evergen Product Guide	√√	–	-	–	–	√	√	√	–
GBTool	√√	√√	√√√	-	√√√	√√	√√√	√	√√
BREEAM	-	√√	√√	-	√√	√√	–	–	√√
Green Globes	-	√√	√√	-	–	√√	√√	–	√√
LEED	-	–	√√	–	–	√√	√√	–	√√
CASBEE	-	√√	√√	√√	√	√√	√√	√√	√
ENVEST	–	√√	√	√	–	–	√	√√	–
ATHENA	√√√	–	–	–	√√√	–	√√√	–	√√
ECO-QUANTUM	–	√√	–	–	√√	–	√√	√√	–
ECOPROFILE	-	√√	-	-	√√	–	√	–	√√
BEAT	–	√√	–	–	–	–	√√	–	–
GreenCalc	–	√√	–	–	√√	–	–	–	√√
BEES	√√	–	-	–	–	–	–	–	–
EQUER	–	√√	–	–	–	–	√√√	–	–
SIMAPRO	√√√	√√√	√√	√√√	√√	√√√	√√√	√√	√√√

(Source: Foliente, Seo & Tucker, 2008) Coverage: √√√√ >> √√√ >> √√ >> √. Shaded portion represents tools from other countries other than Australia. √√√√ Very detailed analysis √√√ Detailed coverage √√ Normal coverage √ Light coverage − Not covered

Table 3.2: Environmental performance attributes and comparison of breadth and depth of coverage of each tool showing environmental impacts

Tools	Environmental Performance Attributes							
	Global warming	Ozone depletion	Acidification	Eutrophication	Human toxicity	Ecotoxicity	Winter/ summer smog	Emission to air	Emission to land
NABERS	√√√	√√	–	–	–	–	–	–	–
Green Star-Office Design	√√	√√	–	–	–	–	–	–	–
LCAid	√√	√√	√√	√√	√√	–	√√	√√	√√
LCADesign	√√√	√√√	√√√	√√√	√√√	√√√	√√√	√√	√√
LISA	√√	–	–	–	–	–	–	√	–
EPGB	√√	√√	–	–	–	–	–	√√	√√
BASIX	√√	–	–	–	–	√√	–	√	√
Firstrate	–	–	–	–	–	–	–	–	–
Nat HERS	–	–	–	–	–	–	–	–	–
AccuRate	–	–	–	–	–	–	–	–	–
BERS	–	–	–	–	–	–	–	–	–
ABGR	–	–	–	–	–	–	–	–	–
EcoSpecifier	√√	√√	–	–	√√	√√	√	√√	√√
Evergen Product Guide	√	√	–	–	–	–	–	√	√
GBTool	√√√	√√√	√√	√	–	–	√	–	–
BREEAM	√√	√√	–	–	√√	√√	–	√	–
Green Globes	√	√	–	–	–	–	–	√	–
LEED	√	√	–	–	–	–	–	–	–
CASBEE	–	–	–	–	–	–	–	√√	√√
ENVEST	√	√	√	–	√	√	–	√	–
ATHENA	√√√	–	–	–	–	–	–	√√	–
ECO-QUANTUM	–	–	–	–	–	–	–	√√	–
ECOPROFILE	–	–	–	–	–	–	–	√√	√√
BEAT	√√	√√	√√	√√	√√	√√	√√	–	–
GreenCalc	–	–	–	–	–	–	–	–	–
BEES	√√	√√	√√	√√	√√	√√	–	–	–
EQUER	√√	–	√√	√√	√√	√√	√√	–	–
SIMAPRO	√√√	√√√	√√√	√√√	√√√	√√√	√√	√√√	√√√

(Source: Foliente, Seo & Tucker, 2008)

Coverage: √√√√ >> √√√ >> √√ >> √. Shaded portion represents tools from other countries other than Australia. √√√√ Very detailed analysis √√√ Detailed coverage √√ Normal coverage √ Light coverage – Not covered

The objective of using ELCA is to identify areas where high environmental impacts realised could be reduced during recycling. According to How (2007), it may not be necessary for an LCA to have all four components (goal & scope, inventory analysis, impact assessment and interpretation), depending on the scope and objectives. In some cases, for example, a simple inventory analysis should be sufficient. Kotaji et al. (2003) and PRe Consultants (2002) have acknowledged that environmental impacts for the end-of-life waste treatment relied on data from many different sources. Therefore, the ELCA study involves all four components outlined in subsequent sections of this chapter.

3.2.1.1 Goal of ELCA

The main goal of this ELCA was to identify the major environmental impacts that occur during recycling including:

- Identifying environmental factors that affect recycling
- Identifying the environmental impacts of recycling, compared to dumping as landfill
- Identifying environmental impacts that should be improved, to facilitate the increased use of RC and brick recycled materials within the building industry

The results of this study would be useful to targets groups such as

- Recyclers
- Waste Management planners/ Regulators
- Construction and Demolition Industry
- Consumers/users of C&D recycled products

3.2.1.2 Scope of ELCA

The scope maps out the critical areas required to analyse ELCA study and these include the functional unit, system boundaries, inventory parameters, and impact categories.

3.2.1.2.1 Functional unit

The functional unit of the study is one tonne of RCC and RCB material.

3.2.1.2.2 System boundary

The system boundary for ELCA in this study includes the various stages involved in the recycling of RC and bricks, as shown in Figures 3.2 and 3.3. Processes in recycling include the collection of C&D waste to the recycler, the cracking of large boulders, the loading of the crusher, crushing, processing, compact testing, and moisture content adjustment (according to customer specification). The inputs and outputs make up the unit processes. Therefore, breakdown of the recycling process into unit processes will include the following inputs:

- The main material inputs – this will constitute the RC and bricks waste
- Transport type, and the energy used in transport – this will include the type of truck used in the transportation of waste. In this study, the diesel-powered 12-tonne 'hook-lift' truck is used
- Energy used to process the material – machinery is diesel and electric powered
- Water used to process the material – water is frequently used in moisture content adjustment, and also during the crushing process, to reduce the dust emissions on-site

Outputs include:

- Recycled Crushed Concrete (RCC) and Recycled Crushed Bricks (RCB)
- National Pollution Inventory (NPI) and other emissions – this involves all the emissions (especially CO_2) that occur as a result of the reprocessing of the materials
- Steel extracted
- Residual waste

Exclusions to this ELCA study are:

- Transportation of the finished product to the building site – tracing of the recycled products to their respective delivery locations is difficult to investigate, due to the variation in distances traveled. It also excludes indirect transport uses, such as the road and truck infrastructure. It is assumed that the travel cost and impact of new and recycled products to building sites is equivalent. These are usually very hard to quantify, due to the variations in technology and distances traveled.

- Capital Infrastructure – the Life-Cycle impact of the crusher will not be taken into consideration. However, the fuel use in the crushers and other on-site machinery is quantifiable and calculated.
- All unit processes involved in the initial production of concrete and bricks are excluded, but where necessary, references made to other studies will be duly acknowledged.

Figure 3.2 shows the system boundary for the RC study recycling process. ‘Avoided processes’ shown are the processes not undertaken and are considered as benefits to the recycling process.

As shown in Figure 3.3, the crushing process of bricks is similar to the RC, but is simpler, since magnetic separation is not required. The system boundary for bricks also includes the crushing and ‘avoided processes’. The avoided process does not include steel recovered however the end product (RCB) could replace gravel use.

Although the production of virgin concrete and brick are shown in Figures 3.2 and 3.3, this study concentrates on the recycling of RC and bricks only (areas in the shaded box). The crushing process is discussed further in Chapter 4 (Section 4.3.1).

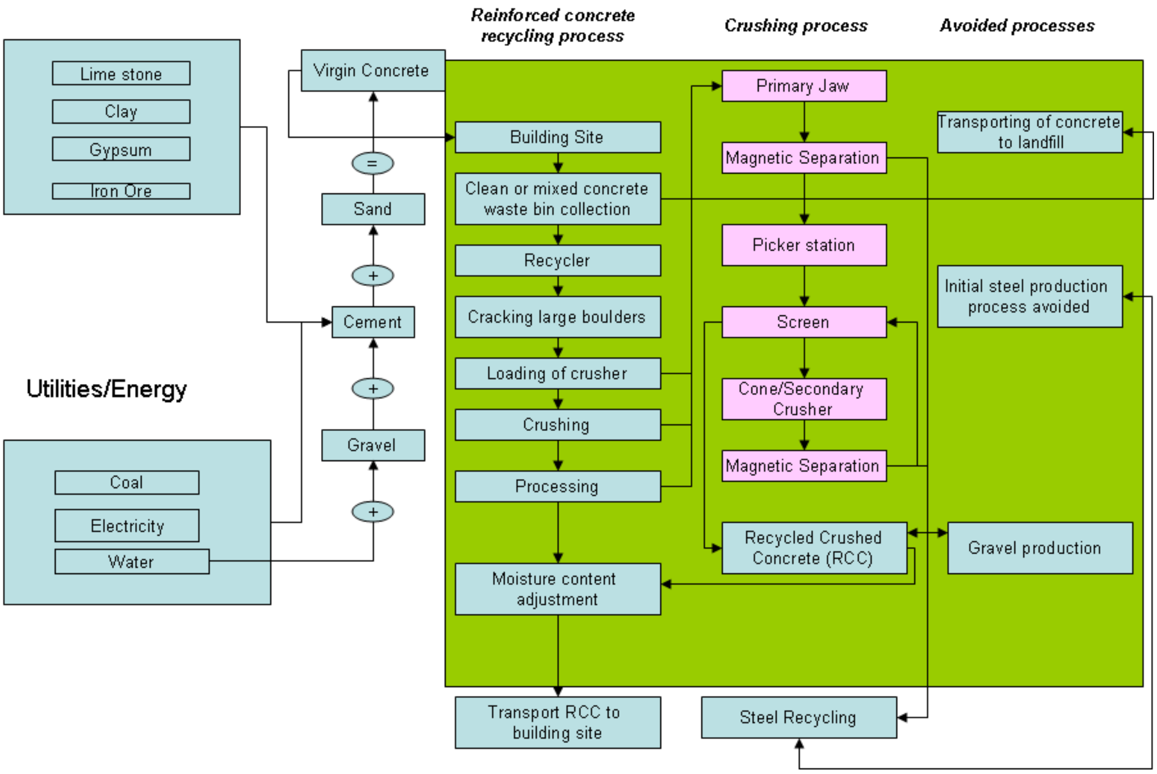


Figure 3.2: System boundary for Reinforced Concrete recycling

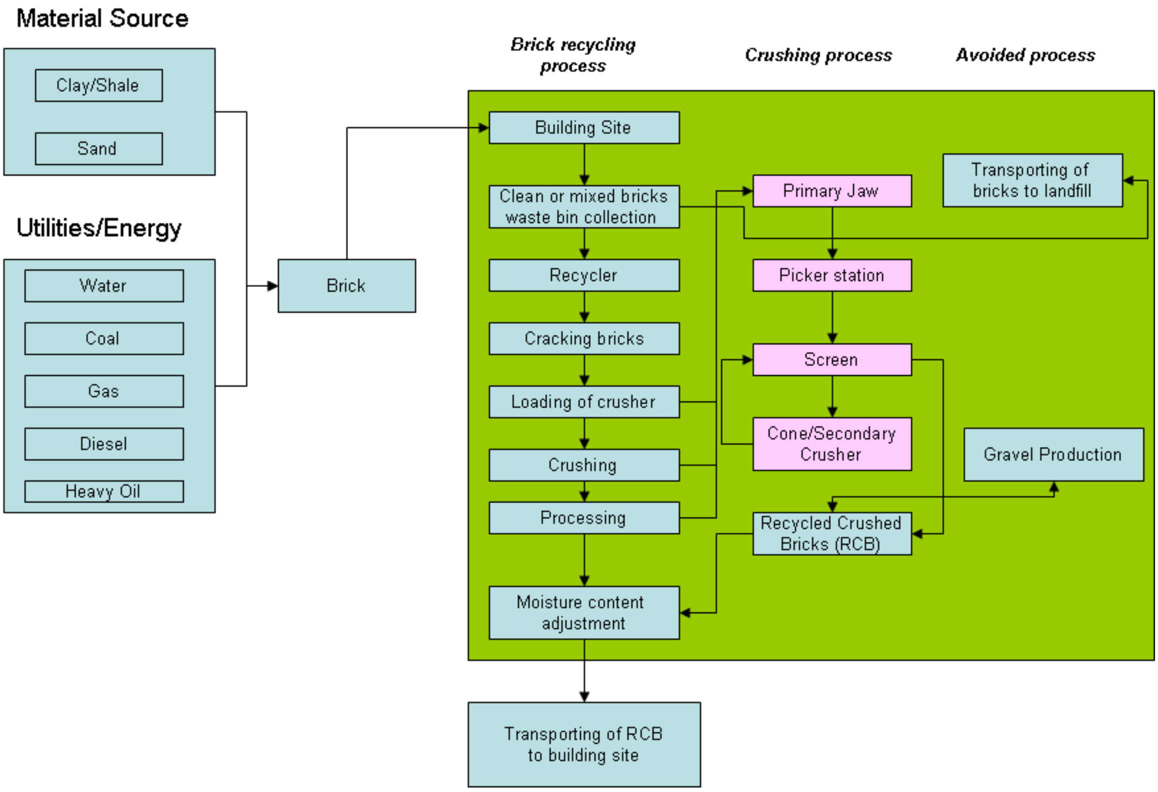


Figure 3.3: System boundary for Brick recycling

3.2.1.2.3 Types of impacts (Classification and Characterization)

Classification involves the sorting of impacts into classes according to the effects they have on the environment. Nine impact categories are identified. These include Global warming, Photochemical oxidation, Eutrophication, Carcinogens, Land Use, Water Use, Solid Waste, Embodied Energy and Minerals. The four impact categories most relevant to this study include Global Warming, Water Use, Solid Waste and Embodied Energy. Environmental impacts are assessed for each impact category, using the following key indicators:

- Greenhouse gas emissions (expressed as tonnes of CO_2 equivalents)
- Water consumption (litres)
- Waste in landfill (tonnes)
- Energy consumption (kilowatt hours)

On the other hand, characterization is the calculated percentage share each process has out of the total impact shown by each impact category of the eco-indicator used (How, 2007). Characterization highlights the process contribution of each impact category. The Australian Impact method with normalization, classified according to Australian standards, was used in this study.

3.2.1.2.4 Types and sources of data

RC and bricks data for this ELCA study was sourced from the Alex Fraser Group (AFG) recycling plant at Laverton, unless otherwise stated, in which case, data source was referenced. Data for this study was collected for all input and output unit processes of recycling over a six-month period. All figures used, either exact or approximate were done after discussions with respective persons involved at AFG.

3.2.1.3 Life-Cycle Inventory (LCI) analysis

The LCI analysis involves the collection of data for the processes outlined in the systems boundary (Figures 3.2 & 3.3). It focuses on the environmental flows, and is a resource input-output procedure.

As explained by EMSD (2007), results from LCI are dependent on the types and quantities of natural resources (including fossil fuels), and other materials used in the production process; the modes and distances of transportation involved; technologies employed in the production processes and its lifespan; and how the product is finally disposed of or reprocessed.

Figure 3.4 shows three inputs and outputs from the recycling process. During recycling, some of the inputs include RC and brick waste, water, and energy. These inputs are used in the unit processes, such as in transporting, processing and crushing RC and brick waste. The system inputs produced the RCC and RCB outputs, as well as carbon emissions, and waste residues (waste that cannot be processed further).

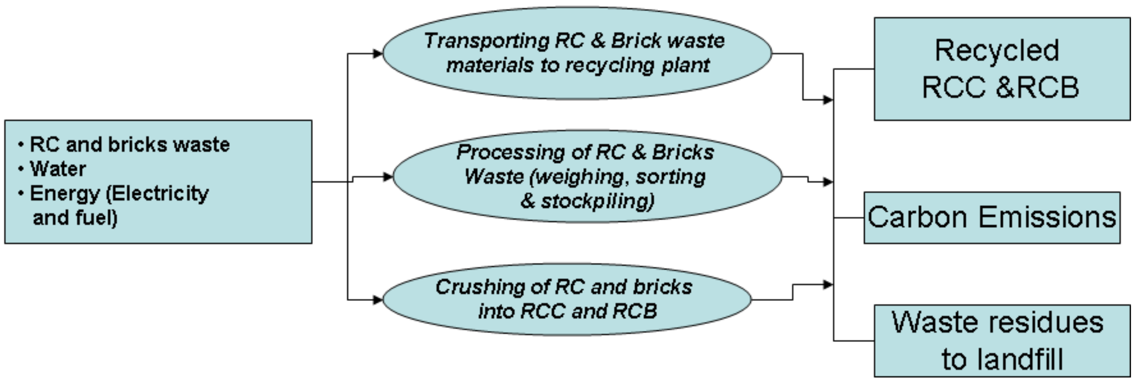


Figure 3.4: Inputs and outputs of Reinforced Concrete and Bricks waste material recycling

3.2.1.4 Impact Assessment

The impact assessment identifies sections of impact categories C&D waste recycling indicators, and classifies data collected in these impact categories. The data collected is then characterized within each impact category. Classification and characterization are obligatory elements (see Section 3.2.1.2.3). The optional elements of normalization, grouping and weighting, can then be applied to determine the magnitude of impacts being assessed. The compulsory and optional elements outlined in Figure 3.5, are applied to assess the recycling and landfill results from the ELCA study. Data quality was also assessed, using the sensitivity and uncertainty analysis techniques.

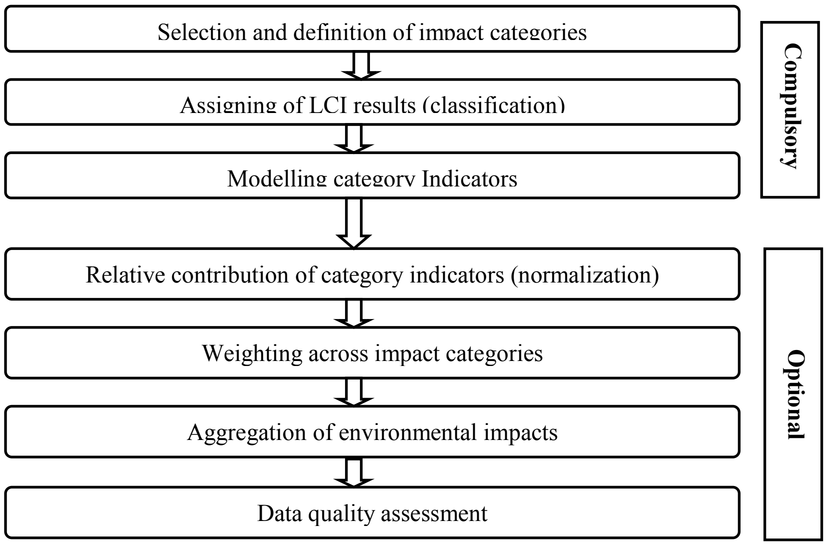


Figure 3.5: Stages of impact assessment as described by ISO
(Source: RMIT, 1999b)

3.2.1.5 Interpretation of Results

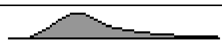
The interpretation of results is based on significant outcomes from LCI and impact assessment. To determine the accuracy of data on results interpreted, the sensitivity and uncertainty analysis techniques are employed. Alvarado (2006) also suggests that sensitivity analyses are run to check the following:

- Choice of data
  - Library
  - Process
- Choice of impact assessment methods
- Missing data

According to the PRe (2008b), a sensitivity analysis is strongly recommended during and after an LCA has been conducted. The sensitivity analysis is run, based on a change in initial data or assumptions, to get a better understanding of the major impacts that affect such data or assumptions. The results from a sensitivity analysis could be entirely different from the initial results, hence conclusions could be altered. Therefore, the data or assumptions on which conclusions are valid should be clearly outlined.

The uncertainty analysis uses statistical methods such as the Monte Carlo analysis[30] to calculate the uncertainty in LCA results. The Monte Carlo analysis is also a numerical way to process uncertainty data, and establish an uncertainty range in the result of the calculation (PRe, 2008b). In SIMAPRO, the Monte Carlo uses four distribution types, to translate the uncertainty to a standard distribution type. These are the Range, Triangular, Normal and Lognormal distribution. In this study, the triangular distribution[31] was used. Table 3.3 shows the how the distribution types are presented.

Table 3.3: Four SIMAPRO distribution types

Distribution	**Presentation**
Range	
Triangular	
Normal distribution	
Log normal distribution	

(Source: PRe, 2010)

In SIMAPRO, the uncertainty is specified on the inputs and outputs of a process or product stage, and even on the parameters, when parameterized modelling is used (PRe, 2010). The resulting range of all calculation results form a distribution from which uncertainty information can be derived with basic statistical methods. For this study, the best guess value, the upper (97.5%) and lower (2.5%) confidence limits with a confidence interval of 95% from 1000 runs is used for the triangular distribution in SIMAPRO. Figure 3.6 shows an example of an uncertainty result.

[30] Monte Carlo analysis is used to calculate uncertainty in inventory results and run comparative uncertainty analysis using advanced process coupled sampling techniques (PRe, 2010)
[31] The triangular distribution requires that the range as well as the best guess value are specified, as this determines the point with the highest probability (PRe, 2008b)

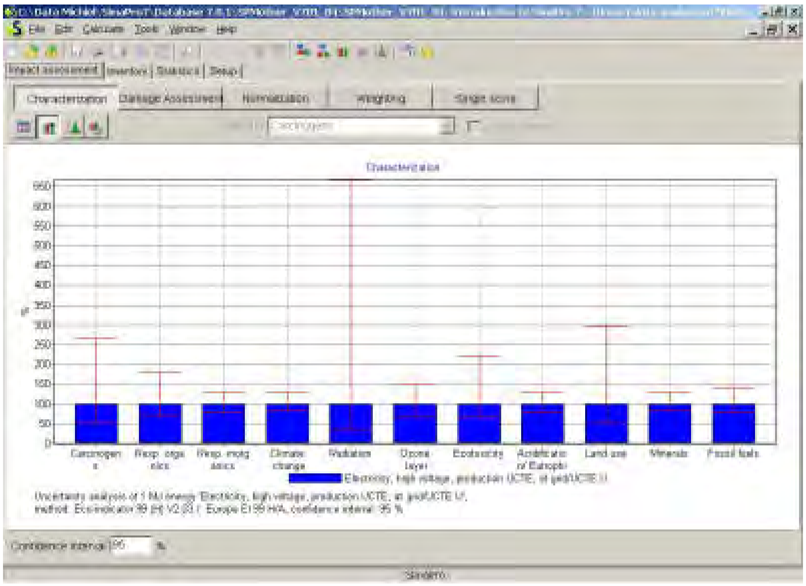


Figure 3.6: An example of an uncertainty analysis result from SIMAPRO
(Source: PRe, 2010)

Results create an opportunity for further assessments to be made, or to improve the outcomes realised. They also create an avenue for other comparative methods to be employed, to assess the results of the initial analysis method used. The sensitivity and uncertainty analysis are discussed in Chapters 4 and 5.

3.2.2 Social: C&D waste recovery and recycling

Sustainability Victoria (2008a) admits that although recovery for recycling is an important step in sustainability, and all efforts are being made to reduce the amount of waste disposed to landfill, there is still an overall trend of waste generation.

The study of the six construction sites focused on waste management practices, and their effect on recycling. To investigate the impacts, a structured open-ended questionnaire was used as an interview guide. The questionnaire was divided into four sections, namely:

- The project planning (corporate philosophy and attitude) – investigating waste management targets in the early stages of the building project

- Site operation – the waste minimisation and recycling practices implemented on-site (sample of recycling report in Appendix A4, Table A4.1)
- Supply chain – building material sourcing and choices on-site
- The economics of recycling – cost and benefits of waste management on-site

Projections in Figure 3.7 suggest that by 2014, whilst landfill disposal of C&D waste will remain unchanged, waste generated and recovered will increase. Bridging the gap between the amounts generated, recovered, and recycled, should involve the tracking of waste generation on C&D sites. Not all recovered materials are recycled, however, the first step is to bridge the gap between the recovered and recycling amounts or reduce the amount of C&D waste generated. The projections show more needs to be done, as generated and recovered C&D waste is predicted to increase. In Victoria, 550,000 tonnes per annum of C&D waste diversion by 2014, could achieve better results in waste, if the necessary measures of waste recovery and recycling are implemented.

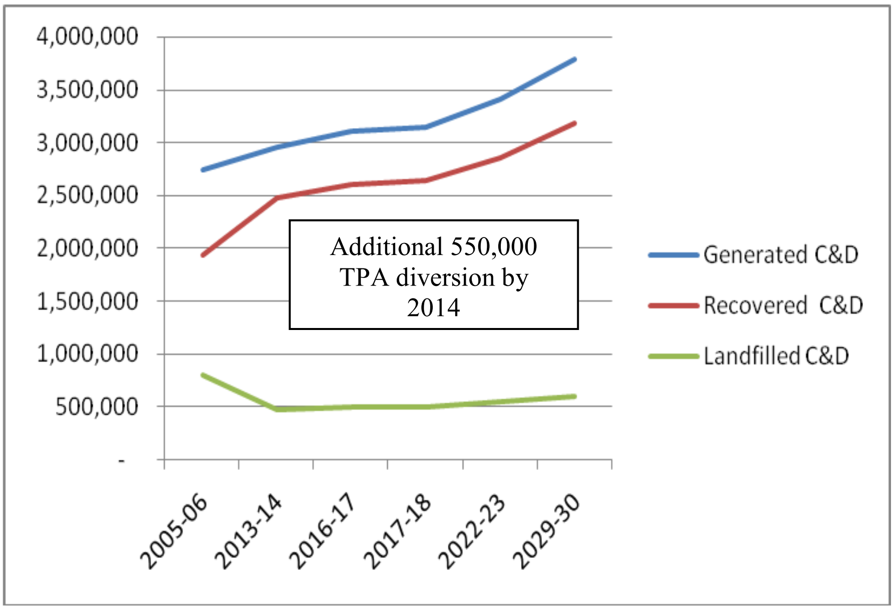


Figure 3.7: C&D waste projections in Victoria

(Source: Coles, 2007)

The social aspect considered the UN Global Compact, which has three sections; namely, human rights, labour, and environment principles 7, 8, and 9. The environmental principles 7, 8 and 9 on human responsibilities to the environment (RMIT, 2009), are outlined as follows:

- Principle 7: support a precautionary approach to environmental challenges
- Principle 8: undertake initiatives to promote greater environmental responsibility
- Principle 9 : encourage the development and diffusion of environmentally friendly technologies

The implementation of these principles relies on human responsibility. To increase recycling, contractors, sub-contractors, managers, and site workers are jointly responsible for effective waste management practices. The study of the six construction sites identifies attitudes, behaviours, and preferences that affect waste management practices.

3.2.3 Economic: End- of-Life-Cycle Cost (ELCC)

ELCC investigates the contributory costs of activities during the recycling RC and bricks process, compared with landfilling and virgin gravel production cost. ELCC is used in much the same way as LCC, the only difference being the boundary of costing involved. ELCC covers the systems boundary in Figures 3.2 and 3.3. In Chapter 7, the cost analysis considered the capital and operational costs to determine the overall costs of recycling, landfill disposal and virgin grave production.

The cost calculations include:

- Electricity cost
- Water cost
- Diesel cost
- Landfill fees
- Tipping fees
- Haulage fees
- Capital cost of crusher

Based on the cost parameters outlined above, the cost calculations highlight the cost impacts and benefits of recycling RC and bricks, compared with landfill disposal and virgin gravel production. Therefore, the capital and operational cost parameters that should be included in the cost calculation of recycling, landfill disposal, and gravel production are outlined. Ideally, cost analysis should include data such as staff administrative and labour costs, however this data was not available for use in this study. Appendix A11 shows the cost calculation tables for RC and brick recycling and landfill disposal.

The Supply Chain Economics principle analyses the cost of environmental impacts. However, it is very difficult to price environmental impacts. The Victorian Government revealed that the lack of available Life-Cycle data regarding the environmental benefits of recycling C&D materials means that benefits cannot be interpreted in financial terms (Sustainability Victoria, 2005). However, RMIT (2009) explained that by understanding the benefits of improved effectiveness of materials management, environmental impact can be incorporated into supply chains. ELCC is used to determine the costs of recycling, and the impact of prices on the supply chain of materials, which subsequently affects the demand of C&D recycled materials.

3.2.4 Governance: Review of waste legislation

Current waste legislation strategies cover a range of waste management issues. Although Victoria's TZW programme was launched five years ago, it is yet to fully address the issue of optimising the use of C&D recycled materials. This study investigates and reviews other legislation that has the potential to improve C&D recycled material use within the building industry and this is presented in Chapter 8. The review involves seven organisations that currently influence waste management, highlights some achievements, and suggests further improvement in issues such as product endorsements for C&D recycled materials. The seven organisations are the Green Building Council of Australia (GBCA), Environmental Protection Agency (EPA) Victoria, Building Commission, Australian Green Procurement, Australian Building Codes Board, Australian Green Office, and VicRoads.

The Australian Governance principle is used to explain the impact of legislation on the C&D recycled materials demand. To encourage good waste management practices, various levels of government implement legislation that influences environmental, social, and economic decisions. However, government legislation is also backed by non-governmental legislation, from institutions such as the GBCA, in an effort to facilitate recycling and use of C&D recycled materials.

3.3 Chapter summary and conclusion

This chapter discussed the methods and methodology, used in the analysis of the six construction sites and recycling plant study, to identify the factors driving recycling and demand within the C&D industry. The TBL+1 framework adopted for the summary of the result findings were outlined as follows:

- Precautionary Principle – Environmental
- UN Global Compact – Social
- Supply Chain Economics – Economic
- Australian Governance – Governance

The four ELCA steps (goal and scope, Life-Cycle Inventory analysis, impact assessment, and interpretation of results) used for the environmental impact study were discussed in this chapter, and are summarized in Table 3.4.

Table 3.4: Summary of ELCA discussion

Goal	• Identify environmental factors that affect recycling • Identify the environmental impact of recycling, compared to dumping as landfill • Identify environmental impacts that should be improved, to facilitate the increased use of RC and brick recycled materials within the building industry
Scope	• the functional unit • the system boundary • types of impacts • types and sources of data
Impact categories considered	• Global Warming • Water Use • Solid Waste • Embodied Energy
Interpretation	• Sensitivity and uncertainty analysis of ELCA results
Target Group:	• Recyclers • Waste Management planners • Construction and Demolition Industry • Product consumers and users
Inputs & Outputs	• Recycling materials 1. The main material inputs in terms of quantities 2. Transport type and the fuel used in transport 3. Energy used to process the material 4. Water used to make the material (Embodied water) 5. NPI and other emissions
End-of-Life-Cycle stages studied: unit processes	• Transporting of waste off-site • Cracking of boulders • Crushing • Processing • Moisture adjustment
Study boundaries	• RC and brick waste material transport to the recycling plant. • All unit processes in the recycling process • Transporting of RC and brick waste materials to landfill
Items excluded from the study	• Transportation of finished product to building site • Capital Infrastructure like crusher

(Adapted: How, 2007)

The RC and brick recycling and landfill disposal environmental impacts will be analysed using the LCA analysis tool called SIMAPRO. Though the Life-Cycle of recycling could be analysed using several LCA rating tools, the tools did not adequately address the impact categories required for this study. The conceptual framework summarizes the methodology of the environmental analysis, as literature-based, site observation, and visual imagery, as shown in Figure 3.8. The method of analysis is ELCA, whilst the TBL+1 Precautionary Principle will be used to summarize the findings from the results in Chapter 9.

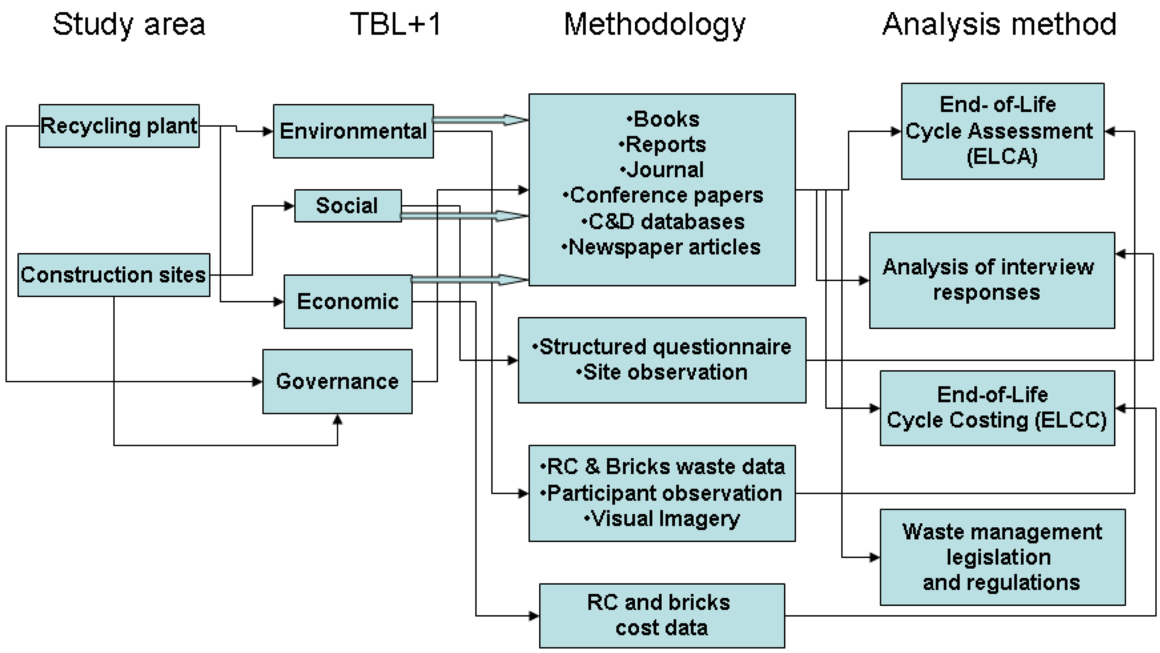


Figure 3.8: Conceptual framework of study

The social impact study will utilize data gathered from the six construction sites, to identify some waste management practices influencing waste disposal options, such as recycling and landfilling. The structural open-ended questionnaire comprised of four sections (project planning phase, site operations, supply chain, and economics of recycling), that cover waste management on-site. The questionnaires were used in interviews with stakeholders, such as contractors, sub-contractors, project managers, environmental managers, and site workers. Other documents such as waste management plans, and recycling targets reports relevant to the study, were also obtained. The methodology and method were summarized in Figure 3.8, whilst the UN Global Compact is used to summarize the discussion in Chapter 9.

The economic aspect of the study will use the ELCC to calculate the cost impact areas of recycling, landfilling, and virgin gravel production. Cost data was collected from the AFG recycling plant, and involved the capital and operational cost, associated with the recycling and landfill disposal of RC and brick waste materials. The methodology and methods were summarized in Figure 3.8 . The Supply Chain Economics is used to summarize the result findings in Chapter 9.

The governance section of the study, reviews waste legislation literature for seven organisations, as summarized in Figure 3. 8. The TBL+1 Australian Governance principle is used to summarize the discussion in Chapter 9.

This study limits its reference and data collection points, to RC and brick C&D waste, C&D sites, and recycling plants in Melbourne, Australia, although comparisons and references are made in various instances to other parts of the country or the world, where necessary.

Chapter 4 discusses the environmental impacts of recycling RC compared to landfill disposal, and virgin gravel production,

4 ENVIRONMENTAL IMPACT OF RECYCLING REINFORCED CONCRETE

This chapter discusses the inventory analysis indicators and the impact assessment results of RC. The study results will be used to compare the environmental impacts of recycling RC to landfill disposal, and virgin gravel production. This research relies on 2 data types namely the foreground data (specific data from company used in case-study), and the background data from literature and the LCA database (ISO 14044, 2006). Sensitivity and uncertainty analysis will be run, to test the accuracy of the data, and initial results of the ELCA. Data was collected at the Alex Fraser recycling plant in Laverton. A previous study carried out at the same recycling plant by RMIT University, to compare quarried stone, and crushed concrete production is briefly discussed.

4.1 Recycling company - Alex Fraser Group (AFG)

AFG was initially set up as a metal dealer in 1879, but has progressed over the past four decades to divert waste such as concrete, bricks, masonry and rubble, which would otherwise go to landfill, for recycling (AFG, 2008a). A recent study of AFG has revealed that over 2 million tonnes of recycled aggregate is produced each year.

With the emphasis on waste in Victoria, AFG is involved in the collection and recycling waste materials, from construction and demolition sites. This has won AFG some awards as well as contracts that seek to promote environmental sustainability through an effective waste management plan. One of such contracts was the upgrade of the West Gate Freeway. AFG won the contract to supply the waste bins, pick up waste bins from designated venues, and recycle the waste collected, during the upgrade of the project. The main waste type collected from the West Gate Freeway upgrade was RC. AFG currently has branches in Laverton, Epping and Clayton. For the purpose of this study, data was collected only from the Laverton recycling plant (the largest of the three sites), hence all reference to AFG refers to the Laverton plant.

Data for RC (from the West Gate Freeway upgrade) was used in the ELCA analysis. The West Gate Freeway[32] has undergone several transformations since its opening in 1978 under VicRoads specifications such as the widening of the Freeway in July 1993 from four lanes to six and a further widening in February 2000 to eight lanes. The bridge was initially meant to carry 40,000 vehicles a day and in the first year of operation, an average of 24,700 vehicles a day used the bridge. By 1981, the number had increased to 29,602, an increase of 17.9% from the previous year (West Gate Bridge Authority, 1981). The overall daily traffic peaks at 155,000 vehicles, more than four times what the bridge was designed to carry. Estimations have revealed that at the current rate of growth, traffic would expect to reach 200,000 vehicles per day by 2021 (Dowling, 2007). The increased usage of this freeway has necessitated further upgrade and changes to accommodate the increasing traffic.

The upgrade was for a part of the freeway, and is set to be completed in late 2010. The upgrade started in early 2008. The project covers the West Gate Freeway section of the Monash- CityLink-West Gate upgrade which is located between the western end of the CityLink tunnels and the eastern end of the West Gate Bridge. Works have been carried out on the ramp that leads from the Bolte Bridge to the West Gate Freeway (MCW upgrade, 2008).

4.2 Concrete and Quarry stone production

This section discusses the production of quarry stone (virgin gravel), and an RMIT university preliminary study carried out at AFG. The SIMAPRO software was used for the preliminary study. Below is a brief discussion on quarry stone production (virgin gravel).

[32] The plan for the West Gate Freeway was first conceived in a 1929 study for a Yarra River crossing west of the CBD, designed to relieve congestion off Princes Highway through Footscray. Construction of the freeway, known at the time as Lower Yarra Freeway, and the Lower Yarra Crossing commenced in 1968. The Country Roads Board completed and opened the freeway between Princes Highway and Williamstown Road on 7 April 1971. The official opening took place on 15 November 1978 at a ceremony in which the bridge was named “West Gate Bridge” and the freeway “West Gate Freeway” (West Gate Freeway, 2005)

4.2.1 Quarry stone production (virgin Gravel)

Recycled crushed concrete is sometimes used as the alternative material to virgin gravel for civil engineering applications such as the sub-base for road construction.

Virgin gravel is a non-renewable resource that is obtained from crushing rock extracted at quarries. Sustainable extraction of quarried stone requires that environmental impacts are reduced during production. Transporting of bulk materials such as virgin gravel could add significantly to CO_2 impacts as shown in Figure 4.1. The Environmental Defender's Office (EDO, 2002) suggests that to minimise the environmental impacts of transport, virgin gravel pits should be as close as possible to markets, or to where the product is used. The transport impact of virgin gravel production is determined by the location of the quarry mine. Other possible environmental impacts of virgin gravel mining are destruction of native vegetation, soil erosion, noise and dust (EDO, 2002). Efforts made to increase the recycling and use of C&D waste will reduce demand for virgin alternatives such as virgin gravel.

Figure 4.1 shows the impacts for virgin gravel production based on the Australian characterization standards, whilst Appendix A 10 (Table A10.1) shows the corresponding table for the process tree in Figure 4.1. Electricity and truck use were identified as the two main sources of environmental impact during virgin gravel production. The process flow arrows show a higher contribution from truck use (75.4%) compared to electricity (25.1%), using the SIMAPRO process tree, shown in Figure 4.1.

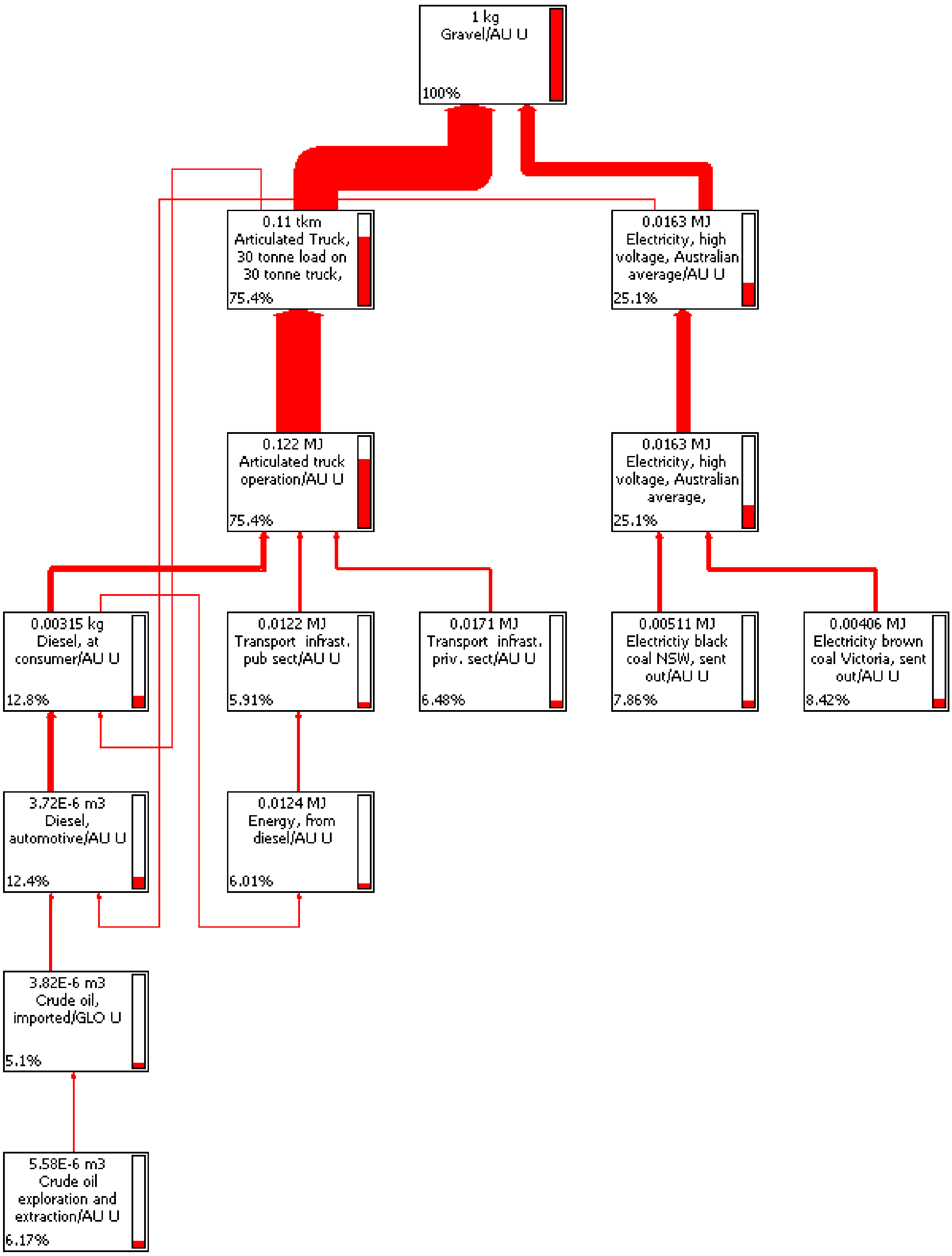


Figure 4.1: Process tree for virgin gravel production in Australia

4.2.2 Preliminary study

The preliminary study was carried out to compare the environmental impacts of quarried stone aggregate and crushed concrete aggregate. Systems boundary for quarried stone aggregate included all activities from the movement of boulders from face, crusher and transporting to building site whilst crushed concrete aggregate also covered all activities from the transporting to and from the plant and processing. The crushing process involved in virgin gravel production and the recycling of concrete are similar, which allows for a comparison of environmental impacts for both production systems. Some of the similarities include, cracking of boulders, loading of crusher, crushing, processing, and moisture content adjustment (optional).

For the preliminary study, the main crushers used at AFG were the jaw and cone crushers. Electricity and diesel were the two main energy sources used to operate the crusher. Other inputs used during the recycling process are outlined in Appendix A9 (Figure A9.1). In the preliminary LCA study, certain assumptions were made based on the initial data collection carried out by RMIT including the following:

- Appendix A9, Figure A9.1 shows the data used for the preliminary study
- Data obtained for concrete was converted into tonnes from the initial unit of cubic meter (m^3) recorded at weighing bridge using a conversion factor of 1.2 (AFG current practice)
- 43% of crushed concrete was produced from the overall waste recycled on-site. Other recycled materials were bricks, rocks, asphalt with wood, plastic, and steel (sent to other respective recyclers)
- 43% was assumed for the proportion of electricity and water usage.
- Estimates were made through comparisons to existing data inventories, and best case data used wherever contradictions arose.

Functional unit was either a tonne of crushed concrete or quarried stone aggregate. The data inputs and outputs used in the LCA are shown in the Table 4.1.

Table 4.1: Data for Quarried stone and crushed Concrete aggregate for 2007

Unit Processes	Quarried Stone Quantity	Crushed Concrete Quantity	Unit
Transport of waste material to crushing plant	None	12	km
Heavy vehicle fuel consumption within plant • Cracking large boulders • Water spreading • Other uses to site	0.98	0.78	l/t production
Electricity use on-site	2.98	2.98	kWh/t production
Water use on-site	153	153	l/t production
Waste generated by recycling process	None	200	t/yr (about 1% of total production)
Transport of waste in landfill	None	4	km
Transport of waste to building site	8	8	km
Transport steel to recycler	None	20	km
'Avoided processes'			
Steel	None	8.1	kg/t
Landfill	None	1.01	t waste / t production

(Source: Carre & Rouwette, 2008)

Table 4.1 outlined the data for the LCA undertaken by Carre and Rouwette (2008) at RMIT, to compare the energy usage, water usage, and transport required for crushing virgin aggregate from quarry with crushing concrete waste. In Table 4.1, the fuel usage was found to be higher for the quarried stone aggregate, compared to the crushed concrete, due to the frequent use of on-site machinery such as the truck used to transfer blasted rock from the quarry to the crushing plant. The avoided production of steel and the disposal of concrete waste in landfill were considered as benefits to the LCA in the study. Unit process similarities between the quarried stone and crushed concrete building materials occur during the crushing process (Table 4.1).

Table 4.2 summarizes the previous impact study results from SIMAPRO. Impact categories focused on global warming, water use, and solid waste. Crushed concrete was found to have negative impacts (benefits) due to the 'avoided processes' of steel and transporting of waste to landfill.

Table 4.2: Characterization results summary

Impact categories	Unit	Crushed concrete aggregate				Quarried stone aggregate
		Concrete recycling process	Avoided steel manufacture	Avoided transport and landfill	**Total impacts**	**Total impacts**
Global warming	**kg CO2**	**1.07E+01**	**-1.32E+00**	**-6.20E+00**	**3.14E+00**	**8.88E+00**
Photochemical oxidation	kg C2H2	4.81E-02	-1.86E-02	-2.93E-02	5.09E-04	2.15E-02
Eutrophication	Kg P O4--eq	7.44E-03	-2.85E-03	-5.15E-03	-5.54E-04	7.03E-03
Carcinogens	DALY	8.07E-08	-1.41E-08	-5.30E-09	6.13E-08	8.52E-08
Land use	Ha annum	2.29E-05	3.60E-07	-5.79E-09	2.32E-05	2.72E-05
Water use	**KL H2O**	**1.33E-01**	**1.82E-02**	**-3.27E-03**	**1.48E-01**	**1.36E-01**
Solid waste	**kg**	**6.91E-02**	**-1.77E+00**	**-1.01E+03**	**-1.01E+03**	**6.70E-02**
Fossil fuels	MJ surplus	1.09E+01	-4.31E+00	-7.51E+00	-8.56E-01	8.29E+00
Minerals	MJ surplus	3.17E-02	-3.29E-01	-5.12E-06	-2.97E-01	3.80E-02

E+01 means one decimal place to the right; E-08 means eight decimal places to the left

(Source: Carre & Rouwette, 2008) - Negative impacts indicate benefits

Results revealed there were similarities between impacts associated with water use for both materials, and differences in energy related indicators such as global warming and solid waste. CO_2 impacts from crushing the quarried stone were higher in the global warming impact category, compared to crushed concrete aggregate. The study revealed that transport to and from the plant, machinery use within the plant, and electricity use were the main contributors in both cases. It was concluded that though impacts were significant for crushed concrete they were offset by the steel recovery and landfill avoidance.

Sensitivity analysis conducted did not show any significant results despite the changes in parameters considered. Sensitivity analysis results also suggested that despite the distance variations from recycler to delivery points, close quarries to building sites did not make much of a difference compared to crushed concrete, which still had a lower environmental impact. The overall results indicated that the recycling of concrete could significantly reduce environmental impacts.

A similar process was used in the study of recycling RC and bricks. To the knowledge of the researcher, no major similar preliminary studies have been carried for bricks at AFG.

4.3 Inventory analysis – Reinforced Concrete

End- of-Life-Cycle stages for recycling RC are:

- Recovery of RC waste materials from site (involves sorting and transporting to site)
- Cracking and crushing of RC (includes weighing, stockpiling and loading)
- Distribution to construction sites

The unit processes data collected, was based on only the first two End-of-Life-Cycle stages and used to model the inventory analysis and assess environmental impacts. As RMIT (1999b) explained, the size and number of unit processes included in the LCA varied depending on available data, the goal and the scope of the study.

4.3.1 Recycling of Reinforced Concrete

This section discusses the processes involved in the recycling of RC. This case-study is similar to the preliminary study (Section 4.2.2), also collected from AFG. In accordance with VicRoads specifications, AFG produces recycled aggregates such as the class 2, 3 crushed concrete and pavement base. The crushed concrete class mixes are allowed a certain quantity of foreign materials, as summarized in Table 4.3.

Table 4.3: Material percentage allowed for crushed Concrete class mixes

Crushed concrete type (Class mixes)	Foreign material type (Max allowable %)		
	High density materials such as bricks, metal and glass	Low density materials such as plastic, rubber, plaster, clay lumps ad friable materials	Wood and other vegetable or decomposable matter
Class 2	2	0.5	0.1
Class 3	3	1	0.2
Pavement base	3	3	0.5

(Source: AFG, 2008b)

Concrete, bricks and other C&D waste materials such as asphalt or glass are recycled together to give the various crushed concrete class mixes shown in Table 4.3. RC and bricks are analysed separately for clarity (Chapters 4 & 5), therefore it is assumed in the ELCA calculation that the crusher operates at the same capacity, during the crushing process for each material (RC and bricks). The RCC are sometimes made according to client specification. The class mixes could be produced as a dry concrete mix, a wet mix (dry concrete mix is put through the pug mill to add some water), and a stabilized mix (both cement and water is added when the dry mix is put through the pug mill). Figures 4.2 to 4.8 are used to explain the crushing and moisture content adjustment processes of RCC production. These illustration figures (Figures 4.2 to 4.8) show the same process for brick recycling, and therefore not repeated in Chapter 5 for the ELCA brick study.

The ELCA study builds on the findings of this preliminary study, which was carried out by RMIT for AFG. The preliminary study had previously calculated electricity, fuel, and water use for 2007, which were adjusted for the 2008 ELCA calculations. The data on quarried stone aggregate (virgin gravel) from the preliminary study was also modified, and used in the ELCA analysis for virgin gravel.

As explained in Table 4.3, brick is one of the materials that can be crushed with concrete to give the various class mixes. Figure 4.2 shows a pile of concrete and bricks waste to be recycled.

Figure 4.2: Concrete and Brick mixed pile

Figure 4.3 shows the primary jaw of the crusher, where the RC and bricks are fed into the crusher. Boulders are crushed at this initial stage, and some water is added during the crushing, to reduce the dust emissions. The next stage is the extraction of the steel from the RC.

Figure 4.3: The primary jaw of crusher

Figure 4.4 shows a pile of steel that has been extracted from the RC. Steel is extracted using the magnetic separator (also shown in picture), before the concrete is crushed into smaller pieces. A second magnetic separator is used to take out any remaining steel not initially extracted.

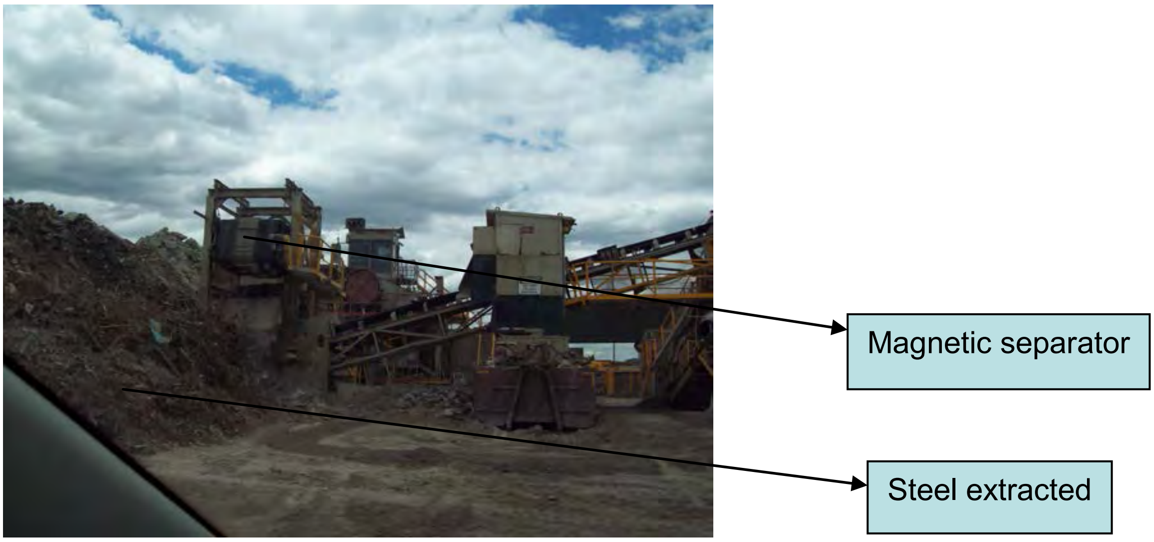


Figure 4.4: Steel extracted from RC

The purpose of the picker station is mainly to sort and separate other waste types that find their way into the crushed aggregate. The picker station is important in reducing the percentage of allowable foreign materials (Table 4.3). Figure 4.5 shows the picker station, two bins, and the blower tube. The picker station gives the crusher operators the opportunity to take out excess foreign material, which is collected in the two bins. Materials most recovered are wood and plastics. Foreign materials not removed at the picker station are blown out, using the blower.

Figure 4.5: The picker station

The crusher conveyor belts are used to transport the crushed aggregate during the recycling process, for example, the conveyor belt sends the crushed aggregate from the magnetic separator to the picker station. Figure 4.6 (far right side) shows a pile of crushed aggregate sent from the conveyor belts, after the crushing process is complete.

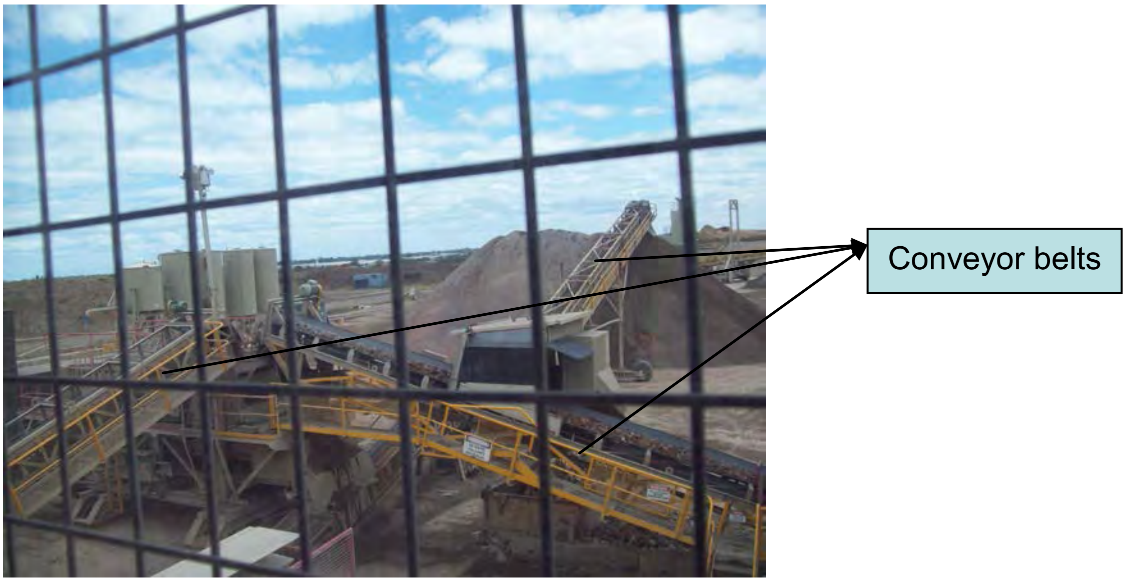


Figure 4.6: The conveyor belt

Figure 4.7 shows an example of a dry crushed concrete mix, before it is run through the pug mill, where water, cement or both (water and cement) is added to the dry crushed concrete mix, subject to client specifications.

Figure 4.7: A dry crushed Concrete mix pile

The laboratory at AFG uses compact testing and moisture content adjusment to determine the right quantity of water, cement, and appropriate particle size to meet client specifications. The dry crushed concrete class mix is sent to the pug mill after the required tests have been completed. Figure 4.8 shows the pug mill where cement and water are added to the dry crushed concrete class mix.

Figure 4.8: A pug mill

The materials flow diagram (Figure 4.9) summarizes the processes shown in Figures 4.2 to 4.8.

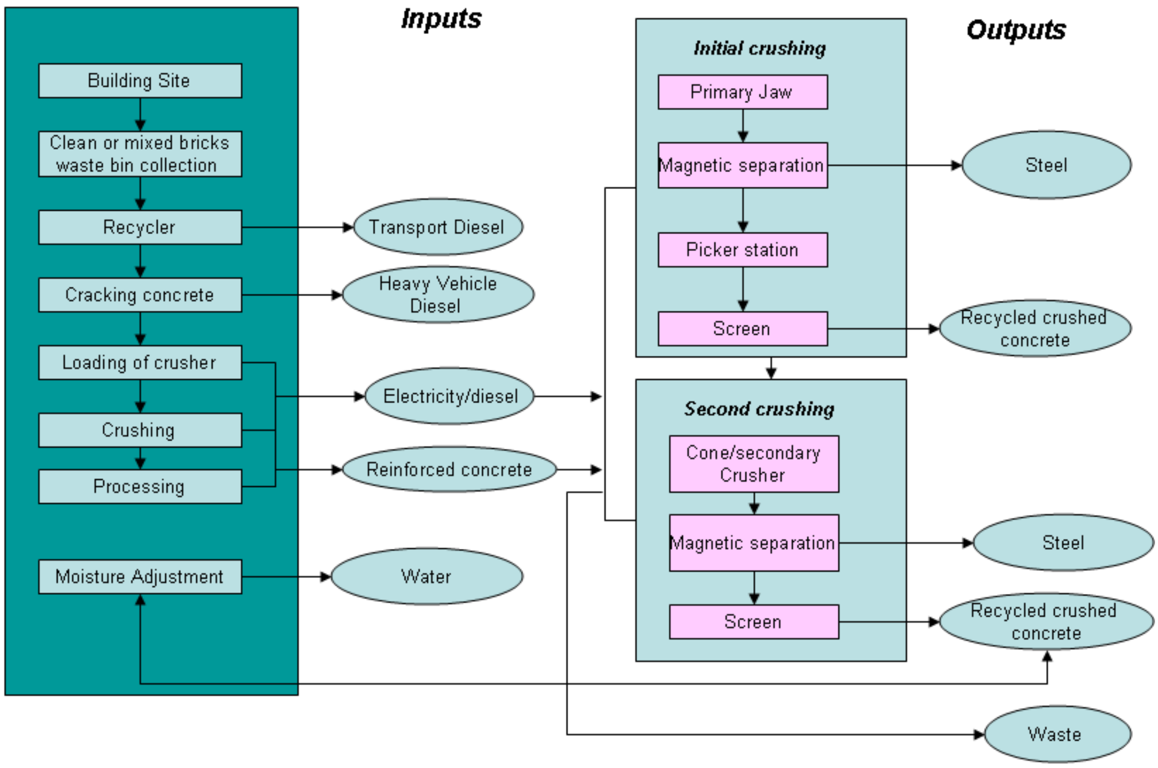


Figure 4.9: Material flow diagram for RC

Assumptions for current AFG study

- Estimates were made through comparisons to existing RC data and LCA inventories. Best case data was used wherever contradictions arose
- The 12-tonne 'hook-lift' truck used for waste collection, allowed for easy dropping and picking up of waste bins by AFG on and off-site
- All travel distances calculated only took into account travel from AFG to pick-up site, and though some errands might have been made along the way, the truck was assumed to be empty on its way to the pick-up site
- RC scenarios used are based on current and predicted recycling situations in Melbourne
- Distance to landfill was estimated to be about 4km and distance to the recycling plant was 20km (one way)
- All RC and brick waste quantities were scaled to 1000 tonnes, for convenience of comparison, and establishing a unit rate

Four scenarios were created to establish the best recycling option for RC, with the least environmental impact.

RC Scenarios

- ***C_0*** represents 100% of waste sent to landfill.
- ***C_1*** represents 100% of waste recycled. It is assumed that waste disposed to landfill, is only residual waste. Residual waste is produced as a result of recycling, and cannot be processed further.
- ***C_2*** represents 97% of waste currently recycled at AFG, with the remaining 3% sent to landfill.
- ***C_3*** represents 80% of waste recycled, with the remaining 20% sent to landfill.

Table 4.4 shows the total quantity of material flows for RC. The residual waste formed 1% of the recycled waste, whilst steel extracted made up 2% of the total recycled material. Total waste disposed to landfill is made up of the residual waste, and waste not recycled. It is important to note that this case-study does not include initial concrete production, but only focuses on the recycling aspect. However, the initial concrete process was acknowledged with a brief mention of input and output figures for the ready-mix concrete in Chapter 2. Table 4.5 outlines the unit process data used in SIMAPRO, for the ELCA analysis of the four RC scenarios, whilst Appendix A9 (Table A9.1), outlines data collected for RC.

Table 4.4: Mass balance of main materials for RC scenarios

Scenarios (% recycled)	**Total RC material quantity (tonnes)**	**Total RC quantity recycled (tonnes)**	**Steel quantity recycled (2% of total RC recycled)**	**Waste disposed to landfill (Residual waste & Waste not recycled)**
C_0 (0%)	1000	0	0	0 + 1000t = 1000t
C_1 (100%)	1000	1000	20t	10t + 0 = 10t
C_2 (97%)	1000	970	19t	9.7t + 30t = 39.7t
C_3 (80%)	1000	800	16t	8t + 200t = 208t

(Source: AFG, 2008b)

Table 4.5: Data for the four 1000 tonne RC scenarios

Unit Processes	Unit	RC scenarios			
		Landfill (100%) C_0	***Rec. (100%) C_1***	***Rec. (97%) C_2***	***Rec. (80%) C_3***
Transport of RC waste material from waste collection site to crushing plant	km per trip	-	20	20	20
Total distance traveled to the crushing plant, based on waste quantities transported (12t truck)	km	-	1,667	1,617	1,333
Heavy vehicle fuel consumption within crushing plant • Cracking large boulders • Loading of crusher • Water spreading • Other uses during crushing	litres	-	809	785	647
Electricity usage at crushing plant	kWh	-	2,734	2,652	2,187
Water usage at crushing plant	kilolitres	-	100	97	80
Waste disposed to landfill from crushing plant (Residual waste & Waste not recycled)	tonnes	1000	10	39.7	208
Transport of RC waste to the landfill site (12t truck)	km per trip	4	4	4	4
Total distance traveled from waste collection site to the landfill site	km	332	4	12	69
<u>'Avoided processes'</u>					
Steel production	tonnes	-	20	19	16
Virgin Gravel production	tonnes	-	950	922	760

4.4 Impact assessment results – Reinforced Concrete

This section discusses the impact results in the study of RC. The four impact categories chosen for the study were global warming (CO_2 emissions), water use, solid waste, and embodied energy. Results that had less than 1% environmental significance to the overall process, based on the cut-off criteria, was not included (Appendix A9, Table A9.5). The ELCA results presented were based on data for the four RC scenarios outlined in Table 4.5. The RC scenarios for landfilling 1000 tonnes (C_0) and recycling 1000 tonnes (C_1) are shown in Figures 4.10 to 4.13.

In Figure 4.10, 100% landfill disposal scenario (C_0) shows no environmental benefits in any of the four chosen impact categories (global warming, water use, solid waste and embodied energy). The two impact areas were identified as truck use (green), and landfill inert waste (orange) in Figure 4.10. The use of the truck increased the effects of the global warming (CO_2 emissions) and embodied energy impacts on the environment, by 94% with landfill inert waste contributing about 6% in both impact categories. The frequent number of trips required to dispose of 1000 tonnes of RC in landfill using the 12-tonne truck, was the main reason for the high impact of global warming and embodied energy. The solid waste impact category was affected only by inert waste which correlated with 1000 tonnes of RC waste (100%) sent to landfill. In the water use impact category, the landfill inert waste (65%) was significant compared to truck use (35%), due to the diesel quantity used to transport RC waste. The overall results indicate that the impact of truck use, was more significant to the landfill disposal scenario (C_0), compared to the landfill inert waste disposed.

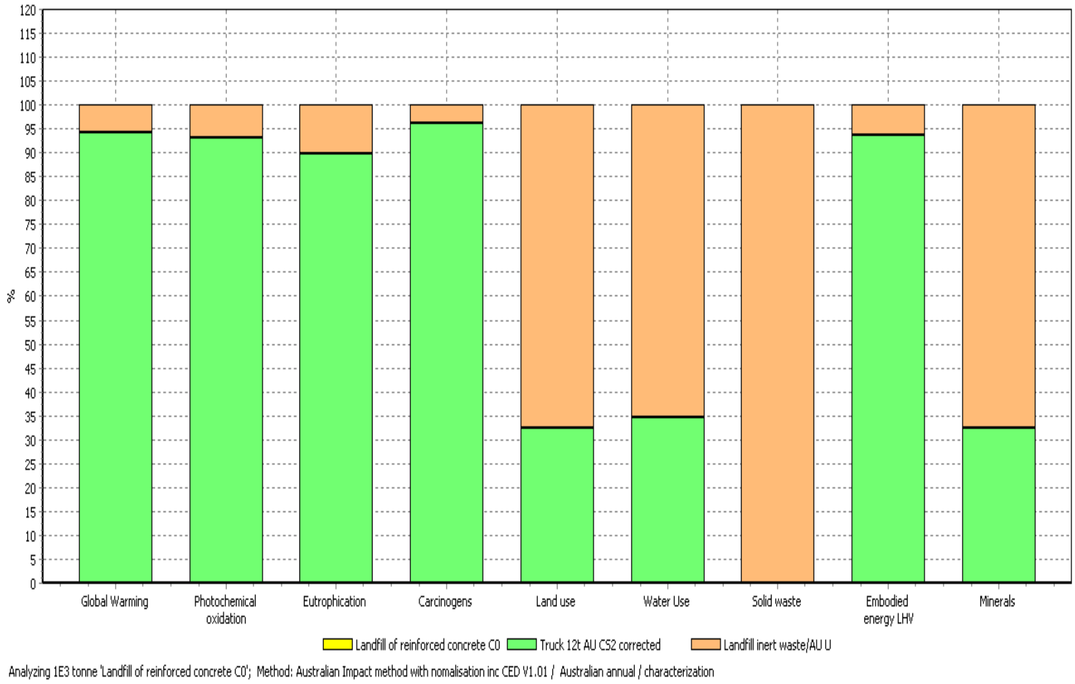


Figure 4.10: Impact assessment of 100% RC landfill disposal (C_0)

Figure 4.11 is the corresponding process tree for Figure 4.10, which shows the impact of landfill disposal (C_0). The main impact of disposing of RC waste in landfill was truck use (thick red arrow- left). Comparatively, the impact from landfill inert waste was less significant. The process flow (thick red arrow- left) indicates that truck use had higher CO_2 environmental imp acts, c ompared to la ndfill in ert w aste (right). A c ontributing factor in the impact of the truck use was the diesel and transport infrastructure, to the overall operation of the truck, as shown in Figure 4.11.

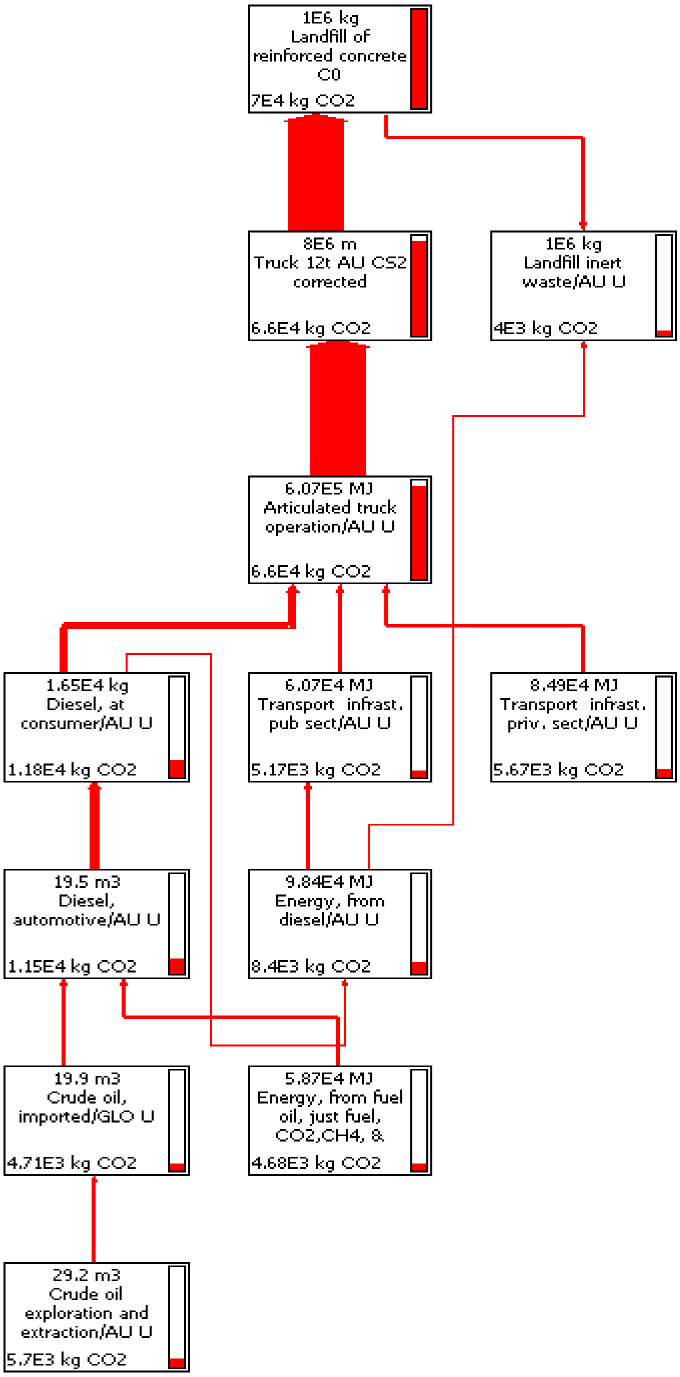


Figure 4.11: Process tree showing 100% RC landfill disposal (C_0)

Figure 4.12 show the environmental benefits of recycling for all four chosen impact categories (global warming, water use, solid waste and embodied energy), whilst Figure 4.13 shows the corresponding process tree (Appendix A10, Table A10.2). In Figure 4.12, all bars below the zero line (on the percentage scale) show the recycling environmental benefits from the avoided production of virgin gravel (purple) and steel (dark green), which occurred in the global warming, water use, solid waste, and embodied energy impact categories. The three dominant recycling environmental impact processes were electricity (orange), diesel (light blue), and truck use (light green). Distances traveled (20km) were found to contribute significantly to the recycling environmental impacts, especially with diesel and truck use. Global warming (CO_2 emissions) and embodied energy impacts mainly occurred during the use of trucks (42%), electricity (11%), and diesel (9%). In the solid waste impact category, the recycling environmental benefits were from the disposal of residual waste to landfill (dark blue), the avoided production virgin gravel (950 tonnes), and steel (20 tonnes) (Table 4.5). Residual waste was sent to landfill (10 tonnes), but the disposal of the residual waste in landfill did not have any recycling environmental impact on the solid waste impact category. The recycling environmental benefits of disposing of the residual waste to landfill were comparatively lower for the global warming and embodied energy impact categories. The overall 100% RC scenario recycling results indicated environmental benefits.

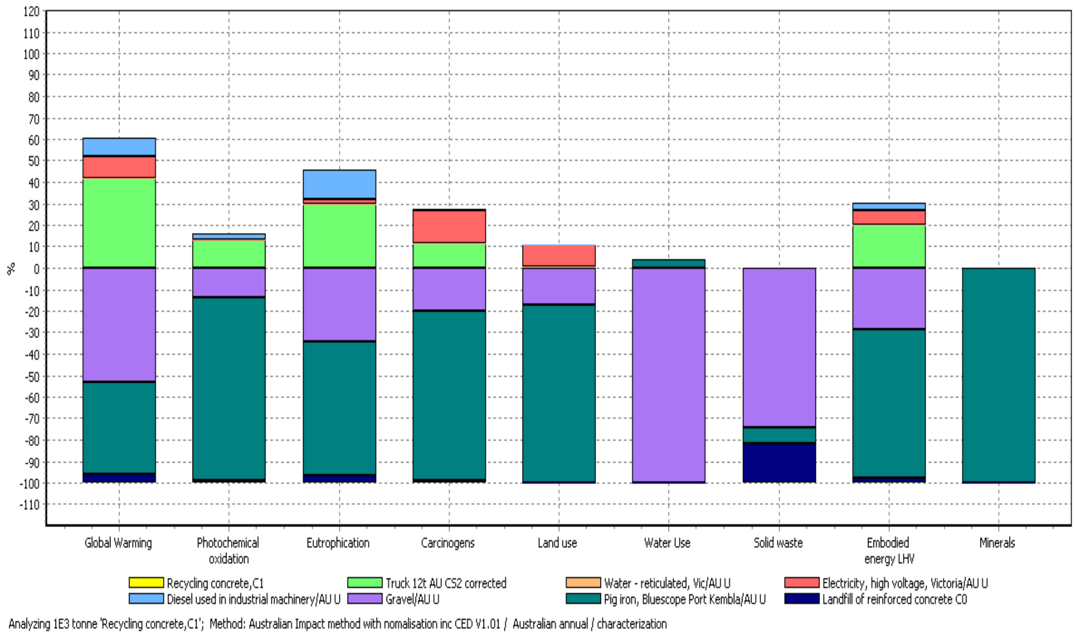


Figure 4.12: Impact Assessment of 100% RC recycling (C_1)

The green process flow arrows in Figure 4.13, show that the avoided production of virgin gravel (especially), and steel, were environmentally beneficial to the recycling process, because impacts from the use of resources in trucks, electricity, and iron-ore mining were avoided. The avoided production of steel meant that the blast furnace slag (red process flow- right) could not be used in the steel production process; however, this did not affect the overall environmental recycling benefits. The impact from the use of the 12-tonne truck (thick red process flow- left), was higher than the electricity use impact (thin red process flow- left).

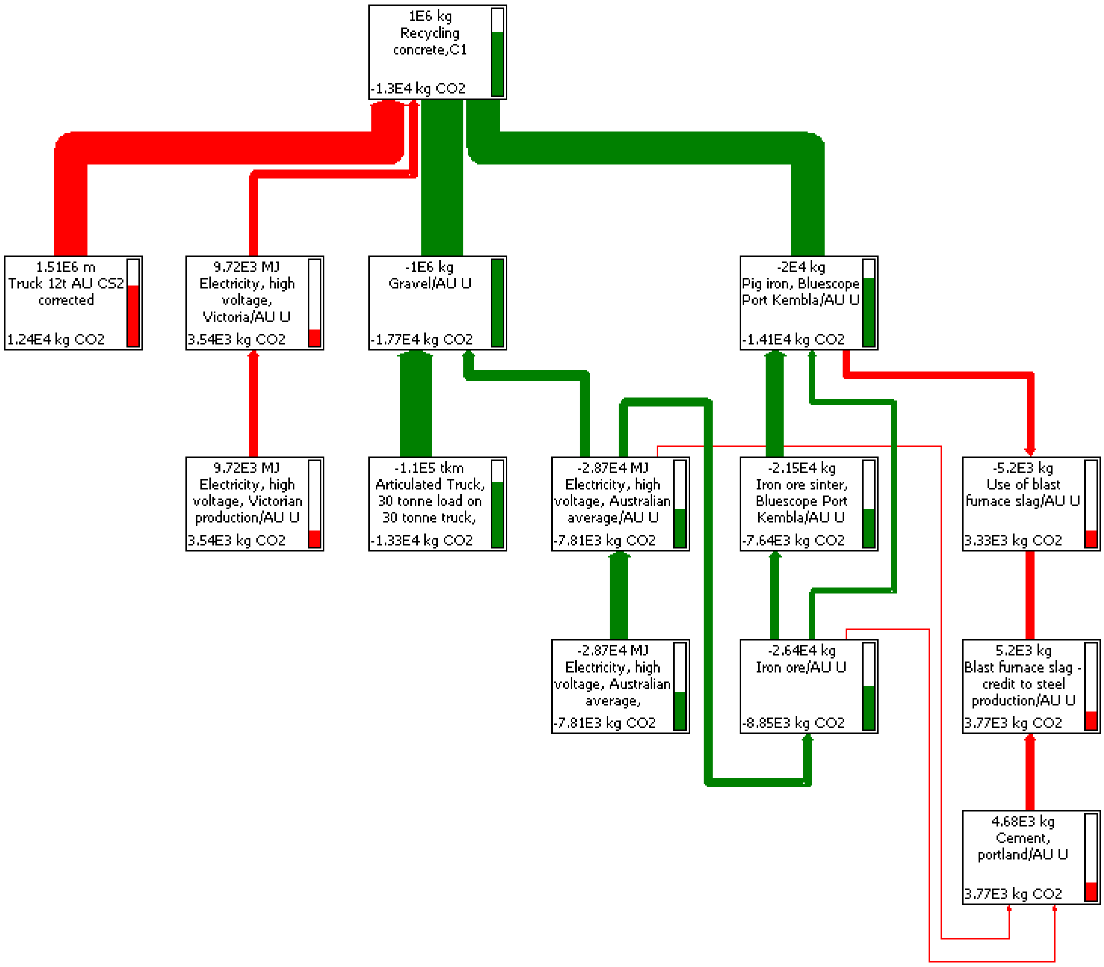


Figure 4.13: Process tree showing 100% RC recycling (C_1)

In comparing the 100% landfill (C_0) and 100% recycling (C_1) processes contribution charts, the RC landfill disposal option (C_0) did not have any environmental benefits (Figure 4.11), compared to RC recycling (C_1), which showed some environmental recycling benefits from the avoided production of steel and virgin gravel (Figure 4.13). The main impact for both scenarios (C_0 and C_1) was truck use.

4.4.1 Comparative impact results – Reinforced Concrete

This section compares the impact for the four RC scenarios, and presents the damage assessment results, based on the ELCA results of the four RC scenarios. Figure 4.14 shows the comparison of the four RC scenarios for the four chosen impact categories (global warming, water use, solid waste and embodied energy). The RC scenarios are presented as C_0 (yellow), C_1 (green), C_2 (orange), and C_3 (red). RC recycling scenarios C_1 (100%), C_2 (97%) and C_3 (80%), had environmental benefits (below the zero line on percentage scale) for all impact categories, except global warming and solid waste, where the C_3 (80%) RC recycling impacts was higher. The high recycling impact (C_3) in global warming and solid waste was a result of transporting 20% RC waste in landfill. The RC scenario with the highest impact for global warming, solid waste and embodied energy was landfill disposal (C_0), whilst the least impact was the RC recycling scenario (C_1).

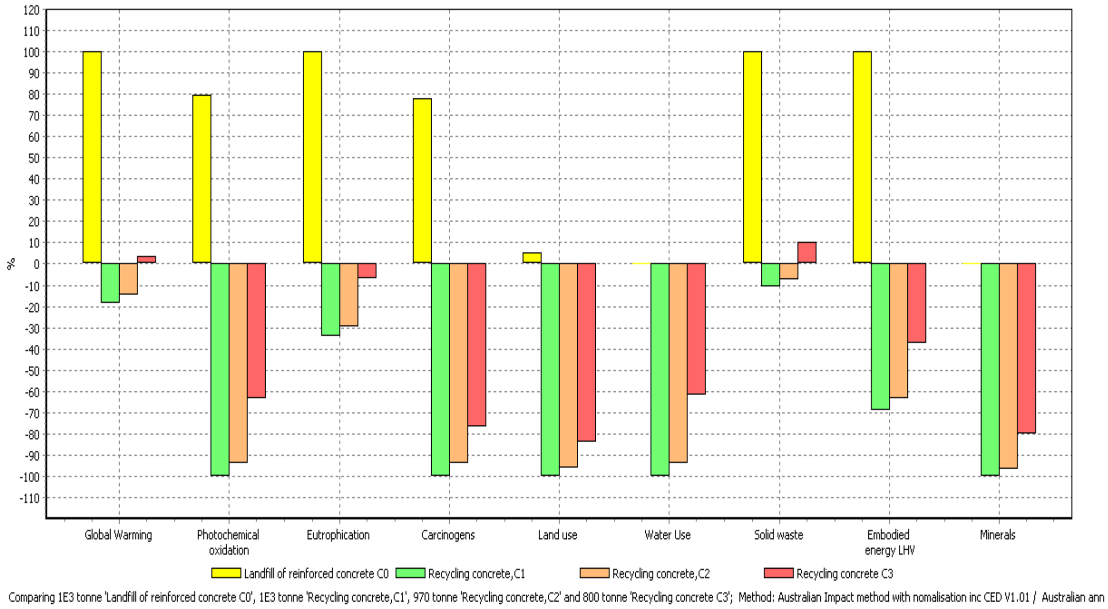


Figure 4.14: Comparison four 1000 tonne RC scenarios

Global warming and solid waste impact categories showed the lowest environmental benefits for the 100% (C_1) and 97% (C_2) RC recycling scenarios in Figure 4.14. Landfill scenario (C_0) had a less than 1% environmental significant impact on water use, since activities at the landfill site that would have required water use, were not included in the ELCA calculations. Comparison between 100% landfill disposal (C_0) and 80% recycling (C_3), showed that global warming (CO_2 emission) and solid waste impact were more than halved for 80% recycling (C_3), although it was the scenario with the least recycled RC waste quantity. Overall results indicated that the 100% (C_1), 97% (C_2), and 80% (C_3) RC recycling scenarios were beneficial to the environment, compared to the 100% landfill disposal scenario (C_0).

During the inventory analysis, the four impact categories (global warming, water use, solid waste, and embodied energy) for this study were individually analysed for all four RC scenarios, as shown in Table 4.6, which corresponds to Figure 4.14. The inventory results are discussed in the sub-sections, whilst Appendix A10 (Table A10.4 to A10.7) shows the breakdown of all the inventory results for the four impact categories shown in Table 4.6.

Table 4.6: Impact categories for four 1000 tonne RC scenarios

Impact category	Unit	Landfill RC, C0 (100%)	Rec RC, C1 (100%)	Rec RC, C2 (97%)	Rec RC C3, (80%)
Global Warming	tonnes CO2	70	-13	-10	2
Water Use	KL	2	-1927	-1811	-1191
Solid waste	Tonnes	1000	-108	-74	103
Embodied energy	GJ	474	-328	-300	-178

4.4.1.1 Global Warming

Carbon emissions for end-of-life waste treatment options such as recycling could be very significant where production is involved. Global warming results shown in Table 6.6, represents the impact of CO_2 for all RC four scenarios. The recycling of 100% RC (C_1) resulted in the least CO_2 impacts (-13 tonnes CO_2), indicating the benefits of recycling. However, the total impact figures for 100% landfill disposal (C_0) were still comparatively high (70 tonnes CO_2) (Appendix A10, Table A10.4).

4.4.1.2 Water Use

Water used during the dust reduction, and moisture content adjustment stages of recycling, were included in the ELCA. The 100% RC recycling scenario (C_1) saved 1927kl of water, whilst the landfill disposal scenario (C_0) had the highest effect (20kl) on the water use impact category (Appendix A10, Table A10.5).

4.4.1.3 Solid Waste

The solid waste impact category shows the impact of RC recycling and landfill disposal. In the solid waste impact category, the RC recycling scenarios (C_1, C_2, and C_3) had recycling environmental benefits, whilst the landfill disposal scenario (C_0) had the total highest impact (1000 tonnes). The highest environmental recycling benefits (-108 tonnes) were seen in C_1, where 100% of the waste was recycled (Appendix A10, Table A10.6).

4.4.1.4 Embodied Energy

There were environmental benefits for the 100% (C_1), 97% (C_2), and 80% (C_3) RC recycling scenarios for embodied energy. The landfill disposal scenario (C_0) still maintained its high environmental impact figures (474GJ), whilst most embodied energy saved (-328GJ) was in the RC recycling scenario (C_3) (Appendix A10, Table A10.7).

The implications of the RC ELCA results are interpreted through the use of the equivalence unit model in SIMAPRO (Table 4.7), which relates the results to everyday activities for easier interpretation. The equivalence unit model conversion factors were used to calculate the damage assessment. The damage assessment results presented in Table 4.7 show the impact for all four RC scenarios. The results indicate, for example, that landfilling of 1000 tonnes of RC waste (C_0) would require 140 mature trees to absorb the resulting carbon emission (70 tonnes CO_2) from the landfill process. However, the recycling of 1000 tonnes of RC (C_1) saved 26 mature trees, that would have been required to absorb the carbon emissions created (-13 tonnes CO_2).

Table 4.7: Damage assessment results for the four RC scenarios

Impact category	Equivalencies	Conversion Factors	C_0	C_1	C_2	C_3
Global warming (tonnes CO_2)	Number of trees planted and grown to maturity required to absorb the carbon dioxide released	2	140	-26	-20	2
Water use (KL)	Number of showers taken/saved *based upon 89 litres for 10 minutes	11.22	0	-21,620	-20,319	-13,363
Solid waste (Tonnes)	Number of 240 litre wheelie bins needed for solid waste generated along the supply chain	9	9000	-972	-666	927
Embodied energy (GJ)	Days of household energy usage - electricity and gas	6	2,844	-1,968	-1,800	-1,068

NB: The negative figures represent the activities not performed or avoided.

4.4.2 Sensitivity Analysis

Sensitivity analysis contributes to ensuring an accurate decision-making process. Sensitivity analysis is carried out when the impact areas identified is re-run in SIMAPRO, to establish if a change to certain unit processes within the modelling system changes the outcome.

The sensitivity analysis was run to identify the appropriate distance between the waste source and recycling plants, and determine which of the three RC recycling scenarios had the least environmental impact. Impact categories were chosen to represent the most affected unit processes during recycling and landfill disposal.

Travel distances still contributed significantly to the environmental impacts of global warming and embodied energy (Figure 4.12). This explains why the travel impact has been calculated for these two impact categories. The project under study was the West Gate Freeway upgrade. The trip from the project site to AFG was 20km, but did not take into account additional errands made during the trip.

Although the three RC recycling scenarios still turned out to be environmentally beneficial because of the avoided production of steel and virgin gravel, there is a potential to further improve transport impact. The initial travel distance for transporting RC to the recycling plant was 20km. Three runs of sensitivity analysis were done. The travel distances used for the sensitivity analysis were decreased by 5km consecutively for each run, with distances of 15km, 10km and 5km calculated. Though the distances for 15km and 10km showed significant improvements to the global warming and embodied energy impact, the 5km distance had the best result. The results of the third run (5km) indicate the environmental impact could be significantly reduced, if a distance of 5km was traveled from the waste collection site to the recycling plant, during the transportation of RC waste.

Tables 4.8 and 4.9 show the impact of transport on the global warming and embodied energy impact categories, where the results indicate that the quantity of waste transported impact on the distance traveled, and ultimately causes environmental impact. For example, in Table 4.8, transporting 800 tonnes (80%) over a 5 km distance, prevented the emission of about 5.7 tonnes CO_2, whilst transporting 1000 tonnes (100%) over the same distance (5km), resulted in a higher savings on global warming (-23.4 tonnes CO_2).

Table 4.8: Sensitivity analysis -Transport impact on global warming for RC

Global warming (tonnes CO2)	**Scenarios**	**Distances Traveled**		
		15km	**10km**	**5km**
	C_1 (100%)	-16.5	-19.9	-23.4
	C_2 (97%)	-13.4	-16.8	-20.1
	C_3 (80%)	-2.6	-3.0	-5.7

The results imply that, to decrease the impact on global warming, the distance traveled to transport 1000 tonnes (100%) of RC should be shorter. Hence, if a large quantity of waste needs to be transported to the recycling plant, then the recycling plant with the shortest route should be considered. This same line of reasoning should be applied to embodied energy (Table 4.8).

Table 4.9: Sensitivity analysis -Transport impact on embodied energy for RC

Embodied energy (MJ)	Scenarios	Distances Traveled		
		15km	10km	5km
	C_1 (100%)	-351	-374	-397
	C_2 (97%)	-323	-345	-367
	C_3 (80%)	-196	-215	-233

4.4.3 Uncertainty Analysis

Uncertainty analysis was carried out using the Monte Carlo analysis to determine the reliability of data used in the ELCA study. The RC data for the ELCA study was collected from AFG, and where appropriate, estimates were made through comparisons to existing data inventories in SIMAPRO and best case data was used wherever contradictions arose. Inventories of data such as transport, energy and carbon emission have been extensively covered in previous studies. Hence, the data obtained was well-substantiated. The release of the Australian Life-Cycle Inventory (AUSLCI) is expected to further minimise uncertainties in future LCA studies.

The triangular distribution was used to translate the information on uncertainty to a standard distribution type. The upper (97.5%) and lower (2.5%) confidence limits with a confidence interval of 95% from 1000 runs are represented by the red lines in Appendix A10 (Figures A10.3 and A10.4) for the 100% RC landfill disposal (C_0) and 100% RC recycling (C_1) scenarios respectively. The figures indicate that the range of uncertainty was relatively low for all four impact categories studied (global warming, water use, solid waste and embodied energy) and not sufficient enough to affect data reliability.

4.5 Chapter summary and conclusion

In the preliminary study, global warming, water use and solid waste were the three impact categories analysed. The environmental impact of virgin gravel, compared to crushed concrete, showed that the benefits for crushed concrete far outweighed virgin gravel. Virgin gravel remains a non-renewable resource, and its use continues to deplete existing resources.

In this study, four impact categories (global warming, water use, solid waste, and embodied energy) were considered relevant to the RC scenarios and unit processes, whilst input and output variables used in the ELCA study were outlined.

The ELCA study revealed that the end-of-life option of RC recycling decreased waste impact, on the environment. Landfill scenario results indicated that it was obviously not the preferred end-of-life option, since its environmental impact was quite significant, especially during the transportation of waste. On the other hand, the results of 100% RC recycling (*C_1*) showed that transport use impacts were offset by the avoided production of gravel and steel, although the distance traveled to the recycling plant was 20km. However, there were still some energy impacts from RC recycling, which needed be minimised. Therefore, measures to reduce energy impacts should be implemented, to ensure that the impacts realised are further improved.

In Victoria, about 80% of concrete is recycled, so it is yet to be seen if a total ban on concrete in landfill can be achieved. A total ban is likely to produce similar results as that of the 100% RC recycling scenario *(C_1)*. The impact of energy and transport on the environment, reiterated the need to find sustainable alternatives to reduce impacts, where possible. The sensitivity analysis results also indicated that reducing the distances traveled could be the key. The uncertainty analysis did not highlight any significant uncertainties for the input data used. Chapter 5 discusses the inventory analysis and impact assessment for brick, whilst the implications of the results in this chapter, and some suggested measures for improvement are discussed in Chapter 9 (Section 9.1).

5 ENVIRONMENTAL IMPACT OF RECYCLING BRICKS

This chapter discusses the inventory analysis and the impact assessment results for the ELCA brick study. Like RC, this study also focuses on the four impact categories (global warming, water use, solid waste and embodied energy). Two end-of-life brick scenarios were considered. The sensitivity and uncertainty analysis are conducted to test the accuracy of the data, and initial results of the ELCA.

5.1 Inventory analysis – Bricks

The materials flow diagram for the recycling and crushing of bricks is similar to that of RC except for the magnetic separator, as shown in Figure 5.1. Similar inputs and parameters are considered for bricks as for RC, thus, most of the resource input details are not repeated in this chapter.

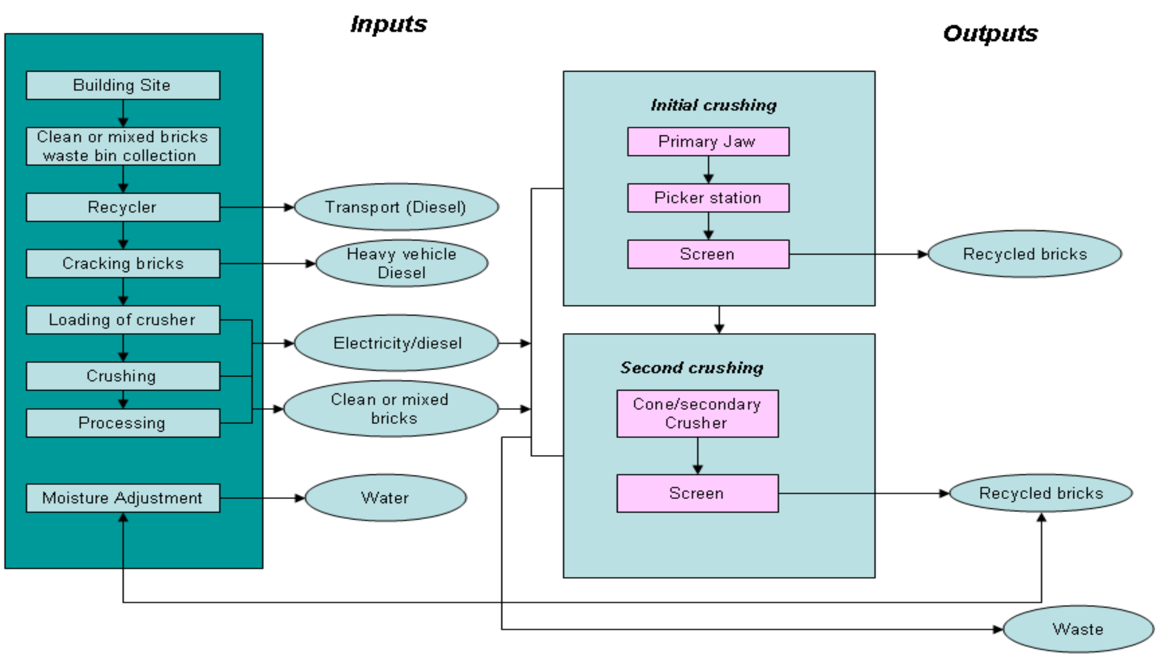


Figure 5.1: Material flow diagram for Bricks

5.1.1 Recycling of Bricks

Data for bricks was collected from the 2008 production year. Unlike concrete, bricks can be re-used or recycled, but re-used bricks are not considered in this study. This study acknowledges that the re-use of bricks remains a sustainable alternative. However, the processing of brick for re-use including demolition, transport, sorting, brick cleaning and preparation was deliberately beyond the scope of this research project, which focused on recycled crushed bricks as an alternative for virgin aggregate. The two brick scenarios for this study calculated 100% of brick waste disposed to landfill, and 100% of brick waste recycled for use as aggregate. Table 5.1 summarizes the total quantities of brick waste for the 2008 production year.

Scenarios

- B_0 – represents 100% of brick waste quantity disposed to landfill
- B_1 – represents 100% of brick waste recycled

Table 5.1: Mass balance for Bricks

Bricks only (total quantity in tonnes)	22,100t
Mixed load containing bricks (30% brick content in tonnes)	8,580t
Total bricks for 2008	30,680t

(Source: AFG, 2008b)

AFG crushes bricks (with concrete and asphalt) as aggregates (Table 4.3), or separately. However, this study assumes bricks are recycled separately, and the crusher runs at the same capacity during the recycling of RC and bricks. Bricks crushed separately (without RC) can be used for purposes such as aggregates for in-situ and precast concrete, filling and stabilizing material for infrastructure, aggregates for calcium silicate bricks, tennis court sand, and plant substrates. The unit processes outline the various inputs required during the 100% brick recycling (B_1) and landfill scenario (B_0). The trip from the waste collection site to the crushing plant was estimated as 15km, whilst the trip from the waste collection site to the landfill site was 4km. Table 5.2 shows the unit processes data for the two brick scenarios used in the ELCA study.

Table 5.2: Data for the two Brick scenarios

Unit Processes	**Unit**	**Brick scenarios**	
		Landfill (B_0)	***Recycling (B_1)***
Transport of brick waste material from waste collection site to the crushing plant	km per trip	-	15
Total distance traveled based on waste quantities transported (12t truck)	km		1,250
Heavy vehicle fuel consumption within plant • Cracking large boulders • Loading of crusher • Water spreading • Other uses during crushing	litres	-	809
Electricity usage at crushing plant	kWh	-	2,734
Water usage at crushing plant	kilolitres	-	100
Waste disposed to landfill from crushing plant (Residual waste & Waste not recycled)	tonnes	1,000	-
Transport of brick waste to the landfill site (12t truck)	km per trip	4	-
Total distance traveled from waste collection site to the landfill site	km	333	-
<u>'Avoided processes'</u>			
Virgin Gravel production	tonnes	-	950
Transport to landfill for disposal of demolition waste (bricks)	km	-	333

5.2 Impact assessment results – Bricks

This section discusses the impact assessment results for the two brick scenarios. Figure 5.2 shows the process tree CO_2 impacts for the 100% brick landfill disposal scenario (B_0). The greatest impact contribution identified was from the transportation of brick (1000 tonnes) to landfill, involving a 12-tonne truck, traveling 4km from the waste collection site to the landfill site. About 83 trips had to be made using a 12-tonne truck, to dispose of 1000 tonnes of brick waste in landfill. In Figure 5.2, the main contributory processes to the brick landfill disposal scenario (B_0), were distances traveled and the operation of the truck.

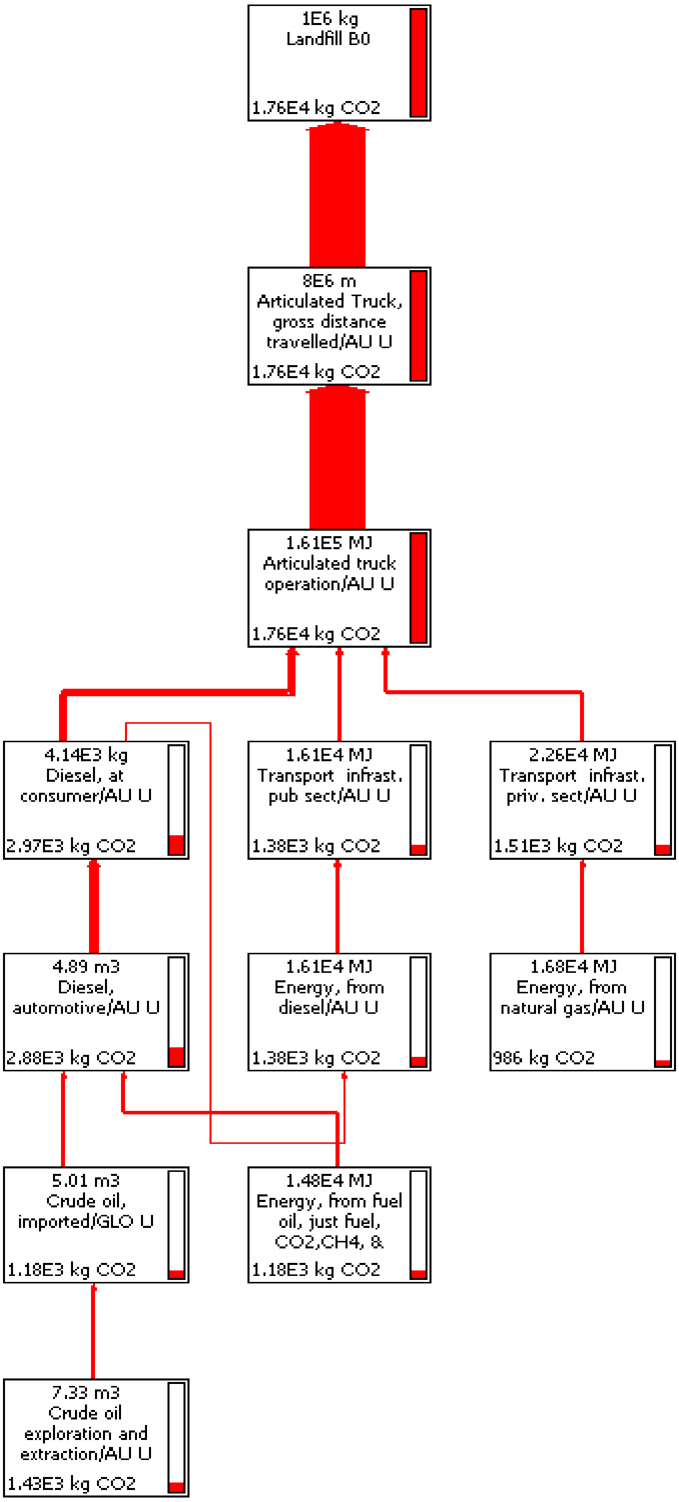


Figure 5.2: Process tree for 100% Brick landfill disposal (*B_0*)

The percentage scale in Figure 5.3 shows both positive and negative values, representing environmental imp acts a nd b enefits. V irgin g ravel (blue) is c alculated a s an environmental benefit to the 100% brick recycling scenario for all the four chosen impact categories (global warming, water use, solid waste and embodied energy). In Figure 5.3, the three main impact processes were truck use (green), electricity use (orange), and diesel use (red). Truck, electricity and diesel use processes contributed significantly to the global warming and embodied energy impact categories. These impacts resulted from the transportation of waste to the recycling plant, and the brick recycling process. The brick recycling process (yellow) contributed to the water use impact category, though it was the category with the lowest impact. The solid waste impact category had no environmental impact, because there was no waste disposed to landfill for the 100% brick recycling scenario. Figure 5.4 shows the corresponding process tree for Figure 5.3.

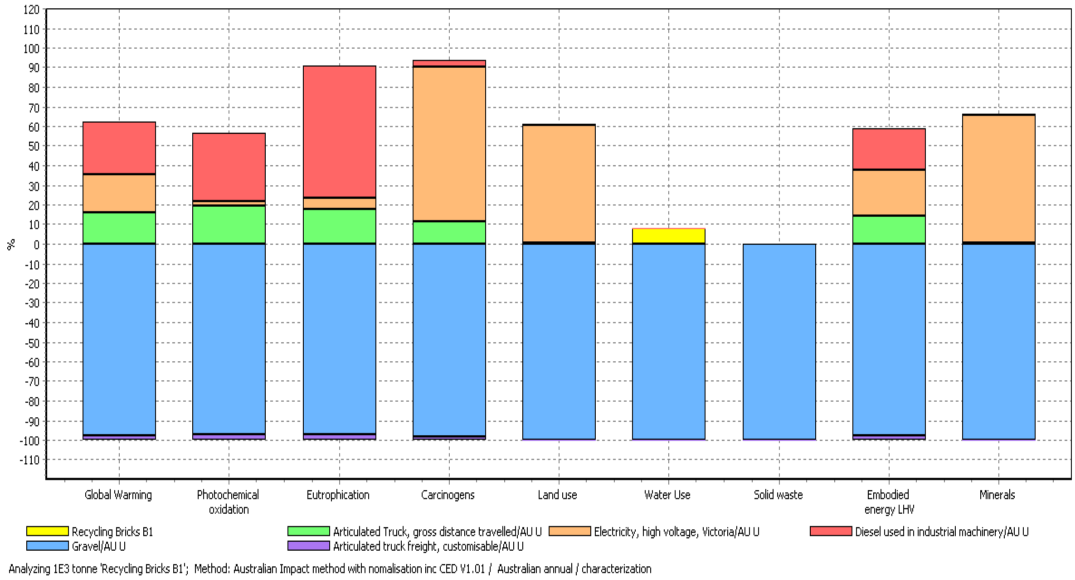


Figure 5.3: Impact assessment of 100% Brick recycling scenario (*B_1*)

Figure 5.4 shows the environmental impacts and benefits of the 100% brick recycling (B_1) scenario. The avoided process of virgin gravel production (green process flow) contributed to the carbon emission benefits (CO_2) of recycling bricks. 1000 tonnes of bricks recycled is equivalent to about 950 tonnes (95%) of virgin gravel. The environmental benefits of 100% brick recycling (green process flow), far outweighed the environmental impact from transporting brick to the recycling plant, diesel used in machinery, and the use of electricity (red process flow) during the brick recycling process.

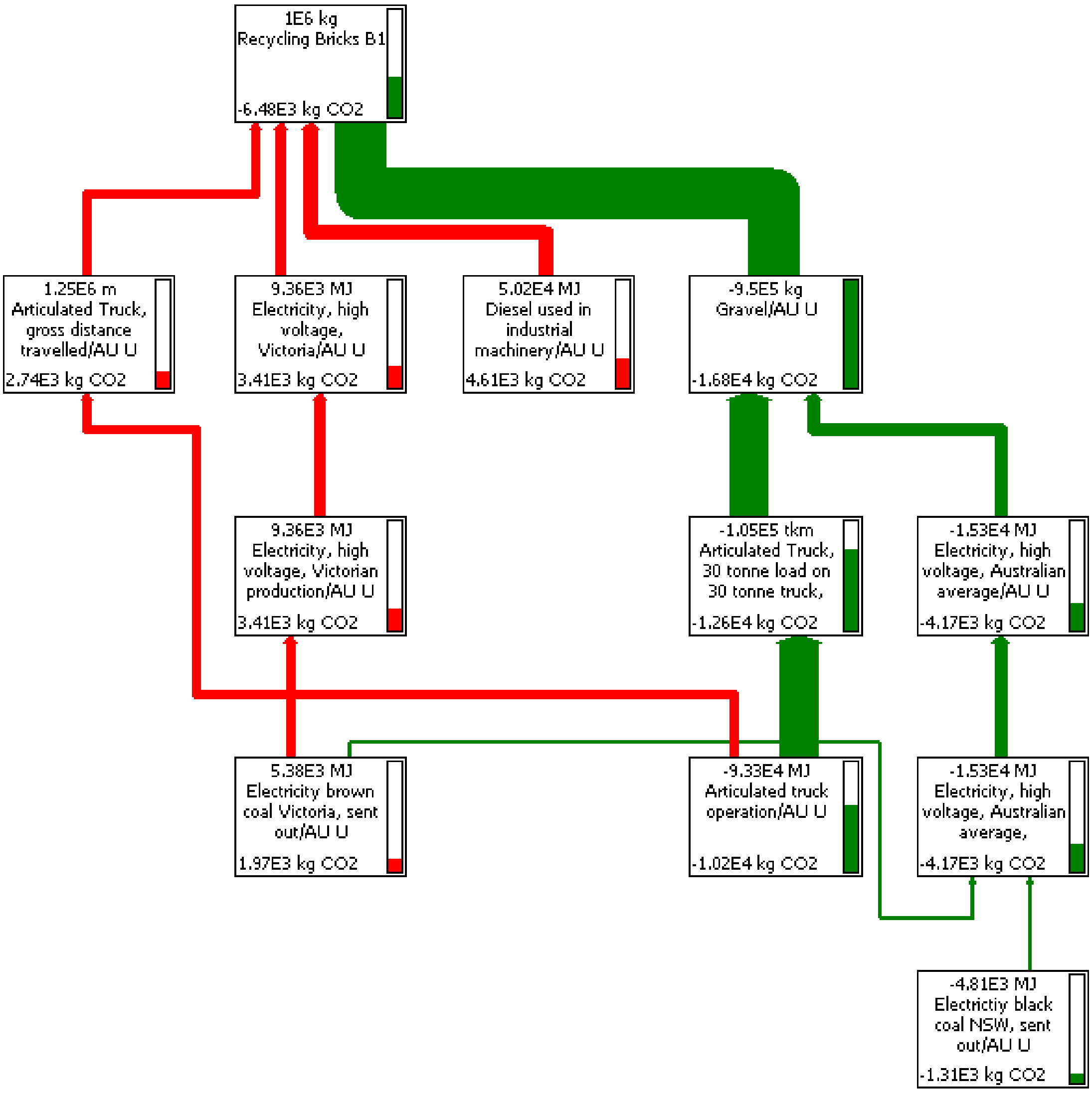


Figure 5.4: Process tree for 100% Brick recycling scenario (B_1)

5.2.1 Comparative impact results – Bricks

This section discusses the comparative impacts of recycling and disposing of 100% of brick waste. Figure 5.5 shows a comparison of the 100% brick disposed to landfill (yellow), and 100% brick recycling (green) scenarios. The percentage scale values in Figure 5.5 represent the impact contribution of disposing of 100% of bricks in landfill (B_0), and recycling 100% of brick waste (B_1), for the four impact categories (global warming, water use, solid waste, and embodied energy). The environmental benefits of the 100% brick recycling (B_1) scenario were realised in the solid waste (least environmental benefits) and water use (most environmental benefits) impact categories. Comparatively, in the 100% landfill disposal scenario (B_0), global warming, solid waste, and embodied energy, had the most impact on the environment. Clay is a natural resource, so its landfill impact is relatively lower than other C&D waste materials like RC, except when mortar is present. However, lower environmental impacts from bricks to landfill should not encourage more brick waste to be disposed to landfill, since the recycling of bricks (B_1) is still a preferred option if bricks cannot be re-used.

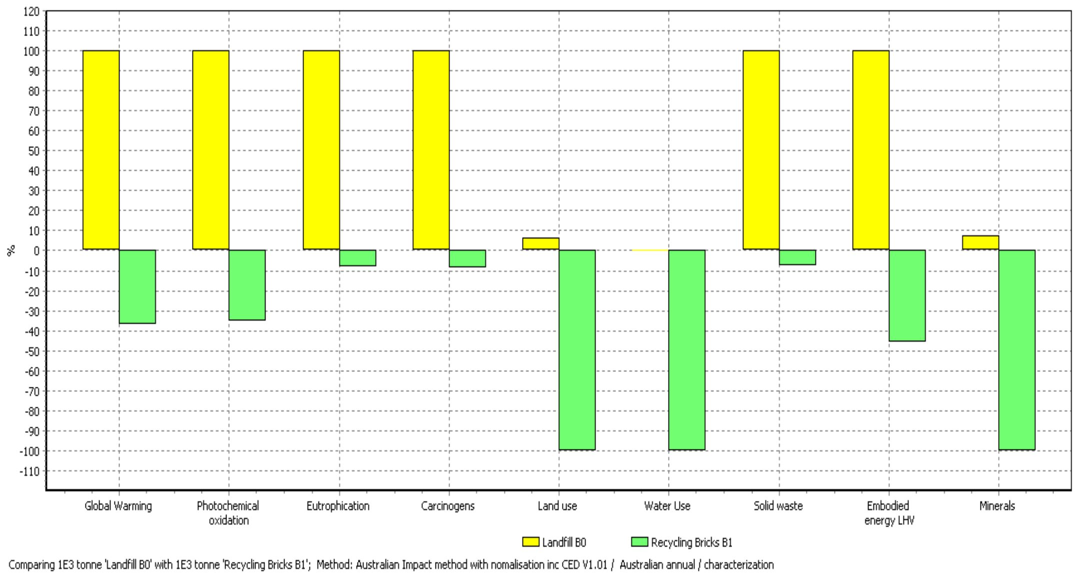


Figure 5.5: Comparison of 100% landfill disposal (B_0) and 100% recycling (B_1)

The four impact categories (global warming, water use, solid waste, and embodied energy) are calculated for the two brick scenarios and summarized in Table 5.3, with further details of the breakdown listed in Appendix A10 (Table A10.10 to A10.13).

Table 5.3: Impact categories for two 1000 tonne Brick scenarios (*B_0* and *B_1*)

Impact category	Unit	Landfill B0, (100%)	Recycling B1, (100%)
Global Warming	tonnes CO2	18	-6.5
Water Use	KL	0	-2
Solid waste	Tonnes	1000	-76
Embodied energy	GJ	118	-54

5.2.1.1 Global Warming

Global warming results in Table 5.3 show the impact of CO_2 for the two brick scenarios. The recycling of 100% brick (B_1) resulted in the least CO_2 impact (-6.5 tonnesCO_2), indicating the benefits of recycling, whilst the total impact figures for 100% landfill disposal (B_0) were still comparatively high (18 tonnesCO_2) (Appendix A 10, Table A10.10).

5.2.1.2 Water Use

Water was used in the dust reduction and moisture content adjustment stages of the recycling process. The 100% brick recycling scenario (B_1) saved on water use (-2kl), whilst the landfill disposal scenario (B_0) had an insignificant (0kl) effect on the water use impact category, since landfill activity was not considered (Appendix A 10, Table A10.11).

5.2.1.3 Solid Waste

The solid waste impact category shows the impact of brick recycled or sent to landfill. The total recycling impact results for brick were negative (benefits), compared to the landfill disposal scenario (B_0), which had the total highest waste impact (1000 tonnes). There was no waste sent to landfill therefore, there was the avoided disposal of 76 tonnes of residual waste in the B_1 scenario, where 100% of the brick waste was recycled (Appendix A10, Table A10.12).

5.2.1.4 Embodied Energy

There were benefits for the 100% brick recycling scenario (B_1) for embodied energy. Although truck, electricity, and diesel use had the main environmental impacts for the recycling (B_1) scenario, the benefits of not producing gravel offset the environmental impacts. The landfill disposal scenario (B_0) still maintained its high environmental impact figures (118GJ), whilst embodied energy was saved (-54GJ) in the brick recycling scenario (B_1) (Appendix A10, Table A10.13).

The impacts of the two brick scenarios are interpreted using the damage assessment results summarized in Table 5.4. The damage assessment results indicate for example, that 36 mature trees will be required to absorb the CO_2 emitted from the landfill disposal scenario (B_0). By recycling (B_1), 13 mature trees were saved from CO_2 emissions absorption.

Table 5.4: Damage assessment results for two 1000 tonne Brick scenarios

Impact category	Equivalencies	Conversion Factors	B_0	B_1
Global warming (tonnes CO_2)	Number of trees planted and grown to maturity required to absorb the carbon dioxide released	2	36	-13
Water use (KL)	Number of showers taken * based upon 89 litres for 10 minutes	11.22	2	-22
Solid waste (Tonnes)	Number of 240 litre wheelie bins needed for solid waste generated along the supply chain	9	9000	-684
Embodied energy (GJ)	Days of household energy usage - electricity and gas	6	708	-324

5.2.2 Sensitivity Analysis

Similar to the RC study, the sensitivity analysis for bricks in Table 5.5 revealed that the transport distances still contributed significantly to the environmental impacts for the brick recycling scenario (B_1). Table 5.5 shows the impact results for global warming and embodied energy, when the distances of 10km and 5km were calculated. The distance to the AFG recycling plant was averaged at 15km, whilst the distance to the landfill site was 4km. Transport use impacts for brick recycling (B_1) were less significant compared to the brick landfill disposal scenario (B_0), although the distance to the recycling plant was further than to the landfill sites. The impacts from transporting waste to the recycling site (15km) were offset by the benefits of the avoided production of virgin gravel. The results indicated that the transport impact of recycling was likely to be improved with shorter distances traveled, as shown in Table 5.5. In contrast, the study revealed that a total travel distance greater than 50km for bricks would not be beneficial to recycling.

Table 5.5: Sensitivity analysis -Transport impact on global warming and embodied energy for Bricks

Impact categories	Scenarios	Distances Traveled		
		15km	10km	5km
Global warming (tonnes CO2)	B_1 (100%)	-6.5	-7.3	-8.3
Embodied energy (MJ)	B_1 (100%)	-54.1	-60.4	-66.5

5.2.3 Uncertainty Analysis

Similar to the uncertainty analysis for RC, the triangular distribution was used to translate the uncertainty information. The upper (97.5%) and lower (2.5%) confidence limits with a confidence interval of 95% from 1000 runs, are represented by the red lines in Appendix A10 (Figures A10.5 and A10.6) for the 100% brick landfill disposal (B_0) and 100% brick recycling (B_1) scenarios respectively. In Appendix A10 (Figure A10.5 and A10.6), the uncertainty score was very low for all the four impact categories (global warming, water use, solid waste, and embodied energy) for both the brick recycling scenarios (B_0 and B_1) and not significant enough to affect data reliability.

5.3 Chapter summary and conclusion

The four impact categories (global warming, water use, solid waste, and embodied energy) were analysed using the brick two scenarios of recycling and landfill scenario.

The ELCA results in this chapter highlighted the impacts of brick recycling, and landfill disposal, on the environment. The result indicated that the distance traveled to the recycling plant and the crushing process contributed most, to the impact of the recycling process. However, the environmental benefits of recycling bricks (B_1) were as a result of the avoided production of virgin gravel, which was enough to offset the impacts of transporting brick waste to the recycling plant (truck and diesel use), and electricity use during recycling. Since there was no portion of the brick waste sent to landfill in the recycling scenario, the impacts from transporting waste to the landfill site were also avoided. The sensitivity analysis results for global warming and embodied energy for the two brick recycling scenarios (B_0 and B_1) indicated the need for shorter distances to be considered, when brick waste was transported. The uncertainty analysis conducted did not reveal any significant data uncertainties that affected the outcome of the ELCA.

On the other hand, the ELCA study results implied that the main contributors to brick landfill disposal (B_0) impacts were truck and diesel use. Clearly, the impact of transport was quite significant for both the recycling and landfill disposal scenarios, but the landfill scenario was still not the preferred option. The composition of bricks (clay and shale) should not cause more brick waste to be disposed to landfill. Although brick waste might not have as much impact on landfill, compared to other C&D waste materials such as RC, the impacts from the transport contributes significantly to the overall environmental impacts realised.

The increased benefits for recycling bricks, occurs when environmental impacts are reduced. Brick production is inevitable, due to increasing infrastructural demand in Victoria, thus, brick re-use should be encouraged, with RCB material being the next best option. Resource inputs such as electricity, water and fuel do not only impact on the environment but also could add to the cost of recycling. Chapter 6 examines the various behavioural patterns, affecting waste management practices such as recycling, at six construction sites, whilst Chapter 9 (Section 9.1) discusses the implications of the result in this chapter.

6 SOCIAL FACTORS INFLUENCING WASTE MANAGEMENT AND RECYCLING

This chapter examines six construction sites in Melbourne, Victoria. A brief history about the features of the buildings, and their current Green Star ratings are outlined. The study identifies disposal and recycling practices, behaviours, and perceptions that influence the recycling of C&D waste, based on human responsibilities. Although the social aspect of this research focuses on the responsibility of industry, impacts such as carbon emissions (Environmental) and costs (Economic) affect society, and are addressed in Chapters 4, 5 and 7 of this study. Hence, site findings are discussed, to highlight the major drivers and barriers to recycling waste quantities, and ultimately the amount available to be purchased or re-used. Recommendations are made based on the findings of the sites study. The construction sites study focuses on C&D waste in general. This was prepared by the researcher, and Business Outlook and Evaluation (a Melbourne based Business Projects Research Company), and submitted to the Building Industry Consultative Council (BICC). This study was undertaken between the period of January and June 2007.

6.1 Building construction sites studied

The six construction sites studied consisted of 500 Collins Street, Melbourne Convention Centre (MCC), 55 St Andrews Place, Corner Bourke and William (CBW) Street, AXA Group building and Waterfront City Docklands. Interviews were conducted through a structured open-ended questionnaire (Appendix A 2), and the results were discussed according to the 4 sections of the questionnaire (Section 3.2.2).

6.1.1 500 Collins Street

This is the first high-rise refurbished Central Business District (CBD) office building in Australia to achieve a Green Star rating, and demonstrates to the marketplace that existing stock can be upgraded to high Ecologically Sustainable Development (ESD) standards. The building achieved a standard of 'Australian Excellence' as symbolized by the 5 Star Green Star (Office Design v1) Certified Rating awarded in October 2006 by the Green Building Council of Australia (GBCA).

Figure 6.1: 500 Collins Street building
(Source: 500 Collins, 2007)

The Kador Group is the owner of the building and Bovis Lend Lease was the construction firm. The project was a staged upgrade of an occupied 28-level office building. The $35million building project was designed to accommodate approximately 25,000 square meters of office space, approximately 1,500 square meters of retail space and two basement car parking levels (500 Collins, 2007). The project was comprised of various parts, including the replacement of the major plant and equipment, reconfiguration of the car park, repair and upgrade of the façade, upgrade of the ground floor entrance, including lobby, lifts and retail areas, and the progressive upgrade of all office floors (GBCA, 2006). The sustainable function of this building comprises of good management, water, energy, indoor environmental quality, transport, low emissions of materials, and other innovations. The project was completed in 2010.

6.1.2 Melbourne Convention Centre (MCC)

The MCC is a new centre forming part of a public-private partnership project that completes the urban renewal of the Yarra River's edge, linking Southbank to Docklands. This 6 Star Green Star building covers an area of 66,000 square meters, with a total building cost of $480million (ANCR, 2009). The finished project consists of:

- A 5,000 seat Convention Centre
- A five-star Hilton Hotel
- An office and residential tower
- A riverfront promenade of retails shops, including cafes, bookstores and wine merchants
- Public spaces, including a revitalized maritime museum

Figure 6.2: MCC development
(Source: MCCD, 2008)

Construction was undertaken by Multiplex Constructions, with Plenary Group as developers and equity investors. Multiplex teamed up with Veolia (previously Collex), to help in the waste management effort. The project was scheduled for completion in 2009 (MECC, 2006). The building was officially opened for business on the 22nd of June 2009.

6.1.3 55 St Andrews Place, East Melbourne

This building was upgraded to achieve a target minimum 4 Star Green Star rating - a level equal to Australia's Best Practice. The $6.2million project covers an area of 6,200 square meters (Montlaur Project Services, 2010). Initiatives included:

- Improving air conditioning efficiency, cutting peak electricity consumption, and improving performance - including a more efficient chilled water system, upgrading the air handling plant, installing 'heat recovery' devices, and reconfiguring fresh air intake
- Lighting system upgrades, enhanced access to natural light, and de-lamping in over-lit areas
- Installing double glazing on the 4th floor, and external shading to the 1st, 2nd and 3rd level windows to cut winter heat loss and summer heat gain
- Improving roof and wall insulation
- Improving water efficiency by installing flow restrictors to taps and showers, installing waterless urinals, and a 25,000 litre rainwater tank
- Improving the indoor environment quality by improved material selection
- Increasing access and facilities for bike riders
- Destination control lifts, which are the first of their kind to be installed in Melbourne

Figure 6.3: 55 St Andrews Place
(Source: Cundall, 2007)

This project was expected to achieve a 48% reduction in annual energy consumption and 2760 tonnes of greenhouse gas emissions, and provide ongoing annual savings of over $115,000 (DSE, 2006). The building was occupied by the Department of Justice before being upgraded. The project was managed by Montlaur Project Services, a project management company. Schiavello was the construction company, and was also responsible for waste management plan on-site. The building upgrade has been completed.

6.1.4 Corner Bourke and William Street (CBW)

Construction and Building Industry Super (Cbus Property) have developed two new 5 Star Green Star rating A-Grade office towers, on the Corner of Bourke and William Street (CBW). The CBW has an area of 58,000 square meters, with a total project cost of $300million (ANCR, 2008).

181 William St, Melbourne

550 Bourke St, Melbourne

Figure 6.4: CBW building

(Source: Cbus, 2008)

The larger of the two office towers, 181 William Street located on the Bourke and William Streets corner of the site, is situated next to the leading insurer CGU, and was completed in September 2008. The design of the second office tower, 550 Bourke Street, has been finalized. Multiplex was the construction company for this project (Cbus, 2007). Some of the development's sustainable design and technologies include:

- Black water re-use systems and rain water collection systems
- Innovative glazing systems to maximize daylight and reduce heat gain and loss

- Intelligent lighting systems which respond to ambient daylight levels
- Use of recycled materials in the construction of the building

6.1.5 AXA Group building

Located on 750 Collins Street at Docklands, this building is the new international head office for AXA Asia Pacific group. The building consists of approximately 40,000 square meters of office space, 4,000 square meters of retail, and a car park that accommodates about 420 cars. The cost of the project was $ 250million (Grocon, 2008).

Figure 6.5: The AXA Group building

(Source: AXA Group building, 2008)

Construction was undertaken by Grocon, and Veolia was also responsible for waste disposal for this site. The new building's campus-style headquarters was completed in 2008.

6.1.6 Waterfront City, Docklands

Waterfront City is a $ 1billion urban development undertaken by ING Real Estate Development and located on 19 hectares within Melbourne Docklands.

Figure 6.6: An aerial view of the Waterfront city showing the observation wheel in the foreground

(Source: Waterfront city Docklands, 2007)

This study looked at the second stage development constructed by Hansen Yuncken, and completed in 2008. The second stage commenced in July 2006, and now offers a mix of retail, residential, commercial and entertainment, including over 41,000 square meters of retail shops.

6.2 Site findings: Best practice and barriers

The study found some best practices of C&D waste management at all six construction sites. It also found a number of critical barriers to good practice. Some of the projects had developed innovative solutions that could be applied to other construction sites. The site practices and the barriers to good recycling practice are discussed in the sections below.

6.2.1 Buy-in from sub-contractors and suppliers

The owners and developers of the six projects incorporated environmental objectives into their initial project planning, so assessment of tenders took account of the primary contractors' waste management strategies. Once the contracts were awarded, the primary contractors (both construction and project management companies) developed more specific and comprehensive waste management plans that included recycling targets. Table 6.1 shows the percentage of total waste that each project aimed to recycle.

Table 6.1: C&D waste recycling targets for the six construction projects

Project	Recycling target
AXA Docklands	85%
CBW	80%
Melbourne Convention Centre	80%
Waterfront City	60%
500 Collins Street	80%
55 St Andrews Place	80%

(Source: derived from various recycling target reports provided)

In some of the projects, responsibility for achieving the projects' environment objectives was assigned to sub-contractors and suppliers. For example, the primary contractors at 500 Collins street (Bovis Lend Lease), CBW, the MCC (Multiplex), and 55 St Andrews Place (Montlaur), all required their major sub-contractors to provide (before starting their work) waste minimisation and management plans for their respective scope of work (Appendix A7).

Bovis Lend Lease was quite specific in some of the required details for the sub-contractors' waste management plan. These included:

- Two practical measures associated with their works, to prevent waste entering the construction site
- Two waste streams resulting from their works, which can be recycled, and will be actively managed as part of their waste reduction plan
- Alternative products containing recycled material that could be utilized in their works, in place of more traditional materials, and which conform with and meet the design specification

6.2.2 Waste sorting

Conventional construction practice involves the builder merely hiring a waste management contractor to provide and haul away the bins. Such co-mingled waste has to be sorted prior to recycling, which adds a significant cost. If different types of waste can be kept separate, then the potential to reclaim value through recycling is significantly enhanced.

For example, at some of the six construction sites in this study, waste was sorted on site into different categories of C&D waste, to facilitate recycling and reduce landfill waste. Common C&D waste sorted for recycling include metals, particularly steel and copper wires, concrete, wood, timber, PVC pipes, cardboard and plastics. At all the six construction sites, separate bins were also provided for food waste (putrescible waste).

The extent of sorting is strongly influenced by the availability of space within the project's confines. The CBD projects in this study, including CBW and 500 Collins Street, did not have the luxury of space to allow for waste sorting. One large bin (averaging 12m^3 in size), was used for dumping all the construction waste. Separate bins were provided for recyclable or food waste. The bins were then hauled away by the waste contractor for off-site sorting, and ultimately recycling.

At 500 Collins Street, where one bin was generally provided for C&D waste, an additional bin was sometimes provided for specific materials when there was concentrated work involving a particular recurring waste material; for example, plaster or concrete. At AXA Docklands, there was also some degree of sorting.

MCC was able to comprehensively sort waste by providing colour-coded bins at collection points in site areas with major activity, because it had ample site space (Appendix A8, Figure A8.1). In addition, there were wheelie bins in strategic places for food waste. Figure 6.7 shows the layout of the MCC recycling compound.

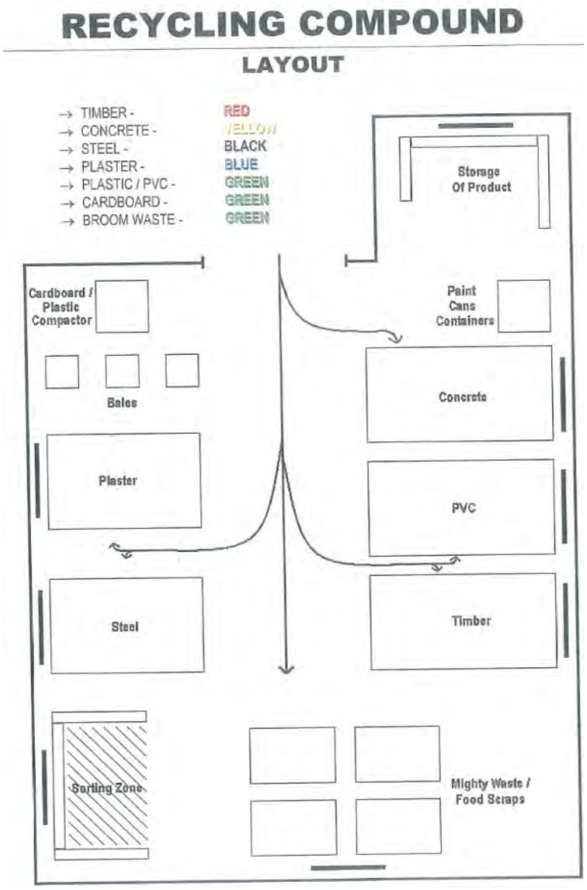


Figure 6.7: Layout of the recycling compound at the MCC site

The sorting procedure at the MCC involved sub-contractors stenciling their names to the appropriate bins, and when any of the bins were full, they were collected and taken into the recycling compound, where they were again dumped into larger, colour-coded bins.

The recycling compound included a sorting zone, where plastic, PVC, cardboard and other waste were further sorted. Cardboard and plastics were compacted and baled. Again, when any of the large bins were full, Veolia, Multiplex's waste management contractor, took it to recyclers.

Depending on the recycling company, Multiplex received a rebate for either the transport cost or the amount of recyclable material delivered, or both. Multiplex's analysis of waste movement and recycling during a three-month period in 2006, delivered an estimated $8,000 in net gain for the MCC project, generated from transport and product rebates, plus savings earned from not having to send material to landfill.

At AXA Docklands, wheelie bins were provided for cans, paper and cardboard, and a larger bin for co-mingled construction waste. In an innovative move, Grocon secured an agreement with CSR to collect plaster waste. Grocon provided the bin, but CSR, a major Australian manufacturer of construction materials, collected the bin two to three times a week, and transported it to an Altona depot, where gypsum was recovered from the waste.

At 55 St Andrews Place, despite its CBD location, construction company Schiavello applied lateral thinking to the waste sorting on-site. Instead of using bins, waste materials were sorted into neat stockpiles along one wall of the building being refurbished. Trucks had access to this side of the building, so when a pile reached an economic quantity for transport, the waste contractor collected it, and delivered it to the National Recycling Group's depot.

Schiavello explained that sometimes, the only thing that went to landfill sites was food waste. The company said it paid about $300 per tonne to transport C&D waste from the site to the different recyclers. To save on transport cost, some of the recyclable materials were sold on-site. For example, carpets were removed free of charge by a carpet company which saved time, space and transportation fees. Merton Demolition was the main waste collector from the site, which delivered the material to the National Recycling Group. Schiavello got some rebate from profits made from the sale of recyclable materials. The National Recycling Group also provided Schiavello with receipts showing the type and volume of materials recycled, as evidence that they did not end up in landfill.

6.2.3 Recycling reports

To track progress against their recycling targets, all the six companies required their waste contractors to provide monthly recycling reports. Typically, the reports showed the type and volume of waste materials that left the sites, the volume of waste recycled, and the amount that ended up in landfill. The documentation also supported the project's application for Green Star certification, and in the case of Waterfront City, for its performance rating under the Melbourne Docklands' ESD Guide.

Interestingly, Veolia Environmental Services acted as waste contractor for all but one of the projects in this study, and developed best practice reporting on site recycling. According to one of the project managers, Veolia's tender was not the cheapest, but it seemed to offer an optimal waste management strategy. Appendix A4 (Table A4.1) shows a sample of Veolia's periodic report for the MCC and CBW projects.

At AXA, the Master Builders' Association (MBA) audited all environmental operations on site, including Veolia's recycling reports. MBA auditors and Grocon's environmental manager for the AXA project also conducted random visits to the recycling facilities that received the waste collected from the site by Veolia. An MBA report describing how waste collected from the AXA site is sorted and recycled off-site is shown in Appendix A5.

At 55 St Andrews Place, the only project not using Veolia, each sub-contractor was required to submit a certified monthly report on the amount of materials recycled and re-used. Periodic contractual payments were made only if the sub-contractors achieved the recycling target.

Initially, the projects had to decide on a target. Based on the recycling reports, all six construction sites exceeded their recycling targets, as shown in Table 6.2. Indeed, simply setting a target seems to be the decisive issue. The lowest target set was that of Waterfront City at 60%, and yet it achieved the second highest recycling rate at 96%. Evidently, the setting of the target focused attention on recycling and the available opportunities simply presented themselves.

Table 6.2: Recycling achieved by projects

Project	Original recycling target	Recycling achieved (Based on a selected month's report)
AXA Docklands	85%	98% - Jan. 2007
CBW	80%	88% - Jan 2007
MCC	80%	92% - Jan 2007
Waterfront City	60%	96% - March 2007
500 Collins Street	80%	96% - March 2007
55 St Andrews Place	80%	90% - March 2007

6.2.4 Worker awareness

All the projects agreed that recycling targets were exceeded largely because of the diligence of on-site workers. However, they also observed that there was still room to improve workers' behaviour in terms of recycling practices, and thus achieve 100% recycling.

As a first step to achieving worker cooperation, site inductions for all six construction sites included an explanation of environmental objectives and waste management practices expected of workers, including recycling. Researchers for this study sat through one of these inductions at the MCC, where inductions were conducted every morning. The session was very detailed, covering all aspects of the waste management practices outlined in the project's waste management plan.

The MCC had extensive bin sorting practices and went to the extent of making it part of the workers' induction to sign a formal agreement to abide by the waste-sorting requirements. The agreement, which was signed by workers and witnessed by representatives of the sub-contractors and the prime contractor, lists the specific materials that needed to go into specific bins (Appendix A6).

At the MCC, a $1,000 penalty applied to sub-contractors whose employees were found to be dumping materials in the wrong bins. A 'sub-contractor-beware' policy was also at work at 500 Collins Street, where sub-contractors found to 'contaminate' bins were liable for the cost associated with tipping or sorting of waste. This applied, for example, when food waste was thrown into the general C&D waste bin, or construction waste was mixed with the food bins.

Despite the efforts at induction and the stick-approach, mixing of waste streams and contamination still occurred. Neither the MCC nor 500 Collins Street applied the penalties. However, at the MCC, an intermediate pre-penalty step had been applied several times, which helped enforce some behavioural change. This intermediate step was the Non-Conformance Report (NCR), which was served on sub-contractors whose employees had been found mixing up waste. A sub-contractor who received an NCR was then required to sort the mixed-up bin on-the-spot, before the bins were transferred to the main recycling compound.

Four NCRs were issued and according to the Multiplex site manager, one sub-contractor who initially ignored the sorting requirement repeatedly became the 'best recycler' among the on-site sub-contractors.

Figures 6.8 and 6.9 show examples of both good and bad practices at some of the sites visited. Figure 6.8 shows that steel has been disposed of in the correct bin, while Figure 6.9 shows how a bin for concrete waste has been mixed with other materials like plastics and cardboard. This is a typical example of a bin that will be rejected by the recyclers, unless it is first sorted. Recyclers also reject C&D waste that has been contaminated by putrescible waste. Figure 6.10 shows some labelled waste bins at the MCC construction site.

Figure 6.8: Steel correctly disposed of in the appropriate bin

Figure 6.9: Incorrect disposal of other waste in Concrete bin

Figure 6.10: Labelled bins at the MCC site

Waste mixing and contamination occur partly because of some workers' entrenched habits. A site manager noted that most of the older construction workers (45 years and older), found it more difficult to change their old waste disposal habits than their younger counterparts. He added that some workers were not motivated to go the distance, and would dump waste material in the closest bin, even if it was not the appropriate bin.

Another site manager said that the level of understanding and appreciation of recycling often depended on the nature of the workers' trades. For example, electricians and plumbers understand the financial gains achieved from recycling materials such as wires and pipes.

At 55 St Andrews Place, the site supervisor found that leading by example had helped change behaviour. For example, the contractor stopped providing disposable cups (for coffee and tea) and plates, which significantly reduced the amount of food waste sent to landfill. Because workers brought their own cups and plates that needed to be washed, the level of food contamination also declined considerably.

6.2.5 Waste minimisation and materials re-use

Besides setting recycling targets, waste minimisation was also a critical part of all the projects' environmental management plans. Most of the site managers said that there was considerable amount of packaging ending up in their bins and some of the companies had already incorporated this into their waste management plans. In some cases, sub-contractor contracts included an undertaking to minimise the packaging they brought onto the site, and to re-use off-cuts wherever possible in their work. This was the case with Multiplex at both the MCC and CBW sites, Bovis Lend Lease at 500 Collins Street, and Hansen Yuncken at Waterfront City.

In addition, Hansen Yuncken encouraged sub-contractors not to over-order materials, so residual material on the project was reduced. Just-in-time delivery of construction materials was also practiced to reduce storage on-site, and thus minimise potential loss or waste due to damage prior to usage.

There was extensive re-use of materials recovered from demolition at 55 St Andrews Place. Being a refurbishment, the deconstruction technique was applied, in which materials were systematically taken apart to salvage as much re-usable material as possible. For example, around 90% of door frames, glass, walls and work stations were re-used for the fit-out.

While 500 Collins Street was also a refurbishment, there was little material that was appropriate for re-use, so the more conventional method of demolition was used. Compared to the four-storey 55 St Andrews Place, 500 Collins is a 28-storey building, and would have made deconstruction less cost-efficient.

6.3 Site recommendations

Recommendations are discussed in this section and summarized in Chapter 10. Based on the findings from the projects in this study, the critical barriers to best practice of C&D waste recycling can be grouped into the following three categories:

- Poor worker awareness
- Slow diffusion of best practices across the building industry
- Lack of detailed information on the economic aspects of recycling

6.3.1 Poor worker awareness - changing worker behaviour

While acknowledging that worker attitude towards recycling has improved in the last three to four years, there is still some frustration from project developers and site managers that the message is not being acted upon by all workers. This is despite the site inductions conveying the message, and the penalties for sub-contractors who do not follow recycling procedures, even though the penalties have not yet been applied.

The attitude and motivation of workers toward innovation and change have been well studied in recent times. Many companies engage workers in the quest for continuous innovation through regular workplace meetings, where workers can feed back ideas for improving site practices. The benefits from this approach can be exceptional. Studies of such innovation have found that the practice can be used to facilitate improvement across a number of fronts, including cost reduction, quality control and accident prevention. The same techniques could be used to improve recycling practices as well.

Multiplex already undertook this practice to some extent on the MCC site, through its regular 'walking inspections' of the site with area supervisors, sub-contractor representatives and Occupational Health and Safety (OHS) officers. The primary focus of these inspections was identification of hazards, but they also identified breaches of recycling procedures, and could be used to search for other opportunities for improvements.

Sharing the rewards of business improvements with workers has also been shown to be a powerful motivator of behavioural change. The most advanced forms of these involve formal 'alliances', that share gains with all site participants, for example, the

Queensland University of Technology, (*Case-study of the Action Peninsula Development*).

It was recommended that reward schemes be put in place for workers that contributed immensely to the on-site waste management efforts.

Discussions with workers and management revealed that part of the difficulty of motivating workers to implement recycling procedures stemmed from their high levels of mobility between sites. Many sites do not observe recycling practices, and so the recycling message at sites that do value recycling loose credibility.

A consistent approach by the industry is needed to overcome this, in much the same way as minimum standards of OHS have become accepted across all sites. Such cultural change will take time, and the next sections of this chapter include recommendations for broader industry change. Discussions with unions and workers strongly suggest that concern for the environment is a major personal concern for workers, mirroring the rise in community concerns. As with the broader community, there is a disconnection between this concern, and the feeling of disempowerment over the impact of individual action.

It was recommended that demonstrations through short videos could be distributed across the industry during site inductions.

6.3.2 Diffusion of best practice to accelerate wider industry uptake

Of course, it is not only worker attitudes and behaviour that need to be influenced. The variation across sites that dims the credibility of the message is a result of employers who do not practice recycling. For the proposed induction video to have impact, it will need to be adopted as standard practice across the whole industry, as part of a broader industry campaign.

The six construction projects in this study are exceptional in that the companies involved are leaders in building waste management such as recycling practices. It was clear from discussions with companies that many sites did not attempt to recycle waste at all, so that overall recycling was limited to what could be achieved by separating co-mingled waste streams at the landfill sites.

It was recommended that a joint programme between the industry and the government be instituted, to highlight the benefits of recycling.

The theme of this information campaign should be based on the win-win-win situation for business, workers and the environment from waste management options such as recycling. It should be presented as a sustainable approach to business that leads to gains in long-term profitability. Potential worker engagement strategies proposed in Section 6.3.1 could also be promoted through the campaign as part of this sustainable business philosophy.

The key content of the information campaign should be based on the best practices evident among the companies participating in this study, and include:

- Examples of cost savings (Chapter 7) and waste reduction from companies, such as those included in Section 6.2
- Demonstrating the business advantages of monitoring and reporting waste management and recycling
- Encouraging a commitment to waste sorting
- Encouraging re-use of 'deconstruction' materials and use of recycled materials
- Promoting the business and waste reduction opportunities resulting from better scheduling of demolition, so that bins could readily be filled with a single waste stream; for example, all timber or all steel. This would reduce the volume of co-mingled waste, and thus the cost of off-site sorting and recycling
- Encouraging better planning and estimation of requirements for construction materials, to minimise oversupply and wastage

- Minimising packaging of materials, and where possible, completely eliminating packaging

The channels for this campaign should be through industry networks and associations, including seminars and supporting articles in industry and trade magazines. These promotions should 'throw' to a reference website, where practitioners could access specific information on tried and proven practices, such as those described in Section 6.2.

It was recommended that incentive programmes be set up to support innovative recycling programmes.

This could be modelled on Sustainability Victoria's Commercial Office Building Energy Initiative (COBEI), in which Sustainability Victoria matches a company's financial allocation for projects, aimed at achieving sustainable building design and practice. This could be managed under Sustainability Victoria's Waste Wise programme.

It was recommended that case-studies be used to promote the best practice within the building industry.

As with COBEI, the output of these projects could be written up as case-studies to replenish and advance the information campaign on the best practices. These case-studies should also focus on the business benefits of the waste minimisation and recycling initiatives so that other companies will follow suit. Documentation of these business benefits will also feed into a programme aimed at improving the understanding of the overall economic aspects of recycling.

6.3.3 Establish the economics of recycling

While the construction companies in this study are industry leaders, who believe that the best practices makes the greatest economic sense, no one had quantified the cost, or indeed the benefits, of the recycling strategies they had employed. The closest company that had come to quantification was Multiplex, who had a computation of rebates gained from recycling at the MCC site for a period of three months.

For all the six construction projects, the cost of recycling was not an issue; recycling was part of the corporate environmental objective, and was therefore not separately priced. However, most agreed that the requirement for the waste contractor to recycle instead of simply sending waste in landfill, added to the total cost. In all cases, the cost was built into the construction contractor's tender price.

It was recommended that subsidies and taxes be implemented whilst increasing landfill cost, to drive recycling across the building industry.

One area where the study could not get clarification was on the rebate system, which applied to the recycling of C&D waste delivered to recycling companies. Different companies got different benefits; some got a rebate directly from the recycler, some got a rebate from the waste contractor, and others got an offset on the cost of transport to the recycling station.

It was recommended that incentives and disincentives be identified, to minimise waste within the rebate system, and recommend changes that will drive best practice.

It was recommended that a cost-benefit analysis of recycling be conducted, building on this study, to track the path of C&D waste leaving a project site, including transport and other costs involved.

The analysis should examine both on and off-site sorting, and could use the projects in this study to gather data. The study could be done in partnership with waste management companies. Veolia, whose services were used by most big projects in Melbourne, expressed interest in collaborating on such a study. Veolia is planning to invest $60 million in building four new recycling stations throughout Melbourne, and will have a significant influence on the future economic aspects of recycling in Victoria.

This analysis should also be used to highlight areas for investigation, research and innovation. An early target should be in regards to concrete recycling, given that concrete accounts for over 82% of waste generated in C&D projects. Recycling of concrete for use in road construction is already common practice, and it would be beneficial to have further R&D aimed at the economic production of recycled concrete for building construction.

Some of the companies reported difficulty sourcing recycled concrete with the appropriate physical properties, and so the reasons for this should be investigated and compared with overseas practices, to identify opportunities for improvement in local operations.

Another area worth targeting is the innovations developed by projects in confined spaces, such as CBD sites. The lack of space is considered a key impediment by most companies, and while 55 St Andrews Place has managed to make progress in this area as noted in Section 6.2, research on this topic could potentially have a major impact across the industry.

6.4 Chapter summary and conclusion

This chapter discussed the social aspects of recycling that focused on the behavioural practices on-site that affect recycling, summarized in Table 6.3.

Table 6.3: Summary of the six construction site practices

Site Practices	Penalties	Rebates	Drivers and Barriers
Buy-in from sub-contractors and suppliers			• Developing of specific and comprehensive waste management plans • Waste management plans includes both contractors and sub-contractors
Waste sorting		Depending on the recycler – Rebates are given based on transport cost or quantity of materials sent for recycling	• Separate bin provision • Space on site • Stockpiling • Selling recyclables on-site
Recycling reports			• Green Star certification • Auditing by MBA • Terms of contract
Worker awareness	$1000 fine and NCRs project manager		• Site induction as condition of on-site work • Supervisors on-site initiatives • Wrong disposal in bins • Waste mixing and contamination
Waste minimisation and material re-use			• Minimising packaging on-site • Avoiding over ordering of materials

The study recommendations described in this chapter are summarized as follows:

- Reward workers who contribute to the on-site waste management efforts
- Use and distribute short demonstration videos during site inductions across the building industry
- Highlight the benefits of recycling, through a joint programme between the industry and the government
- Set up incentive programme to support innovative recycling programmes
- Use case-studies to promote the best practices within the building industry
- Implement subsidies, and taxes whilst increasing landfill cost, to drive recycling across the building industry
- Identify incentives and disincentives, to minimise waste within the rebate system, and recommend changes that will drive best practice

- Conduct a cost-benefit analysis of recycling, building on this study, to track the path of C&D waste leaving a project site, including transport and other costs involved

The study involved six construction sites. Construction sites could improve waste management in three areas. Areas identified included waste creation reduction, waste re-use, and the use of C&D waste recycled materials.

Reduced packaging and waste minimisation strategies are crucial to keeping waste creation under control. During refurbishments, there are always opportunities for re-use if deconstruction is carried out. The challenge for construction sites in this respect is to use as much of the C&D recycled materials as possible. Waste creation reduction and re-use are not always possible, so recycling is employed.

To a large extent, C&D material recyclability depends on how well waste is sorted on-site. The steps taken by those responsible for waste management on-site, contributes significantly to recycling efforts. The six construction companies have initiated some good practices that should eventually become common practice. This can be achieved if the best practices are adopted at all construction sites. This means that the need to recycle should not be an option, but part of every C&D site practice, whilst barriers realised should be minimised or avoided. The option of not recycling has severe consequences. The next chapter discusses cost impacts for recycling, landfill disposal and virgin gravel production, whilst the implications of the results in this chapter are discussed in Chapter 9 (Section 9.2).

7 ECONOMIC IMPACT OF RECYCLING REINFORCED CONCRETE AND BRICKS

Although some construction and recycling companies have records to help keep track of quantities that are recycled or disposed of, the impacts of costs and benefits are most often hidden, and might be initially overlooked as a major contributor to the overall cost analysis of a project. The recycling cost analysis involves capital cost such as the acquisition and maintenance of land, building, machinery, whilst the operational costs includes transport (fuel), energy (electricity), administration and technical staff costs, which are incurred by the recycler. Some of these cost parameters are analysed in subsequent sections of this chapter. Due to the unavailability of data on administration costs, crushing plant, and other miscellaneous activities for 'commercial in confidence' reasons, this study acknowledges that not all cost and benefit parameters could be calculated for RC and brick scenarios studied. Consequently, the capital and operational cost inclusions and exclusions for this study have been outlined for clarity. This study also makes reference to cost parameters considered for a similar cost study in Queensland by Tam (2008), where appropriate. Cost data was collected in 2008, and Appendix A11 contains all calculation tables used in this chapter.

7.1 Cost framework

The cost calculation in this study is made up of the capital and operational costs. This section outlines the various cost parameters that make up the capital and operational costs for recycling, landfill disposal and virgin gravel production. Although there was insufficient data for all cost parameters in this study, it is advised that these are included in every waste management cost analysis, to determine the actual overall cost.

7.1.1 Capital cost

The capital cost involves money invested in the setup and maintenance of buildings, land, machinery, trucks used in recycling, landfilling and virgin gravel production. Table 7.1 outlines the capital cost parameters included or excluded from the cost analysis in this study. The cost parameters with sufficient data have been included from this study, whilst cost parameters with insufficient data have been excluded.

Table 7.1: Capital cost parameters for RC and Brick recycling, landfill disposal and virgin Gravel production

Cost parameters	Included	Excluded
Recycling costs for RC and Bricks		
Land and building	-	*
Sorting Process and Excavation	-	*
• Equipment	-	*
• Working capital	-	*
• Equipment maintenance	-	*
• Fixed overhead		
Crusher cost	*	-
Manual removal of contaminants	-	*
Washing, screening or air-sitting	-	*
Landfill disposal costs for RC and Bricks		
Truck for transporting waste	-	*
Virgin Gravel production		
• Crusher cost	-	*
Stripping, blasting, sorting process, crusher cost, shaper, and washing, screening or air-sitting		
• Land and building	-	*
• Equipment	-	*
• Working capital	-	*
• Equipment maintenance	-	*
• Fixed Overhead	-	*

(Source: Adapted from Tam 2008 and modified)

The capital cost parameters included for the recycling analysis is the crusher cost, however, all other parameters are excluded from this study. This cost calculation also excludes capital cost parameters for the truck used to transport the waste to the landfill site and all parameters for virgin gravel production.

7.1.2 Operational cost

The operational cost results from the various processes involved in the recycling, landfill disposal, and virgin gravel production. Table 7.2 outlines the operational costs included or excluded from the cost analysis in this study. Most of the costs incurred during the recycling process are included in the calculations except for the labour cost for stockpiling and the manual removal of contaminants. All cost for landfill disposal was included in the cost analysis. For virgin gravel production, all parameters were excluded from the cost analysis.

Table 7.2: Operational cost parameters for RC and Brick recycling, landfill disposal and virgin Gravel production

Cost parameters	Included	Excluded
Recycling costs for RC and Bricks		
Haulage fee	*	
Stockpiling – Labour	-	*
Sorting Process and Excavation • Labour (technical staff and administration costs) • Fuel (machinery and transport)	 *	 *
Crushing process (Primary crushing, Magnetic separation, Secondary crushing) • Labour • Electricity (machinery) • Water • Fuel (machinery and transport)	 * * * *	 - - - -
Manual removal of contaminants • Labour	 -	 *
Washing, screening or air-sitting • Water • Fuel (machinery)	 * *	 - -
Landfill disposal costs for RC and Bricks		
Haulage fee	*	-
Landfill tipping fee	*	-
Fuel for transporting waste	*	-
Landfill site activities such as landfilling	-	*
Virgin Gravel production		
Stripping, blasting, sorting process, crusher cost, shaper, and washing, screening or air-sitting • Labour • Fuel • Electricity • Water	 - - - -	 * * * *

(Source: Adapted from Tam 2008 and modified)

7.2 Cost analysis for Reinforced Concrete and Bricks

This section analyses the cost related to recycling that influences the selling of RCC and RCB within the building industry. The costs are calculated for the four RC scenarios and two brick scenarios earlier discussed in Chapters 4 and 5.

7.2.1 Operational cost – Reinforced Concrete

Cost parameters for the RC and brick cost analysis include:

- Landfill disposal cost – \$67 per tonne
- Electricity cost – \$0.29 per kilowatt hour
- Water cost – \$1.11 per kilolitre
- Fuel cost (machinery and transport) – \$1.11 per litre
- Truck and labour cost – \$6 per kilometer

The average cost of RC and brick per tonne disposed to landfill was calculated at \$67. It was assumed that 1000 tonnes of RC and brick waste (C_0 and B_0) not recycled was sent to landfill.

Electricity costs were calculated as kilowatt hours (kWh) for the four RC scenarios (Table 4.5). The price of electricity used was based on the service provider for the Laverton recycling plant, where AFG data was collected hence, a costing rate of 29 cents per kWh was used in the cost analysis. AFG works from Monday to Friday peak period, and therefore, the commercial D tariff for peak period was used. There was no electricity use for the landfill (C_0) scenario, since all waste went directly to landfill, and no further processing was done. Appendix A11, Table A11.1 shows the electricity cost for the four RC scenarios.

The main water company responsible for the Laverton area is City West Water, and a water cost of \$1.114 per kilolitre was used in the analysis. Water was used in dust reduction, and moisture content adjustment. There was no water use for the RC landfill scenario (C_0), as landfill site activities were not calculated. Appendix A11, Table A11.3 shows water cost for the four RC scenarios.

Fuel cost calculations included diesel used in machinery on-site, and in transport. The RC waste quantity transported for recycling, distance traveled and diesel used in machinery, were the main factors considered for the calculation of fuel cost. Fuel cost for transporting waste in landfill was calculated, but there was no cost for fuel use in machinery, because the activities at landfill sites were not considered since, it was assumed no further processing of RC was carried out. Fuel cost was calculated at $1.112 per litre, based on the Victoria Transport Association (VTA). Unit prices were determined in close consultation with AFG. Appendix A11, Table A11.2 shows fuel costs for machinery and transport.

Truck and labour cost was included in the cost of transport at $6 per kilometer. The allocation of truck and labour cost per kilometer consisted of drivers wages (45%), repair and maintenance (12%), fuel and oil (17%), miscellaneous (1%), and depreciation (20%). The allocations were included in the transport calculation (Appendix A11, Table A11.4). The use of the 12-tonne 'hook-lift' truck increased transport cost, due to the number of trips required to transport a 1000 tonnes of RC to the recycling plant. Table 7.3 summarizes the total cost for each of the four RC scenarios. Though the distance to landfill was shorter, the use of diesel for the trip to landfill increased the cost of fuel for the landfill scenario (C_0).

The cost of recycling 1000 tonnes of RC (C_1) was about a third of the cost of disposing 1000 tonnes of RC (C_0) in landfill as summarized in Table 7.3. There was significant cost savings for the RC recycling scenario (C_1). A standard haulage fee was charged for the usage and removal of the 12-tonne waste bins from the project site. The haulage fee for the landfill (C_0) and the recycling (C_1) scenarios were the same ($24,900) since, 1000 tonnes (100%) of the RC waste was either hauled to the landfill site or the recycling plant. The tipping fee ($66,732) for disposing RC in landfill was the most significant cost for the RC landfill scenario (C_0), and the fuel cost to landfill ($724) was the highest of the RC scenarios. The total costs for the three recycling scenarios (C_1, C_2, and C_3) were lower than the landfill disposal cost (C_0). Appendix A11, Tables A11.1-A11.5, and A11.7 shows the calculations for Table 7.3.

Table 7.3: Operational costs for four 1000 tonne RC scenarios

Haulage fee to recycling plant/ landfill site ($)	Transport fuel cost to recycling plant ($)	Electricity cost ($)	Diesel use in machinery cost ($)	Water cost ($)	Tipping fee at landfill site ($)	Transport fuel cost to landfill ($)	Total for each scenario ($)
Cost for landfilling 1000 tonnes of RC ($C_{0,}$ 100%)							
$24,900	0	0	0	0	$66,732	724	**92,356**
Cost for recycling 1000 tonnes of RC ($C_{1,}$ 100%)							
24,900	3,618	793	900	113	804	9	**31,137**
Cost for recycling 970 tonnes of RC ($C_{2,}$ 97%)							
24,300	3,531	769	873	110	2,412	29	**32,024**
Cost for recycling 800 tonnes of RC ($C_{3,}$ 80%)							
20,100	2,920	634	719	91	13,668	151	**38,283**

7.2.2 Operational cost – Bricks

The same unit prices for RC (outlined in Section 7.2.1) were applied to the cost analysis for bricks. These included:

- Landfill cost – $67 per tonne
- Electricity cost – $0.29 per kilowatt hour
- Water cost – $1.11 per kilolitre
- Fuel cost (machinery and transport) – $1.11 per litre
- Truck and labour cost – $6 per kilometer

The cost was calculated for 1000 tonnes of brick waste, where 100% brick waste was disposed in landfill (B_0), and 100% of brick waste was recycled (B_1). Table 7.4 shows the total cost for the two brick scenarios. The cost of fuel used in transport and machinery was calculated for the brick recycling scenario (B_1). However, there was no machinery fuel use, and therefore no cost for the landfill scenario (B_0). Electricity and water cost was only calculated for the recycling scenario (B_1). The cost of tipping at landfill (B_0) was higher ($66,732), compared to the haulage fees ($24,900). The haulage fees ($24,900) were the same for both scenarios (B_0 and B_1), because 1000 tonnes of brick waste was either hauled to the recycling plant or landfill site. There was no brick waste disposed to landfill for the recycling scenario (B_1), and thus, no landfill related charges were incurred. The total cost of recycling bricks (B_1) was $29,419 compared to a higher landfill disposal (B_0) cost of $92,356. Calculation tables are shown in Appendix A11 (Table A11.6).

Table 7.4: Operational cost for two 1000 tonne Brick scenarios

Haulage fee to recycling plant/ landfill site ($)	**Transport fuel cost to recycling plant ($)**	**Electricity cost ($)**	**Diesel use in machinery cost ($)**	**Water cost ($)**	**Tipping fee at landfill site ($)**	**Transport fuel cost to landfill ($)**	**Total for each scenario ($)**
Cost for landfilling 1000 tonnes of Brick ($B_{0,}$ 100%)							
$24,900	0	0	0	0	$66,732	724	**92,356**
Cost for recycling 1000 tonnes of Brick ($B_{1,}$ 100%)							
24,900	2,713	793	900	113	0	0	**29,419**

In conclusion, the cost incurred for RC and bricks (C_0 and B_0) disposed to landfill implied that it was cheaper to recycle (Tables 7.3 and 7.4). The results indicated that there was a high landfill cost ($92,356) for both scenarios (C_0 and B_0) compared to the RC and brick recycling scenarios (C_1 and B_1). Appendix A11 (Table A11.7) shows the tipping and fuel costs calculations for the landfill disposal scenarios (C_0 and B_0).

7.2.3 Capital cost – crusher cost

The type of equipment used affects waste treatment alternatives, costs, and environmental impact. Bohne et al., 2008 states that "*the eco-efficiency of future waste management strategies is highly dependent on exploring the aggregated cost and environmental impacts of different end-of-life treatment alternatives*". The end-of-life treatment alternative of recycling was investigated, to identify the environmental and economic aspects that are crucial to implement efficient waste management strategies. The environmental analysis in Chapters 4 and 5, focused on input variables such as energy use (electricity & diesel) of the crusher, during the end-of-life option of recycling, whilst Tables 7.3 and 7.4, showed the operational cost of using the input variables in recycling RC and brick waste.

The crusher is the machinery used during the process of recycling RC and brick C&D waste (Section 4.3.1). The sorting of materials, on or off-site, manually or mechanically, is carried out before the crushing process. The crusher is also used to break down quarried stone into virgin gravel. Three types of crushers are most commonly used for recycling RC and bricks. These crushers could be used together or separately, depending on the choice of the material sizes. They include:

- Jaw crusher – for boulders/coarse aggregates (usually used as a primary/initial crusher)
- Impact crusher - crushes into medium sized particles
- Cone crusher – crushes into small/fine sized particles

As outlined in Table 7.1, the crusher cost was the only capital cost used in the cost calculations for the RC and bricks (C_1 and B_1), and virgin gravel production. It is assumed that the same type of crusher was used to recycle RC and bricks, and crush quarried stone into virgin gravel.

In determining the capital cost of the crusher, the crusher capacity was calculated as the annualized cost of equipment divided by the production tonnage per annum. In close consultation with AFG, it was estimated that a crusher with a 500-tonne-an-hour capacity, would cost about $10 million. The interest rate on the crusher was estimated to be a fixed 8% of the capital cost per annum, for a period of 10 years. Thus, the total annualized cost of the crusher was $1, 463,415 million, whilst the total production tonnage per annum for RC and bricks per annum was 650,000 tonnes. The capital cost of the crusher per annum was $2,250 for crushing 1000 tonnes of RC and 1000 tonnes of bricks (Appendix A 11, Section A11.4 shows more detailed calculations for the crusher).

7.3 Recycling benefits for Reinforced Concrete and Bricks

In this study, the income (benefits) from recycling includes the price for depositing waste to the recycling plant, the selling of the RCC/RCB, and steel waste. An effort by AFG, to increase incoming waste quantities for recycling, meant that they did not charge for receiving the waste, during the time of data collection, however, AFG provided the estimated amount charged across the recycling industry for depositing concrete and brick waste for recycling, and landfill disposal (Table 7.5).

Table 7.5: Price of depositing waste for recycling and landfill disposal

Products	$ (2008)
Charge for receiving clean concrete and bricks (per m^3)	8-17
Charge for receiving mixed loads (per m^3)	15-25
Disposal in landfill (per tonne)	67

(Source: AFG, 2008b - recycling industry estimation)

The cost of recycling clean concrete and bricks was found to be significantly cheaper than the cost of disposing a 12-tonne load of waste in landfill. The charge for depositing mixed loads to the recycling plant was higher than the price of accepting clean waste. The high price charged for depositing mixed load takes into account the cost of labour needed to sort out the waste. Similarly, most of the construction sites studied in Chapter 6 also revealed that higher fees were charged when waste was mixed. This encourages prior sorting, and appropriate waste disposal practices on-site.

AFG also provided the estimated selling prices for RCC, RCB, and recovered steel waste across the industry (Table 7.6). The prices included consideration for client specifications, costs, and bulk-buy concessions.

Table 7.6: Selling price per tonne of RCC/RCB and Steel

Products	$ (2008)
Selling class 4 (RCC/RCB)	10-15
Selling class 2&3 (RCC/RCB)	15-20
Selling price for recovered steel	100

(Source: AFG, 2008b) **NB:** Various class mixes are explained in Section 6.3.1

In Tables 7.5 and 7.6, the charge for depositing concrete (includes RC) and brick waste, ranged between \$8 and \$25, and the selling price ranged between \$10 and \$20 respectively. The depositing charge for RC and brick waste, and selling prices for RCC and RCB, were considered as sources of income for the recycler. An industry standard conversion factor for RC waste of $1m^3$ being equivalent to 1.2 tonnes, has been used in the analysis to calculate the income, for example, 1000 tonnes is equivalent to $833m^3$ of RC waste (Table 7.5). In Table 7.7, the income from recycling 1000 tonnes of RC and bricks is calculated, based on the minimum and maximum charges for depositing and selling RC and bricks from Table 7.5 and 7.6. Recycling income is calculated as a sum of the income from depositing RC and brick waste, and income from selling RCC/RCB.

Table 7.7: Income for recycling 1000 tonnes of RC and Bricks

Charges	Income from depositing waste ($)	Income from selling ($)	Total income from depositing and selling ($)
RC (C_1)			
Minimum	6,664	10,000	***16,664***
Maximum	20,825	20,000	***40,825***
Bricks (B_1)			
Minimum	6,664	10,000	***16,664***
Maximum	20,825	20,000	***40,825***

The results in Table 7.7 showed that the total minimum income for recycling 1000 tonnes of RC and bricks was $16,664, whilst the total maximum income from depositing and selling RC and bricks was $40,825. The significant difference in the total minimum and maximum income from recycling RC and bricks (C_1 and B_1) indicated that the charge for depositing RC and brick waste, and selling RCC/ RCB was a major contributor to recycling income. The results imply that to increase recycled RC and brick quantities, the maximum price should be charged. On the other hand, there could be a decrease in the production of C&D materials like RC and bricks, if the minimum charged is applied. Clearly, the income from depositing waste and selling RCC/RCB, are very important to the overall economics of recycling, and should be compared to the price of disposing waste in landfill.

7.4 Costs and benefits comparisons

This section compares the cost and benefits of recycling RC and bricks, virgin gravel production, and landfill disposal (RC and bricks) for this study. The overall costs results presented only represents the costs and benefits for the available data, therefore, other cost parameters outlined in Tables 7.1 and 7.2 should be considered to determine actual total costs and benefits. This study acknowledges that there are other input and output data that could not be obtained for the cost analysis.

For this study, Table 7.8 shows the costs and benefits comparison of 100% RC and brick recycling (C_1 and B_1), 100% landfill disposal of RC and bricks (C_0 and B_0), and virgin gravel production. 1000 tonnes of RC and brick was either recycled, disposed to landfill, or alternatively virgin gravel was produced. The same unit prices for electricity, water and fuel were used for virgin gravel production, as it was for RC and brick (C_1 and B_1) recycling, because the crusher was assumed to be operated at the same capacity for both crushing processes. The RC and brick recycling results (C_1 and B_1) indicated that the total cost of recycling was still about a third of the landfill disposal cost (C_0 and B_0) as shown in Table 7.8.

The cost savings gained by not disposing of waste to landfill, and selling recovered steel, was calculated as a benefit to the recycling process. However, the cost per tonne for selling virgin gravel was estimated to be $25, which was still $5 more than the maximum cost per tonne for selling RCC and RCB ($20). The benefits of the avoided processes should be considered with RCC and RCB use (Table 7.8). The cost savings from recycling 1000 tonnes of RC and bricks was over $62,000.

Table 7.8: Costs and benefits comparison for RC and Bricks (1000 tonnes)

Cost	Recycling 100% RC (C_1) ($)	Recycling 100% Bricks (B_1) ($)	Landfilling 100% RC and Bricks (C_0 and B_0) ($)
Collection/depositing of waste			
Haulage fee	24,900	24,900	24,900
Tipping fee	804	-	66,732
Transporting to recycler/landfill site			
Fuel cost to recycling plant (Transport)	3,618	2,713	-
Fuel cost to landfill	9	-	724
Resource inputs used in crushing			
Water	113	113	-
Electricity	793	793	-
Fuel cost at recycling plant (Machinery)	900	900	-
Cost results	**31,137**	**29,419**	**92,356**
Benefits from 'avoided processes' in RC recycling (C_1)			
Steel sold at $100/t for 20 tonnes ($)		Landfill avoided cost ($)	**Total ($)**
2000		92,356	**94,356**
($) Benefit of RC recycling (C_1)*			
94,356 – 31,137 = 63,219			
Benefits from 'avoided processes' in Brick recycling (B_1)			
Steel sold at $100/t for 20 tonnes ($)		Landfill avoided cost ($)	**Total ($)**
-		92,356	**92,356**
($) Benefit of Brick recycling (B_1)*			
92,356 – 29,419 = 62,937			

*** The benefit calculation is based on incomplete costing as earlier explained in introduction chapter**

In Table 7.9, the cost of RC and bricks recycling and landfilling was calculated as the sum of the capital and operational cost. The total minimum and maximum income gained from recycling RC and bricks, is the sum of the income calculated in Table 7.7 and the income from the avoided processes (Table 7.8). For example, the minimum income from RC recycling (C_1) was $16,664 and the cost savings from the avoided processes was $63,219, therefore the minimum income from recycling was $79,883 (Table 7.9).

The summary of the costs and benefit results indicated, for example, that the minimum income from RC recycling ($79,883) was lower than the landfill disposal cost ($92,356). On the other hand, the maximum income from recycling RC and bricks was higher than the cost of landfill disposal. This implies that the maximum charge makes recycling economically viable, especially since the maximum selling charge per tonne of RC and bricks ($20) is still less than the cost of depositing waste to landfill ($67), and selling a tonne of virgin gravel ($25). The cost savings from the 'avoided processes' (Table 7.8), significantly increased the monetary benefits of recycling, irrespective of the charge applied for depositing RC and brick waste, and selling RCC or RCB.

Table 7.9: Total costs and benefits for RC and Bricks (1000 tonnes)

Costs			
Process cost	**($) RC recycling cost ($C_1$)**	**($) Bricks recycling cost (B_1)**	**($) Landfill disposal for RC and bricks (C_0 and B_0)**
Capital cost – Crusher cost	2,250	2,250	-
Operational cost	31, 137	29,419	92,356
Total recycling cost	**33,387**	**31,669**	**92,356**

Total benefits of RC recycling (C_1)		
	Minimum ($)	**Maximum ($)**
RC recycling income (depositing and selling)	16,664	40,825
Additional benefit from 'avoided processes'	63,219	63,219
Total recycling benefit	**79,883**	**104,044**
Total benefits of Brick recycling (B_1)		
Brick recycling income (depositing and selling)	16,664	40,825
Additional benefit from 'avoided processes'	62,937	62,937
Total benefit	**79,601**	**103,762**

7.5 Chapter summary and conclusion

The recycling costs for RC and bricks were comparatively cheaper than landfill disposal of RC and bricks. Clearly, the cost savings of recycling far outweighed landfill disposal, and virgin gravel production. However, the results in this cost analysis could not be considered entirely conclusive due to insufficient data for some of the cost parameters outlined in Section 7.1.

The pricing of recycled products like RCC and RCB, determined the income from recycling, but the cost savings from charging the minimum or maximum prices should be compared to the alternative of landfill disposal. From the data obtained, the selling price per tonne of virgin gravel remained higher than the selling price for RCC/RCB, and there was significant cost savings from recycling compared to landfill disposal. The cost analysis for the waste management option of recycling should consider cost and benefits in their entirety. Therefore, it is suggested that where a cost analysis is required to determine the most effective waste management option, the input and output variables outlined should be considered (Tables 7.1 and 7.2).

Undoubtedly, the results from this chapter's cost study indicated that the benefits from recycling cannot only be determined by analysing the cost of recycling, as other factors such as the 'avoided processes' of landfill disposal and steel production, have to be considered. The potential to reduce the quantity of C&D waste materials such as RC and bricks disposed in landfill will be dictated by market forces such as the tipping fees, and the overall cost of landfill disposal.

The next chapter discusses some of the waste legislation that influences recycling, and the use of C&D recycled materials. The proposed improvements from this chapter's findings are discussed in Section 9.3.

8 GOVERNANCE – ORGANISATIONS INFLUENCING C&D RECYCLED MATERIALS USE

Building sustainably involves an effective waste management plan. Waste management plans should be based on waste legislation that promotes C&D waste recycling and recycled materials use. Seven major organisations that have influenced C&D recycled materials use through product certification, in this chapter include:

- Green Building Council Australia
- EPA Victoria
- Building Commission
- Australian Building Codes Board
- Australia Green Office
- Australian Green Procurement
- VicRoads

In the last decade, new construction companies have opened, and with these, new practices have been introduced. Hence, these organisations have been empowered with tools that could continue to shift C&D recycled material use trends in the right direction. These tools directly or indirectly impact on such trends. Some of their measures are discussed next.

8.1 Green Building Council of Australia (GBCA)

Green Star recognition is awarded by the Green Building Council Australia (GBCA). The GBCA performance indicators are based on the principles of two widely recognised international tools: the British Building Research Establishment Environmental Assessment Method (BREEAM), and the North American Leadership in Energy and Environmental Design (LEED). These two international tools were also referenced in the development of the GBCA's Green Star tool.

GBCA[33] has played a major role in ensuring that most commercial buildings that apply for the Green Star ratings, meet the eight criteria[34] plus innovations points awarded where applicable. The nine criteria are divided into credits, each of which addresses an initiative that has the potential to improve environmental performance. Points are awarded in each credit, for actions that demonstrate that construction projects have met the overall objectives of Green Star. Once all claimed credits in each category are assessed, a percentage score is calculated and Green Star environmental weighting factors are then applied. These environmental weighting factors vary across states and territories, to reflect diverse environmental concerns across Australia. The credits reward reduction, re-use, the use of C&D recycled materials, and recyclable building materials wherever possible (GBCA, 2009).

In the GBCA requirements for achieving a Green Star rating, the 'Materials'[35] category consists of credits, which target the consumption of resources through selection, use, re-use, and efficient management practices of building and fit-out materials. The 'Materials' category currently encourages the recycling of concrete, steel and timber, and has the third highest points rating (20 points) after Indoor Environment Quality (27 points), and Energy (24 points).

The Green Star certification includes the 4 Star rating, which represents 'Best Practice', 5 Star rating for 'Australian Excellence', and 6 Star rating for 'World Leadership'. In the past decade, some government buildings have joined the building 'green' campaign, by leading the way themselves. One such example is the recently completed Council House 2 (CH2) in Melbourne (2006), which is the first Australian 6 Star rated office building. Builders and owners of green offices like Multiplex, Lend Lease, and Grocon, have welcomed the increasing tenant demand for 'green' offices. Victoria currently has

[33] The GBCA is a non-profit organisation run by some of the major players in the industry. It seeks to develop a sustainable property industry for Australia and drive the adoption of green building practices through market-based solutions. It was launched in 2002 (GBCA, 2007b).
[34] The 8 criteria include Management (12 points), Indoor Environment Quality (27 points), Energy (24 points), Transport (11 points), Water (13 points), Materials (20 points), Land Use & Ecology (8 points) and Emissions (14 points) plus Innovations (5 points)
[35] It states "*Aim is to facilitate the recycling of resources used within offices to reduce construction waste going to landfill*" for which points are awarded if provided (GBCA, 2007a).

two 6 Star offices, namely CH2, and Szencorp (the first office refurbishment to obtain a 6 Star rating in Australia).

More than 2,500 building permits are issued each year, and there are more than 4,500 sites in the City of Melbourne where there is some kind of excavation, building or demolition activity (Waste Wise, 2002). In the last two years, an important driver for increasing recycling has emerged with the growing market demand for sustainable buildings. In particular, the high end of the commercial property market has shifted strongly toward 'green' building. In a recent article, Mr. Tony Arnel, the Building Commissioner, cited property valuers' reports that public concern about sustainability was evident in property valuations, with most action in the Premium and "A" Grade sector of the market. Corporate and professional services tenants in this market segment were willing to pay a premium for 'green' offices (Property Australia, 2007).

Tenant demand for green offices is underpinned by major companies' rising conviction of the need to promote a "green brand", and to demonstrate their environmental responsibility to customers, and shareholders. Property owners and developers are moving to service this emerging demand. Indeed, the property owners, construction companies and consultants in the construction sites' study, were among the leaders in the 'sustainable building' market. They believe that new buildings and refurbishments that do not deliver good environmental performance will not hold their long-term value, because corporate tenants are increasingly demanding 'green' offices. For a building to be recognised as 'green', the developer needs to maintain and monitor sustainable practices, including waste minimisation, and recycling. This is why under the GBCA's Green Star rating system, projects that recycle C&D waste, and use recycled building materials, can earn points towards Green Star certification. The GBCA Green Star rating impacts directly on the recycling industry. This could be a key to increased C&D recycled materials use.

All but one of the six construction sites studied in Chapter 6 (500 Collins Street, 55 St. Andrews Place, Melbourne Convention Centre, AXA building, Corner Bourke and Williams (CBW) street building, and Waterfront City Docklands), aspired to have their buildings certified under the GBCA's Green Star rating system. 500 Collins Street, refurbished in stages, was already a certified 5 Star Green Star building, becoming the first tall commercial building in Australia to be so certified. The Melbourne Convention Centre attained 6 Star rating, which only a few buildings have achieved including the earlier mentioned iconic CH2 building (the City of Melbourne's new headquarters on Little Collins Street). 55 St Andrews Place worked towards a 4.5 Green Star rating, but the construction contractor, Schiavello, was hopeful that a 5 Green Star rating was achievable on the project. The AXA and CBW projects achieved a 5 Green Star rating (Office Design v2). Waterfront City was planned and the contract awarded before the Green Star tool was developed, but the project is covered by the Melbourne Docklands ESD Guide, which sets performance indicators for building design and performance.

8.2 Environmental Protection Agency, Victoria (EPA Victoria)

EPA Victoria continues to work closely with institutions like Sustainability Victoria, the Regional Waste Management Groups, and the Ministry of Environment, in areas of waste management. EPA Victoria acts as a legislative body on waste issues such as landfill, transporting waste, and on disposal of various kinds of waste. EPA Victoria is also actively involved in the recycling and purchasing of recycled materials through programmes like the Life-Cycle Management (LCM). EPA Victoria’s LCM programme is identified as a tool that could help businesses improve their eco-efficiency, ecological footprint, product stewardship, Life-Cycle costing, and supply chain management in production and services (EPA Victoria, 2008a).

EPA Victoria (2008a) acknowledges that a key component of the LCM programme is supply chain management, which is driven by consumer demand for product information, and corporate purchasers' needs to identify and reduce product or reputation risk. In the building industry, both public and private sectors have identified the need to build sustainably. In the public sector, the Victorian Government now requires that new office buildings leased or built by the Government; meet Australian Best Practice benchmarks for sustainability, and environmental standards (EPA, 2008a). In the private sector, businesses have made efforts to apply the LCM to keep up with industry's demand for 'green' buildings, and stay ahead of the competition. Adopting LCM creates an avenue for consumer to be informed about the benefits of sustainable purchases. According to the EPA (2008a), the LCM ensures that producers provide consumers with sustainable products, resulting in a global trend from consumers to incorporate environmental considerations into their purchasing decisions. This provides an opportunity for producers to promote their products and services as environmentally preferred. It is important that recycled materials maintain a certain quality, durability, and have less environmental impact, whilst meeting consumer demand. LCM has been successfully applied in the promotion of new products, and should be extended to recycled materials. To effectively disseminate product information across the building industry, and reduce product or reputation risks, product manufacturers need to be transparent about benefits to the environment, through avenues such as product endorsement.

The EPA's contribution to recycling and C&D recycled materials use is in direct partnership with various organisations. EPA Victoria continues to be in partnership with the industry through Environmental and Resource Efficiency Planning (EREP), Sustainability Covenants, Resource Efficiency[36] improvements, and Environmental Management Plans (EMP). The major EPA partners include schools, manufacturing and distribution companies, recyclers and construction companies.

8.3 Building Commission (BC), Victoria

Sustainability is at the forefront of the building industry. BC[37] is one of the major influential bodies within the industry, and has amongst its duties the power to accredit building products, construction methods, designs, components, and systems associated with building (Building Commission, 2008). The BC has regulations and acts such as the Building Act 1993, the Building Regulations 2006, and the Building Code of

[36] Resource efficiency is often a cheap and fast way to solve problems as reducing waste will reduce the size and cost of any subsequent treatment process and/or disposal costs (EPA Victoria, 2007a).
[37] The Building Commission is a statutory authority that oversees the building control system, building legislation, regulate building practices, advise Government, and provide services to industry and consumers in Victoria (Building Commission 2008).

Australia (BCA) 2006. The latter two are based on the 1993 Building Act. BC encourages the recycling of building materials, whilst its Building Practitioners Board deals directly with human conduct within the building industry.

Similar to the GBCA, the BC is also involved in the Australian Green Building mission, which has six recommendations to help the building industry in Victoria (Building Commission, 2009). Three of the six recommendations, most relevant to the promotion of C&D recycled materials include:

- Government departments to tenant only sustainable buildings by 2010
- Encourage industry to adopt Green Star as a rating system for commercial buildings
- Develop standards for recycling construction and debris in all commercial buildings by 2005

The Victoria Government's commitment, to promote green buildings by 2010, reinforces the need for more C&D recycled materials to be used in construction projects, and highlights the benefits on cost/return. According to the Building Commission (2009), this should create a domino effect through the industry as developers strive to secure contracts, and investors to fund their projects. Currently (in 2010), the Victorian Government's push towards 'green' building is still gradual in the public sector, and this recommendation could be applied to other commercial buildings within the private sector. Building 'green' not only requires that C&D waste materials are recycled but the C&D recycled materials are used in the 'green' building projects.

As mentioned in the GBCA section of this chapter (Section 8.1), the Green Star was modeled on the LEED rating system from the United States. Green building stakeholders in Victoria have been advised to adopt the best practice of the LEED rating system, which shows that LEED is transforming the market, as building companies and owners compete for higher ratings and buyers demand 'green' products. The Green Star rating tool continues to define the market, and has an important role to play in promoting C&D recycled materials within the building industry. Taking on Green Star as the rating system for all commercial buildings, gives Victoria the opportunity to go even further than the United State's LEED rating tool (Building Commission, 2009).

The recommendation of recycling C&D waste by 2005 has been further enforced with programmes such as Victoria's TZW. Although the Building Commission (2009) has identified recycling of C&D waste saves embodied energy in materials, lessens the demand for virgin resources, lowers the need for limited landfill space, and offer substantial financial savings, its adoption in the industry has been slow. The desired outcome of increased C&D waste recycling and materials use is yet to be fully realised.

The BC oversees legislation that affects all aspects of building, from the planning stage through to the end-of-life options, and consumption stages. Therefore, the BC's contribution to the promotion of C&D recycled materials use, within the building industry could be directly significant, through programmes such as the Australian Green Building Mission.

8.4 Australian Building Codes Board (ABCB)

The Australian Building Codes Board (ABCB) is a joint initiative of all levels of the Australian Government, and includes representatives from the building industry. The Board has been responsible for building regulatory matters since 1st March 1994, and this was reaffirmed by State Ministers in July 2001 (Planning SA, 2008). The Building Code of Australia (BCA) is produced and maintained by the ABCB. In 1996, a performance-based BCA was introduced, and focused on issues such as permitting the use of alternative materials, the innovative use of materials, and allowing designer flexibility in the use of materials in construction or designs, to prescriptive requirements (ABCB, 2010). In June 2004, the ABCB endorsed sustainability as one of the key areas within the BCA that deals with issues such as energy, building materials, water, and indoor environmental quality (RMIT, 2006).

The ABCB oversees the Australian Building Products and Systems Certification Scheme, which was changed to the Joint Accreditation System of Australia and New

Zealand (JAS-ANZ), and is popularly known as the 'CodeMark Scheme'. JAS-ANZ is in accordance with other international organisations,[38] and therefore is recognised by trade partners. Legislation requires that products certified as CodeMark are accepted. The third party certification ensures that products are certified to meet specific requirements of the BCA, hence promoting the environmental benefits of such products.

This third party certification serves as an accredited scheme for building products and services on a national level. The endorsement of a product by a third party involves an independent assessment of a product's demand, and aims at encouraging consumer demand. Therefore, the third party certification could boost consumer confidence in products and services (JAS-ANZ, 2005a). The JAS-ANZ also focuses on certification of personnel and various management systems. Two such management systems of relevance to this research are the Environmental[39] and Quality Management[40] Systems. These two schemes cover the areas of endorsement, carbon emissions, energy, and cost issues. This certification is yet to extend to C&D recycled materials. The quality of recycled materials should be improved through certification, as this allows for an effective assessment of environmental impacts. On the other hand, the certification of new building materials, could facilitate their recyclability at the end-of-life, and reduce likely environmental impacts. The certification of virgin and recycled building materials could be the most effective way of ensuring that product quality is maintained, beyond the end-of-life-stages. The ABCB's contribution to recycled materials use is directly dependent on the implementation of third party certification.

[38] International organisations like the International Accreditation Forum (IAF) and Pacific Accreditation Cooperation (PAC) and a bilateral arrangement with the European market through the European cooperation for Accreditation (EA) for Product Certification (JAS-ANZ, 2005b).

[39] The Environmental Management Systems (EMS) certification scheme is based on the AS/NZS ISO 14001:2004 certification standard. The scheme assists organisations to minimise the harmful effects of their activities on the environment, meet legal environmental requirements, and to achieve continual improvement of their environmental performance (JAS-ANZ, 2007a).

[40] The Quality Management Systems (QMS) scheme helps organisations to meet customers' quality requirements and relevant regulatory requirements, while also enhancing customer satisfaction and achieving continual improvement of its performance (JAS-ANZ, 2007b).

8.5 Australian Greenhouse Office (AGO)

It is important to consider emissions when mapping out an effective waste management plan. In Australia, the AGO is the main body responsible for the Green House Gas (GHG) emissions. As at 2006, Victoria had a total net emission of 120 million tonnes of CO_2 equivalent ($MtCO_2$-e), which contributed 20.9% to national emissions. The AGO (2008) figures showed sector contributions included the electricity generation 64$MtCO_2$-e (32.3%), manufacturing and construction 5.8$MtCO_2$-e (12.3%), transport 19.9$MtCO_2$-e (25.2%), and waste 4.2$MtCO_2$-e (25.5%). Although waste seems to have the least amount of emissions, it could contribute to the high emission figures in the electricity and transport sectors. Table 8.1 shows the emissions figures for the March 2009 to March 2010 period. The highest emissions sector was the Fugitive emissions, which comprises of emissions produced when coal, oil, and natural gases are extracted and distributed. Emissions from waste was the second highest followed by transport. The annual emissions estimates for the four quarters up to the March quarter for each year, from 2000 to 2010, showed that the national inventory has increased from 490 $MtCO_2$-e in 2000 to 542 $MtCO_2$-e in 2010 (DCCEE, 2010b). Although some sector emissions may have decreased in 2010, the overall national emissions were still higher over the ten year period.

Table 8.1: National Inventory for the four quarters to March quarter 2010

Category	**Annual emissions through the March quarter Mt CO2-e**		**Percentage change in annual emissions**
National Inventory – Annex A sectors	**March 2009**	**March 2010**	
Energy – Electricity	206	203	-1.8%
Energy – Stationary energy excluding electricity	91	90	-1.6%
Energy – Transport	79	80	0.2%
Energy – Fugitive emissions	40	42	5.1%
Industrial processes	29	29	-3.1%
Waste	15	15	1.5%
Agriculture	86	85	-1.8%
National Inventory total	**547**	**542**	**-1.0%**

(Source: DCCEE, 2010b)

The building industry needs to focus its efforts towards reducing carbon emissions. The Australian Government has revealed that measures implemented include renewable energy, clean energy, and the much anticipated CPRS. The impact of energy, especially from fugitive emissions, only reiterates the fact that energy substitutes are required. There is an obvious need for the building industry to change its building material choices, to reduce energy impacts from building materials, and embrace the use of sustainable substitutes such as C&D recycled materials. Carbon emissions reduction is a requirement for products to be certified, and endorsed. Therefore, the promotion of C&D recycled materials endorsement, could be a step to facilitate the AGO's push towards carbon emissions reduction. Chapters 4 and 5 highlighted the waste impacts on carbon emissions.

8.6 Australian Green Procurement (AGP)

The AGP is a database initiative of the Australian Environmental Labelling Association (AELA), and the Australian Green Procurement Network, as a showcase of green products and services available in Australia (AGP, 2004). This database is an opportunity for manufacturers to showcase their product's environmental performance. The quality of materials displayed in this database is determined by several screening processes that focus on the product's Life-Cycle. Products have thus been made competitive on their environmental performance basis. The AGP, however, admits that only some of the environmental labelling programmes in operation comply with the ISO 14020[41] methodology in Australia, but all have the general objectives outlined in the international standards. As at 2008, there were only a few C&D recycled materials displayed on the AGP website. This screening process needs to be fully applied to all C&D recycled materials.

[41] The international standard ISO 14020 states the formal objectives as "through communication of verifiable and accurate information that is not misleading, on environmental aspects of products and services, to encourage the demand for and supply of those products and services that cause less stress on the environment, thereby stimulating the potential for market-driven continuous environmental improvement" ISO 14020 –objectives (AELA, 2004).

Environmental labelling is a third party certification that gives credibility to products and services. The Life-Cycle of a product is important when considering environmental labelling however, in an attempt to increase demand and profit, care must be taken not to mislead consumers. Issues such as verification of environmental claims, false advertising, and bad company image could arise. Although the varying standards used to measure environmental performance are country-specific, countries like Japan, New Zealand, Korea and Germany agree that it still contributes significantly to economic growth in all of their respective countries.

In Australia, the AELA runs the Good Environmental Choice Australia (GECA)[42] Programme that serves as a link to inform consumers of products that are environmentally labelled (AGP, 2004).

The GECA outlines its objectives for an independent environmental labelling scheme as the following:

- Provide incentives for suppliers to reduce the environmental impacts of products sold in Australia
- Provide a clear, credible, and independent guide to consumers wishing to take account of environmental factors in their purchasing decisions
- Encourage consumers to purchase products, which have lower environmental impacts
- Recognize genuine moves by companies, to reduce the adverse environmental impacts of their products
- Aim ultimately to improve the quality of the environment, and to encourage the sustainable management of resources

On the AGP (2004) website, various groups of new and recycled products had been environmentally labelled however, there were only a few C&D recycled materials that had been environmentally labelled. The GECA has been very transparent on the various environmental performance aspects that need to be satisfied, to gain the certified label.

[42] Good Environmental Choice Australia is the national Life-Cycle based environmental labelling programme for consumer and building products (AGP, 2004).

Consumers rely on information provided on websites such as the AGP database, to make an informed decision, and while this is a good starting point, it should be extended to more C&D recycled materials. The labelling system for C&D recycled materials should consider similar factors, as for other recycled materials, displayed on the AGP website. Advocating for C&D recycled material endorsement requires that environmental impacts are minimal, and could be key to improving the quality of C&D recycled materials as well as demand.

In Victoria, the ECO-Buy[43] programme (called the LGBRA) focuses entirely on purchasing products with recycled content. Most consumers are willing to buy products that are 'green' or with fewer emissions, provided there is material awareness, and affordability issues are addressed. The AELA (2004) conducted a survey, which included an investigation of consumer purchasing trends for environmentally labelled materials. When consumers where asked 'if they would use a logo such as the GECA, as a credible indicator, if it were awarded to products', 458 (96.4%) consumers said 'Yes', whilst 17 (3.6%) said 'No'. However, when consumers were asked 'if they would pay more for a product that was clearly environmentally preferable than a similar product', 100 consumers said 'No', and only about 10 consumers said 'Yes'. Clearly, the responses show that consumers might be less willing to accept a trade-off between price and environmental performance. In the same survey, consumers also indicated that they would like to see more product information for environmentally preferable materials before purchase.

Environmentally labelled products do not come cheap, especially since producers have to abide by strict guidelines to obtain certification. C&D recycled materials that end up being certified might also be subject to price increases. Such price increases will be influenced by the price of inputs required to remanufacture the C&D waste, and other associated costs. The demand for environmentally sustainable products is likely to fall if

[43] ECO-Buy is Victoria's local government green purchasing programme that works primarily with Victorian councils to increase their purchasing of recycled, greenhouse friendly, water saving, non-toxic and other green products. The programme is a joint initiative of the Municipal Association of Victoria, EcoRecycle Victoria and the Department of Sustainability - Victorian Greenhouse Strategy. ECO-Buy is an expansion of the Local Government Buy Recycled Alliance (LGBRA), which was established in April 2000 (AELA, 2004).

high costs are passed on to consumers. However, there is already a persuasive case for the increased demand of environmentally labelled products. A Victorian survey conducted, showed that environmental labelling was considered as highly important when it was third-party accredited, and therefore considered as a powerful strategic tool (AELA, 2004).

8.7 VicRoads

VicRoads[44] is an influential body when it comes to promoting the use of RCC and RCB materials in road construction, in Victoria. C&D waste such as concrete and bricks, are usually recycled according to VicRoads specifications of 20mm class 2, 3 or 4 crushed concrete aggregate. In March 2005, VicRoads committed to an Environmental Strategy Programme 2005-2015, which was based on the principles of Ecological Sustainable Development (VicRoads, 2006). Currently, recycling companies willing to improve quality and increase the demand for materials such as concrete and brick products rely on Sections 820[45] & 821[46] (refer to Appendix A12 for Section 820) of the VicRoads standard specifications. Other materials that are recycled according to VicRoads specifications include tyre/rubber materials, glass waste, and quarry based materials.

Like Victoria, other state and local governments in Australia have made efforts similar to the TZW initiative through various waste reduction strategies and programmes. Table 8.2 clearly shows that the fight against waste goes beyond the state level, and has become a national issue. Australia is accountable both nationally and internationally for its waste management strategies. Table 8.2 outlines some waste management efforts and initiatives in Australia States and Territories.

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[44] VicRoads is a Victorian statutory authority established under the Transport Act 1983. It is one of several state government agencies that assist the Government to achieve its integrated transport policy objectives (VicRoads, 2010).

[45] Section 820 of VicRoads Standard Specifications – Recycled Crushed Concrete for Pavement sub-base and Light Pavement base

[46] Section 821 of VicRoads Standard Specifications – Cementitiously Treated Crushed Concrete for Pavement Sub-base

Table 8.2: The legislation and policy for waste management in all Australian states

STATE/ TERRITORY	LEGISLATION	WASTE REDUCTION STRATEGIES
Commonwealth	• Natural Heritage Trust of Australia Act 1997 • National Environment Protection Measures (Implementation) Act 1998 • Environmental Protection and Biodiversity Conservation Act 1999	• Waste Management Awareness Programme • Natural heritage Trust – Waste Wise Construction Programme • Building Code of Australia
Australian Capital Territory	• Environmental Protection Act 1997 • Waste Minimisation Act 2001 • Litter Act 2004 • Waste Management in the ACT 1999	• No Waste by 2010 strategy • Development Control Code for Best Practice
New South Wales	• Waste Minimisation and Management Act 1995 • Protection of the Environment Operations Act 1997 • Waste Avoidance and Resources Recovery Act 2001	• Construction and Demolition Waste Action Plan 1998 • Waste Planning and Management Fund • Waste Reduction and Purchasing Policy – A Guide for Agencies 1997 • Waste reduction and purchasing policy • Waste Education Strategic Directions Statement 2000-2002
Northern Territory	• Waste Management and Pollution Control Act 1999 • Environmental Assessment Act 1994	• Waste Management and Pollution Control Strategy 1995 • Guidelines for Siting, Design and Management of Solid Waste Disposal Sites in the Northern Territory 2003
Queensland	• Environmental Protection Act 1994	• Waste Management Strategy for Queensland 1996 • Environmental Protection (Waste) Policy and Regulation 2000
South Australia	• Environment Protection Act 1993 • South Australia's Waste Strategy 2005-2010 • Zero Waste SA Act 2004	• Environment Protection (Waste Management) Policy 1994 • (Draft) Environmental Protection (Waste Reduction, Recycling and Disposal) Policy 1999 • Zero Waste SA (2008)
Tasmania	• Environmental Management and Pollution Control Act 1994 • Land Use Planning and Approvals Act 1993 • Environmental Protection (Waste Disposal) Regulation 1974	• Guidelines for the Establishment and Management of Landfill Sites for Construction, demolition and Solid Inert Waste 1996 • The Landfill sustainability sites 2004
Victoria	• Environment Protection Act 1970 • Environment Protection (Amendment) Act 1996	• Becoming Waste Wise Education Programme • EcoRecycle Victoria • Towards Zero Waste 2005 • Waste wise purchasing policy • Environmental Sustainability framework 2005
Western Australia	• Environmental Protection Amendment Act 1998 • Environmental Protection (Landfill) Levy Act 1998	• WA Waste Reduction and Recycling Policy • Waste Management and Recycling Fund • Zero waste WA • Statement of strategic direction for waste management in Western Australia 2004

(Source: Crowther, 2000 updated)

8.8 Chapter summary and conclusion

This section discussed seven organisations (Green Building Council Australia, EPA Victoria, Building Commission, Australian Building Codes Board, Australia Green Office, Australian Green Procurement and VicRoads) that influence legislation on carbon emissions, building materials endorsements, costs, and the supply chain management of C&D waste recycled materials. In Victoria, targets like the TZW, are scheduled to be achieved however, issues such as product quality, and overall environmental impacts required for product certification need to be addressed.

Melbourne has seen an increase in 'green' commercial buildings over the past 2-3 years. The certification of 'green' building requires that new construction materials not only meet certain environmental standards, but C&D waste materials are re-used or recycled, as specified by organisations such as the GBCA, BC, AGP, and VicRoads. The study of the six sites [500 Collins Street, Melbourne Convention Centre (MCC), 55 St Andrews Place, Corner Bourke and William (CBW) Street, AXA Group building, and Waterfront City Docklands] was necessitated by Melbourne's increased waste generation, as a result of its infrastructural growth.

The push by consumers for building owners to go 'green' could see a change in trends. A consumer-driven need for 'green' building is a good step, to increasing awareness for all building owners to upgrade their existing buildings, and infrastructure to sustainable standards. C&D recycled materials use, can be increased during such upgrades however, the optional state of these upgrades could slow down or hinder this development. Victoria's adoption of C&D waste recycling practices is reliant on encouraging consumers to purchase C&D recycled products. The responsibility lies with consumers, producers, and the government.

A change in the building industry is needed, to increase the number of C&D recycled materials displayed and promoted as certified. Organisations such as the GBCA and VicRoads (Section 820 and 821specifications) have implemented regulations that could encourage the recycling and use of more C&D waste products. The major issue hampering this effort is the generalized classification of most recycled materials. However, an independent assessment of C&D recycled materials is required prior to certification. Legislation on product certification could be a key to gaining optimal use of C&D recycled materials.

The next chapter presents the research findings and implications of the environmental, social, economic, and governance aspects of recycling and use of C&D recycled materials, whilst the implications of this chapter's review is discussed in Chapter 9 (Section 9.4).

9 DISCUSSION OF FINDINGS

Current practices have not created adequate opportunities to increase recycling, and the use of C&D recycled materials. Analysis Chapters 4, 5, 6, 7, and 8 investigated some drivers and barriers to significantly improve recycling and re-use. It is important to reiterate that this study sought to answer the following questions:

- *"What are the major factors that could increase recycling of C&D waste materials?"*
- *"How best can these factors be incorporated into existing practices to facilitate increased demand for RC and brick recycled materials?"*

This chapter attempts to answer these questions, highlight the contributions to the study, and make future projections based on the research findings.

The TBL+1 principle (Section 3.2.5) adopted to discuss the results in this research include:

- the Precautionary Principle (Environmental)
- the UN Global Compact Sections 7, 8, and 9 on human responsibilities to the environment (Social)
- the Supply Chain Economics (Economic)
- the Australian Governance (Governance)

Having earlier discussed some efforts made to optimise C&D waste recycling in Chapter 2, it appeared that some steps had been taken to recycle and increase demand for recycled materials. There are predictions of an increase in waste generation in the next fifteen years (Coles, 2007). The environmental impact of such an increase was highlighted in Chapters 4 and 5, whilst, social and economic factors affecting recycling and demand were covered in Chapters 6 and 7. Recycling still remains high on the list of most environmentalists' agenda. The aspects of TBL+1 are used to summarize this chapter's discussion, and highlight the key areas that still need to be addressed. The chapter summary section applies the four aspects of TBL+1, to discuss the various aspects of the study results from Chapters 4, 5, 6, 7, and 8. According to Del Borghi et al. (2009), the aspects identified in the study as TBL+1, assist with the integration, and quantitative considerations related to cost and social dimension, as complementary information to the environmental aspects of sustainability in waste management. The various sections of this chapter may discuss several similar points, due to the interrelated nature of the four aspects (environmental, social, economic, and governance).

9.1 Environmental findings

The section discusses the energy (9.1.1), transport and location (9.1.2), and carbon emission impacts (9.1.3). This study used the ELCA to highlight the environmental impacts of recycling RC and brick waste, using four key environmental impact categories (global warming, water use, solid waste and embodied energy).

This section discusses the implications of the results from the ELCA analysis in Chapters 4 and 5. Table 9.1 shows a summary of 100% RC and 100% brick recycling, compared to landfill disposal and virgin gravel production. There were higher environmental impacts for landfill (C_0 and B_0) and virgin gravel, compared to the impacts of the two 100% recycling scenarios for RC and bricks (C_1 and B_1).

Table 9.1: Summary of 1000 tonnes recycling, landfilling and virgin gravel results

Impact category	*Recycling 100% RC (C_1)*	*Landfill disposal of 100%RC (C_0)*	*Virgin gravel 100%*	*Recycling 100% Brick(B_1)*	*Landfill disposal of 100%Brick (B_0)*
Global warming (tonnes CO_2)	-13	70	17.7	-6.5	18
Water use (KL)	-1,927	2	2010	-2	0
Solid waste (Tonnes)	-108	1,000	80.2	-76	1,000
Embodied energy (GJ)	-328	474	135	-54	118

9.1.1 Energy

The term energy in this study refers to fuel (diesel) and electricity. Electricity and diesel were the main contributors to the embodied energy impacts for the RC and brick recycling processes (Tables 4.5 & 5.2). The embodied energy impact results are shown in Table 9.1 for RC and brick recycling and landfill scenarios, compared to virgin gravel. A St John's University (2010) study on recycling supports the research findings on energy, which revealed that energy used during the recycling process was significantly less, compared to the amount used during the virgin materials production.

Diesel use in the 12-tonne truck was determined by the number of trips traveled, therefore transport impact on embodied energy was significantly reduced with shorter distances traveled (Tables 4.8 & 5.5). Although the distance to the landfill site (4km) was shorter than the distance to the recycling plant (20km and 15km), the impact of the longer distance was offset by the avoided production of virgin gravel (Figures 4.13 & 5.4). Hence, the embodied energy impact of landfill disposal was higher for RC (474GJ) and bricks (118GJ), since there were no environmental benefits for disposing of RC and bricks in landfill (Table 9.1). On the other hand, RC (-328GJ) and brick (-54GJ) recycling resulted in significant energy savings. A study by Crowther's (2000) argued that the distance traveled to sites could reduce recycling benefits, and it was not always advisable to assume that all recycling would lead to environmental benefits. Ideally, shorter distances to the recycling plant are preferred. Travel distances of over 50km will not produce the net benefit from an energy perspective. For example, if a 30-tonne truck was used (instead of a 12-tonne truck) to transport 1000 tonnes of waste over 20km, the number of trips would be less, and decrease the quantity of fuel used. Another school of thought by MacSporran (1994) also argued that the impacts of energy used in transport decreased the recycling benefits realised. Longer travel distance (due to frequent trips) would require the use of more fuel resources and result in less environmental benefits. Hence, an effort to reduce the overall energy impacts from travel is critical. Though Crowther and MacSporran both make very convincing arguments about the benefits of distance traveled and energy, there are several other important factors that improve the environmental benefits of recycling. These include the capacity per load of the truck, and the benefits from the avoided production of virgin alternatives such as gravel. Therefore, important factors to consider in the assessment of transport impact on energy should include the capacity (per load) of the truck, distance traveled, avoided production benefits, and the type of fuel used in the truck.

Electricity was used in the RC and brick recycling scenarios, but not in the landfill scenario. Comparative data for RC recycling (C_1), bricks recycling (B_1) and virgin gravel in Table 9.1 showed a higher embodied energy impact for virgin gravel production (135GJ).

The study of energy in this research was to investigate the extent to which recycling impacted on energy, compared to landfilling or virgin gravel production. Sustainability Victoria (2009) states that *"Some of the greatest environmental benefits of recycling are in the conservation of energy and natural resources and the prevention of pollution when a recycled material, rather than a raw material, is used to make a new product. Manufacturing material the second time around is much cleaner and less energy-intensive than the first"*. Though the study's findings were consistent with Sustainability Victoria's statement, and the results showed recycling impacts were comparatively reduced, the type of electricity source and fuel used in machinery should be reviewed. The notion that recycling prevents pollution and is a much cleaner process is still premature. There are various ongoing research and developments from institutions such as the Department of Primary Industries (DPI, 2010), to continuously promote and improve the use of energy in Victoria, for example, the Energy Technology Innovations Strategy (ETIS) programme and national initiatives such as National Average Fuel Consumption targets, the Alternative Fuels Conversion Programme, and government bio-fuels measures. The State Government's ETIS aims at using cleaner brown coal and more renewable resources for electricity and diesel production. Several Liquefied Natural Gas (LNG[47]) plants have also been commissioned in different parts of Australia to fuel Heavy Duty Vehicles (HDV). In Victoria, the plant is predicted to reduce greenhouse gas emissions by 20%, compared to diesel. The adoption of sustainable options like these for recycling might take a few years to come to fruition. There are numerous efforts at developing sustainable energy sources, both at the state and national levels, and this should be fully utilized by recyclers.

9.1.2 Transport and location

The distance traveled to deposit C&D waste materials depends on the location of the recycling plants. Most recycling plants are usually situated on the urban fringes, due to the vast amount of land needed for set up, stockpiling of waste, dust, and noise pollution. Some contractors faced with such long travels to these plants, might consider a much easier option of taking their waste to landfill sites, with shorter travel distances. Most city councils have one or more landfills in their local area that allows for quicker disposal.

In Chapter 2, the impact of transport in Victoria (Table, 2.2) was found to be amongst the highest in Australia. Transport made up 26% of the CO_2 emissions from all the sectors (AGO, 2007). This study's findings on high transport impact (Figure 4.10 & 5.2) was consistent with the adoption of alternatives such as mobile crushers, across the building industry, to reduce the impacts of transporting waste to recycling plants. Benefits from mobile crushing include avoided travel, spacious sites (due to prevention of stockpiles), avoided haulage, and landfill fees. Mobile crushers are usually located

[47] The Victorian LNG plant has a capacity of 50 tonnes per day (t/d) of LNG. Benefits of LNG include stable fuel prices, quieter running and lower maintenance costs. The Western Australian plant is much bigger, producing about 175 t/d of LNG, and supporting 130 HDV, that suits journeys of up to 1,200km (Gas Today Australia, 2009 & 2010)

where the waste is generated. The question is how sustainable is this compared to transporting waste to the stationary recycling plant? Fuel is needed to power both stationary and mobile crushing plants. The debate is based on the distance traveled, the amount of crushing done, the quantity of fuel needed, and the time saved. Clearly, there are different crushing capacities for these two systems. The study of the construction sites in Chapter 6, identified barriers such as the lack of space on-site, affected the proper management of C&D waste on-site. A combination of both systems should be considered where distance is a major factor. This study did not include mobile crushing activities however; further research could compare the environmental benefits of both types of crushers.

In this study, the use of the 12-tonne 'hook-lift' trucks meant that the trips to the recycling plant were more frequent. Though the distance traveled to recycle RC (20km) and bricks (15km) were offset by recycling (B_1 and C_1), there is no doubt that location impacts on distances traveled, fuel use, and tonnages transported (per number of trips). The Waste Management Association of Australia (WMAA, 2008) has identified some factors that could influence the transportation of waste to a resource recovery site. These include:

- Time and cost constraints for removal of material from sites
- Access to sites and sufficient space for loading and handling materials
- Traffic management issues applicable to loading materials at the site of origin
- The availability of suitable vehicles for transportation of materials
- Selection of appropriate routes for transportation of materials to the recycling facility
- Traffic management relating to the C&D recycling facility to which the material is being taken

These factors are foremost on minds of most contractors when considering options for waste disposal. Findings by the WMAA are necessary when mapping out an effective waste management plan, and choosing the recyclers for projects, to resolve the waste issues that arise at construction sites. Similarly, findings from the construction sites study (Chapter 6) revealed that factors such as time, cost constraints, and space for loading waste materials, were some of the issues that needed to be addressed. Incorporating transport into a C&D waste management plan could make a significant difference to distance traveled and resources used.

Another critical factor to consider is the central location of transfer recovery stations, which will allow for shorter traveling distances for both recyclers and contractors. This could create opportunities for quicker transfers and disposal of C&D waste to recycling plants, allowing recyclers to supply the recycled material quantities required on demand.

9.1.3 Carbon emissions

This study identified carbon dioxide (CO_2) as the main gas released during the recycling process and disposal of waste. In Table 9.1, the global warming figures showed higher impacts for the RC disposal in landfill (70 tonnesCO_2), brick disposal in landfill (18 tonnesCO_2), and virgin gravel (17.7 tonnesCO_2), compared to the recycling RC (-13 tonnesCO_2), and bricks (-6.5 tonnesCO_2). The emission impact realised for the landfill scenario was mainly from the transportation of waste to the landfill site. Energy and transport were the main contributors to CO_2 emissions (Figures 4.10, 4.12, 5.2 & 5.3).

Overall energy (coal, oil and gas) contributes 68.6% of Australia's net GHG emissions, whilst the use of petroleum products in the road transport sector, is directly associated with high levels of particulates, carbon monoxide, and other pollutants (Beeton et al., 2007). The DCC (2008c), states "Australia is the world's ninth largest consumer of energy on a per capita basis, and this consumption is projected to grow by an average of 1.6% per annum until 2030. Australia is heavily reliant on brown and black coal for energy. In 2005 –06, black and brown coal accounted for 42% of primary energy consumption (and, according to ABARE[48], 75.6 % of electricity generation), while renewable energy sources represented 5%".[49] Australia's continuous reliance on emissions intensive energy resources contributes a significant amount to carbon emissions.

[48] Australian Bureau of Agricultural and Resource Economics
[49] Australian Bureau of Energy and Resource Economics (2008)

Transport emission is one of the main sources of emissions growth in Australia, since emissions from this sector were 26.9% higher in 2007 than in 1990, and have increased by about 1.5% annually on average over this period (DCC, 2009). Trucks were the main contributors to the overall transport sector emissions. Diesel-powered vehicles play a very important role in waste transportation, and regulations are needed to improve the related CO_2 emissions. Diesel-powered vehicles (includes diesel trucks) are required to meet certain road standards. According to the National Environment Protection Council (NEPC, 2008), four guidelines for the management of in-service diesel emissions[50] were outlined to control emissions from diesel-powered vehicles, as listed below:

- Schedule A(1): Guideline on Smoky Vehicle Programmes
- Schedule A(2): Guideline on Emission Testing and Repair Programmes
- Schedule A(3): Guideline on Audited Maintenance Programmes for Diesel Vehicles
- Schedule A(4): Guideline on Diesel Vehicle Retrofit Programmes

The guidelines address all the aspects of the vehicular operation that contribute to diesel emissions. The building industry requires similar guidelines, to monitor the emission level of its trucks on a weekly or monthly basis. Careful planning will be needed to effectively implement the monitoring process, as most of the waste trucks are owned by different companies. Companies that operate trucks should be equipped with the essential mechanisms and tools to effectively manage overall truck emissions, and ensure best practice across the C&D waste industry for all truck owners and users.
In Australia, estimated emissions from solid waste disposal decreased by 3.8Mt (25.5%) during the period 1990–2007, reflecting changing patterns of disposal, and particularly higher rates of recycling (DCC, 2009). For the recycling industry, promotion of recycling does not mean that emissions will be entirely eliminated. Although reduction in emission levels can be achieved by recycling, other measures such as the adopting alternative fuel resources (bio-fuels), and change in transport infrastructure are required. Whilst some have predicted that the necessary alternative modifications will be

[50] ***In-service emissions*** means exhaust emissions, excluding emissions of noise from diesel vehicles in use

expensive, and add to the overall cost of recycling, others (Eide 2008; Mitchell, 2008) are of the view that resources that rely on these sustainable fuel options might become more expensive. There are several energy alternatives (Section 9.1.1) on the market currently, that are likely to reduce carbon emissions however, in an attempt to reduce emission there is the likelihood of depleting some of these resources.

9.2 Social findings

This section discusses the implication of research findings on industry practices and preferences (9.2.1), and landfill (9.2.2). The discussion focuses mainly on the six construction sites studied in Chapter 6, where the following drivers and barriers were identified:

- Buy-in from sub-contractors and suppliers
- Waste sorting
- Recycling reports
- Worker awareness
- Waste minimisation and material re-use

9.2.1 Industry practices and preferences

Various industry practices and preferences influence waste management efforts, such as recycling. This involves all waste management stakeholders.

Based on the six construction sites study in Chapter 6, several stakeholders were identified as being responsible for on-site waste management, and these included contractors, sub-contractors, site workers, project and environmental managers. Decisions made by these stakeholders determined the on-site practices, and ultimately affected management. Waste management responsibilities range from the correct sorting of waste on-site, aimed at reducing contaminants, to deconstruction for re-use, instead of outright demolition.

Some contractors have the mandate to choose the building materials used in their construction projects. In the building industry, it is common to see builders or building contractors with a number of suppliers, who constantly supply building materials for a reduced price, so builders could reduce the overall project duration and cost. However, the contracted building materials supplier might not necessarily provide C&D recycled materials. Some of the sites discussed in Chapter 6 were faced with this challenge. Coupled with project time constraints and cost, other factors such as ignorance, choice of material, and lack of accountability, lessen the sense of responsibility within the industry. A good co-ordination between stakeholders is critical in the recycling of C&D waste, as discussed in Section 6.2. Perhaps the behavioural patterns have been, in most cases, underestimated, as environmentalists search for other causes for the low patronage of C&D recycled materials.

Education plays an important role in any waste management effort. Building and demolition contractors and site workers should be briefed about the waste management plan (usually project specific), due to their contribution to waste management on-site. Contractors are responsible for the practices of site workers and waste disposal on-site, to avoid waste contamination. Contaminated products are mostly impossible to recycle, and therefore it is important that all site workers are aware of the implications of their actions through site inductions (Section 6.2.4). One school of thought believes that people who are concerned about the environment are more inclined to recycle (Domina & Koch, 2002; Meneses & Palacio, 2005), whilst another study concluded that there were no significant differences between recyclers and non-recyclers in their attitude towards environmental issues (Oskamp et al., 1991;Vining & Ebreo, 1990). However, others like Sidique et al. (2010) argue that if personal convictions do not facilitate the recycling process, then positive attitudes relating to convenience and effort, should increase participation in recycling efforts, besides investment of time, space, and money. The findings by Sidique et al. (2010) were consistent with the findings at the six construction sites, which revealed that the issues of time, space and money were identified as crucial to recycling. However, sites could also rely on positive attitudes, as there were set waste management plans, and targets implemented as part of on-site regulations. All on-site workers were responsible and accountable for the waste management practices. Yet relying on positive attitudes cannot always deliver the desired outcomes, and clearly, the implementation of an effective waste management plan on-site is crucial.

Architects have the important task of proposing the use of recycled materials during the design stage of a building project. Organisations such as the GBCA continue to encourage the use of C&D recycled materials through the Green Star rating system. This sustainable initiative has been adopted only by building owners and construction companies who want to promote 'green' buildings. It is currently not compulsory to use the material choices proposed by architects. It remains optional. Factors such as the cost of proposed building materials, availability of material quantities required, and builder's preference, sometimes supersede using sustainable building materials. However, current trends have seen a growth in consumer demand for 'green' buildings (Section 8.1). Thus, consumer demand for sustainable buildings will facilitate a change in the C&D recycled materials use pattern across the building industry.

On the other hand, planners and site and environmental managers have the responsibility of ensuring good waste management on construction sites. In Chapter 6, the six construction sites study exceeded targets on waste quantities produced and recycled (Table 6.2). Chapter 6 also identified building owners, contractors, and site workers, responsible for maintaining a good waste management plan. In Australia, organisations like EPA, Building Commission, and the GBCA (Chapter 8), have spear-headed the initiative to incorporate effective C&D waste management plans for 'green' buildings, but this is still a very slow process. The level of stakeholder participation in every project is obviously critical to success, however, it is not just the number of people who participate, but their dedication to participating is an important parameter (Thomas, 2001).

This section's discussion focused on the before, during, and after practices on construction sites, because the activities there to a large extent determine the possibility of recycling C&D waste materials. Table 9.2 is a stage-by-stage outline of some of the areas where waste minimisation strategies could be applied, and some users who could influence out comes. Therefore, the tendering and operational management process creates an opportunity for waste management to be incorporated at the design and planning stages of every construction project. Architects and planners have the responsibility of proposing recycled materials use and recycling of C&D waste during construction projects, to encourage on-site stakeholder participation (Brown & West, 2003).

Table 9.2: Waste minimisation for construction areas

Minimisation strategy	Users	Action
Project Planning	• Developer • Builders • Sub-contractors	• Waste Management Strategy
Pre-construction	,,	• Design • Estimate • Purchase
Off-site Activities	,,	• Prefabrication (e.g. for timber)
On-site Activities	,,	• Deliver and storage • Packaging • Separation of materials for collection • Recycling • Litter Management on site • Safe disposal of unavoidable waste

(Source: Sustainability Victoria, 2001)

9.2.2 Landfill

The waste management sector broadly comprises of landfill and transfer station facility operators, collectors, sorters, and recyclers/re-processors (EcoRecycle, 2002). Each has a role to play in landfill disposal or recycling. Whilst some offer services to landfill and transfer stations, others collect, sort, and recycle. The efforts are currently geared towards encouraging more of the landfill owners to take on a recycling role as well. However, the fiscal capital involved in making this happen might take a while to obtain, especially for privately owned landfill sites. The focus for many local governments now is to close down as many landfill stations as possible for other uses. As at 2008, the resource recovery and efficiency was said to be growing at a rapid rate (Parliament of Australia, 2008). If this was indeed the case, then landfill disposal should have been significantly reduced.

This study did not include any data collected on the impact of landfill sites activities, but acknowledges that GHG continues to contribute to landfill. The impact of CO_2 emissions and solid waste were quite significant for the landfill RC and bricks disposal scenarios (C_0 and B_0). The WMAA (2008) admits that measures need to be taken to properly assess landfill emission contributions. Carbon emissions impacts relating to landfill in this study were mainly from the transportation of RC and brick waste materials to the landfill site. The ELCA results indicated that the truck emissions were as a result of truck and fuel use, required to dispose of 1000 tonnes of RC and bricks to landfill (C_0 and B_0). For RC, the main impact was a result of the chemical composition of concrete, although other sources of GHG could also contribute to landfill emission impact. Comparatively, bricks had a less significant landfill emission impact.

Landfill fees were identified as a major driver to recycling (Section 9.3.1), and to a large extent, determines the waste management strategies adopted. The extent to which the drive to recycle remains effective can only be compared to examples such as the impacts seen in NSW. Although this will no doubt drive recycling, as proposed by other studies, little is said about investing monetary benefits obtained from the landfill levies back into waste management. A committee set up to address waste management issues has recommended that state and territory governments pursue the hypothecation of landfill levies, their investment into resource efficiency initiatives and infrastructure to the fullest extent possible (Parliament of Australia, 2008). This will, in effect, enable governments to project and assess the potential impacts for the building industry, and an example of this was carried out in South Australia in 2007.

9.3 Economic findings

This section discusses the cost (9.3.1), demand and supply (9.3.2) impacts on recycling. Based on the findings in Chapter 7, this section discusses some of the areas that could improve the usage of C&D recycled materials within the building industry.

9.3.1 Cost

Major cost impact areas identified included fuel cost for transport, landfill fees and haulage fees (Tables 7.3 and 7.4).

Fuel cost was one of the major contributors to high recycling costs. According to the DCC (2008c), the government has proposed to include transport in the Carbon Pollution Reduction Scheme (CPRS - initially scheduled for 2010), with initial fuel tax cuts for the first three years. It states that *"heavy vehicle road user's fuel taxes will be cut on a cent-for-cent basis to offset the initial price impact on fuel associated with the impact of the Carbon Pollution Reduction Scheme which will be reviewed after one year".* These cuts should be applied within the recycling industry to subsidize the fluctuating fuel costs currently incurred by recyclers. Whilst this is yet to be enforced, other alternatives for fuel (Section 9.1.1) should be pursued, to reduce the reliance on diesel-powered vehicles.

Before July 2010, landfill fees in Victoria were set at \$15 per tonne (EPA Victoria, 2007c), compared to the maximum fee of \$25 for depositing waste to the recycling plant (Table 7.5). Victoria's landfill fee has now increased to \$30 per tonne (Environment Victoria, 2010). In Tables 7.3 and 7.4, the results showed that landfill fees had significant cost impact for the RC (C_0) and brick (B_0) landfill disposal scenarios, compared to the recycling scenarios (C_1 and B_1), especially when 'avoided processes' were considered (Table 7.8). The increasing trend of landfill fees has been identified as significant to increased recycling. It is yet to be seen if Victoria will follow in the footsteps of states like New South Wales (NSW,) where high landfill fees correlated with increased recycling performance (EPA NSW, 2001). In 2008, NSW landfill fees were predicted to reach between \$52 and \$59 per tonne by 2010, from the \$47 per tonne that year, which was still higher than the fees for Victoria (Parliament of Australia, 2008). However, the actual fees for 2010/2011 show the landfill levy is currently between \$65 and \$71 (DECCW, 2010). A study by Duran et al. (2006) similarly concluded that economic viability was likely to occur, when the cost of landfilling exceeded the cost of bringing the waste to the recycling centre, and the cost of using primary aggregates exceeded the cost of using recycled aggregates. Landfill fees are critical towards the drive to increasing recycling, and the overall cost savings for waste management in C&D projects.

The haulage fee was considered as a cost to the recycling process, and it contributed significantly to the overall cost (Tables 7.3 & 7.4). The haulage fee is either incurred by site managers who choose to contract recycling companies to haul waste from C&D sites, or arrange for waste to be collected by other haulage companies. Other cost impacts of recycling RC and bricks (C_1 and B_1) in Chapter 8 included electricity, fuel and water. Roe (1993) has noted that tracking the costs and benefits of recycling will require construction projects to:

- Estimate project waste and amount of materials recycled
- Estimate the cost effectiveness of recycling
- Estimate the intangible benefits of recycling

In Chapter 7, the avoided cost of virgin gravel production and landfill disposal can be considered as tangible benefits to the recycling process. However, the intangible benefits of recycling depend on the willingness of C&D companies to have a competitive edge, although the efforts might not show immediate cost savings. For example, in Queensland, one of the refurbishments (Newton House) credited their cost savings to conscious efforts by staff to cut cost during the entire construction process (Newton House, 2010). The costs incurred by recycling C&D waste are internally controlled by stakeholders, such as building owners, as well as construction and recycling companies within the building industry. However, external factors are more difficult to manage, as they are driven by other forces, usually beyond the control of recyclers. External factors such as recycling incentives, a fluctuating market, and C&D waste material availability, affect the overall cost of C&D recycled materials.

Recycling incentives are needed to help sustain the recycling market, and produce competitive, high quality recycled materials, increase demand, and revenue. Nunes et al. (2006) explained that public owned recycling centres were more economically viable than their privately owned counterparts. Victoria is known to have many privately owned recycling centres. Most recycling plants in Victoria, such as AFG, do not receive any recycling incentives from the government. Though Table 7.9 showed beneficial outcomes for recycling, the monetary benefits might not necessarily be enough to sustain the recycling market, and ensure continuous production. This might be worsened by the cheaper pricing of virgin alternatives. The Nunes et al. (2006) study found revenue from recycling to be usually inadequate in sustaining the recycling market, and advised that other sources of revenues were needed to subsidize production. As the Victorian government promotes the TZW, it should take the opportunity to review the management of recycling plants. Subsidies and incentives may hold the key to the establishment of more recycling plants, whilst simultaneously reducing C&D waste through increased landfill charges.

Some study findings have identified issues such as capacity of the plant, high fixed capital, and planning permits, as responsible for the economic disparity between private and public recyclers. According to feasibility studies done in India and Germany (Kohler, 1997; Technology Information Forecasting and Assessment - TIFAC, 2006), the findings stated that *"due to market preference of the customers to use natural aggregate, recycled aggregates have to be marketed at a discount to achieve sale of 25,000t/y in 2-3 years time. The unit is viable but its operations highly sensitive to fluctuations in sale price of recycled aggregate and capacity utilization of the plant"*. Therefore, the high fixed capital investment, planning permits, and C&D waste facilities were economically viable from a production of around 200,000 t/y (around 800 t/d) or more. The total quantity of RC and bricks recycled at AFG is estimated to be about 650,000 tonnes annually. Although this should imply that recycling is economically viable, this is not always the case, as other factors such as the market for recycled products, needs to be considered. A study by Duran et al. (2006) argues that recycling centres benefit from economies of scale, implying that an increase in the scale of a centre in turn results in a decrease in recycling costs. Contrary to the argument by Duran et al (2006), an increase in the scale of recycling can only achieve an outcome of decreased recycling costs, by increasing demand for recycled materials across the industry. Clearly, highlighting the cost savings of recycling (Table 7.9) is a crucial step to create awareness of C&D recycled materials. For recyclers, it is essential that recycling is subsidized to maintain the scale of production and economic viability. Economic viability can be achieved by considering the cost savings, and the continuous demand for C&D recycled materials.

It is not immediately known how much of the C&D waste sent to the recyclers is disposed to landfill due to high processing costs, and low demand. Calculations in Chapter 7 revealed that recycling of RC and bricks (C_1 and B_1) added significantly to cost, though it was comparatively cheaper than landfill disposal (C_0 and B_0). According to Nunes et al. (2006), for companies that produce finished products, the price of the processed C&D product was a direct function of the conventional product market. The type of C&D recycled material in demand may cause prices to fluctuate, as dictated by specific market factors. The effects of such price fluctuations could trigger an increase or decrease in the demand for other C&D recycled materials. Based on such demand, recyclers might choose to recycle only what will bring increased sales, and dispose of materials in less demand. Duran et al. (2006) identified taxes and subsidies as a solution to the issue of pricing recycled materials. The Duran et al. (2006) study revealed that when taxes were imposed on the sale of virgin aggregates, and subsidies were given to recyclers and C&D recycled material users, the cost of landfilling and purchasing virgin aggregates became higher. Taxes and subsidies were found to be more effective than the costly approach of monitoring the use of landfill and quarried stone, which may lead to illegal dumping. The use of market-based instruments seems a more optimal solution, because they are more efficient, and ensure the operation of markets to allocate resources. The use of taxes and subsidies as market-based instruments constitutes an efficient way to internalize externalities (Duran et al. 2006). The effective operation of taxes and subsidies is based on a typical human behavioural trend, driven by the need to make profit; hence, if markets change, a shift in production is necessary to allow companies to at least break-even.

Consultations with AFG revealed that prices were dictated by the availability of materials recovered for recycling, and the quantity actually recycled and available for use. According to Tam (2008), unless the recyclers have established long-term contracts for consistent and high-quality feed material, it may be difficult for the recycler to maintain a predictable revenue stream, because of uncertainty related to future feed availability, and quality or market price fluctuations. Tam's study noted that the above mentioned reasons will, in time, affect the use of recycled materials in the industry. This study found that certain effective measures had been put in place by AFG to encourage the deposition of C&D waste materials to the recycling plant, but the market for recycled products was the main concern. The promotion of increased C&D waste recycling, without the demand for the C&D recycled products, will not result in the desired cost savings.

9.3.2 Demand and supply

According to the United States Environmental Protection Agency (USEPA) 2007, the recycling process is not complete until collected materials are used to manufacture products, and those recycled products are sold. The USEPA (2007) further explains that consumer demand for recycled-content products, including recycled building products drives recycling, and makes it economically viable for the governments and businesses involved in collection. With introductions like the ECO-Buy, the Victorian and local governments have realised that the promotion of recycling without matching supply to demand, creates an imbalance. Resource Smart (2008), a Sustainability Victoria initiative, admits that for recycling to be truly effective, there needs to be strong markets for collected recyclable materials. Supply and demand depends on what producers/suppliers and consumers are willing to supply and pay for a particular product.

Basic Economics (2009) outlines the laws of demand as being motivated by income, price of related products, taste, preferences, and expectations. For the six construction sites in this study, the challenge was to effectively combine time and cost during projects. Hence, if C&D recycled materials appeared to be initially expensive, they are likely to be overlooked.

There is the need to resolve the issue of quality to allow for the use of C&D recycled materials, such as RCC and RCB for other purposes. According to Chong & Hermreck (2010), the supply of recycled material is affected by the material quality from the supply source. Currently, RCC and RCB are mainly used for road bases, because doubts still exist about the quality of their use in structural projects. In the United States, there have been a few examples of RCC used in structural applications, but they were not major projects. Other current uses of RCC and RCB, according to the CMRA (2009), include ready-mix concrete, soil stabilization, pipe bedding, and as landscaping materials. Increased C&D recycled material use in structural applications is highly dependent on improvement in quality. Further research is needed to explore other avenues for use and improved quality of C&D recycled products, such as RCC and RCB.

Chapter 6 discussed the impact of waste management practices on the quantity of C&D waste materials recycled. To recycle C&D waste materials, there should be enough C&D waste material available for recycling. Therefore, the supply of recycled products depends on the supply of C&D waste materials. The challenge is to ensure that waste contamination is reduced at the waste collection and sorting points. The findings of this study were consistent with a study by Chong & Hermreck (2010), which concluded that the supply and demand of recycled construction materials was more inconsistent than the supply and demand of new construction materials. The findings of the Chong & Hermreck (2010) study was similarly based on the fact that supply of recycled construction materials depended on the supply of construction wastes from demolition and renovation projects, the locations where the materials were extracted, and the presence of transportation to deliver the materials to another site.

Supply is also driven by input prices, available markets, and expectations (Basic Economics, 2009). Unfortunately, recycling resource input prices (like fuel) keep rising, and this is likely to affect the prices of recycled products. Consumers are likely to find cheaper alternatives to recycled products if prices increase. For recyclers, the challenge is to make profits, without exploiting consumers. The ability to monitor prices of C&D recycled materials across the building industry could create a good system of fair pricing.

The cost incurred during recycling could affect the supply and demand of C&D recycled products. If demand does not exceed supply, then recyclers need to reduce prices to clear existing stock, and vice-versa. The demand for recycled products is driven by cheaper prices, and the calculation in Chapter 7 revealed that the cost per tonne for virgin gravel was higher ($25) than the cost of RCC/RCB ($20). The lack of a ready-market for recycled materials could cause the recycling companies to incur losses, especially with lower recycled material prices. Clearly, the fee for dumping C&D waste in landfill is critical in establishing a reasonable fee for the alternative of delivering the C&D waste material to the recycling plant, to improve the economies of recycling.

9.4 Governance findings

Governance aspect focuses on waste legislation (9.4.1) and product endorsement (9.4.2). In Chapter 8, the legislative contributions of seven organisations were discussed.

9.4.1 Waste legislation

Waste legislation discusses the impacts of the environmental, social and the economic aspects of recycling.

The overall benefits of recycling have not been clearly outlined in most existing waste legislation. In the absence of taxes and subsidies for landfilling and recycling (Section 9.3.1), most recyclers are not convinced of the monetary benefits of recycling. The uncertainties of the recycling benefits were also evident at some of the construction sites studied in Chapter 6.

The Victorian Government announced that it had exceeded its TZW target for 2008, and was on track to achieve the overall target of recovering 80% C&D waste material by 2014. However, a waste committee set up by the Australian Government, has pointed out that the evidence before them suggests, that many of the zero and limited waste in landfill targets of various jurisdictions, is not going to be reached. One of the primary reasons given is that price and regulatory signals indicate that landfill is still the most economically attractive means of waste management. The committee, however, suggests that to establish realistic targets on waste reduction that are achievable, appropriate and obtainable, cost-benefit analysis that factors in environmental and social externalities need to be undertaken (Parliament of Australia, 2008). In accordance with the committee's suggestions, this study attempted to quantify the environmental benefits of recycling, by calculating some cost impact and benefit areas crucial to the recycling process. However, measuring the social impacts of recycling is difficult, as human influence is dynamic, and may not necessarily follow any logical behavioural pattern. However, social impacts based on legislation, allow for an effective analysis of the economic and environmental impacts. For example, the construction sites study (Chapter 6) revealed that once on-site regulations were set, and disseminated through inductions, site workers were bound by those regulations, and became more involved in the waste management process.

Certain major government organisations are responsible for the legislation that governs the waste management industry, as summarized in Figure 9.1. The various aspects of waste management such as waste handling, recycling, and landfill are influenced by legislation from the various levels of government. The challenge for the government is to effectively apply the waste legislation to a dynamic building industry. Waste minimisation targets are not likely to be met, unless waste management strategies are strictly adhered.

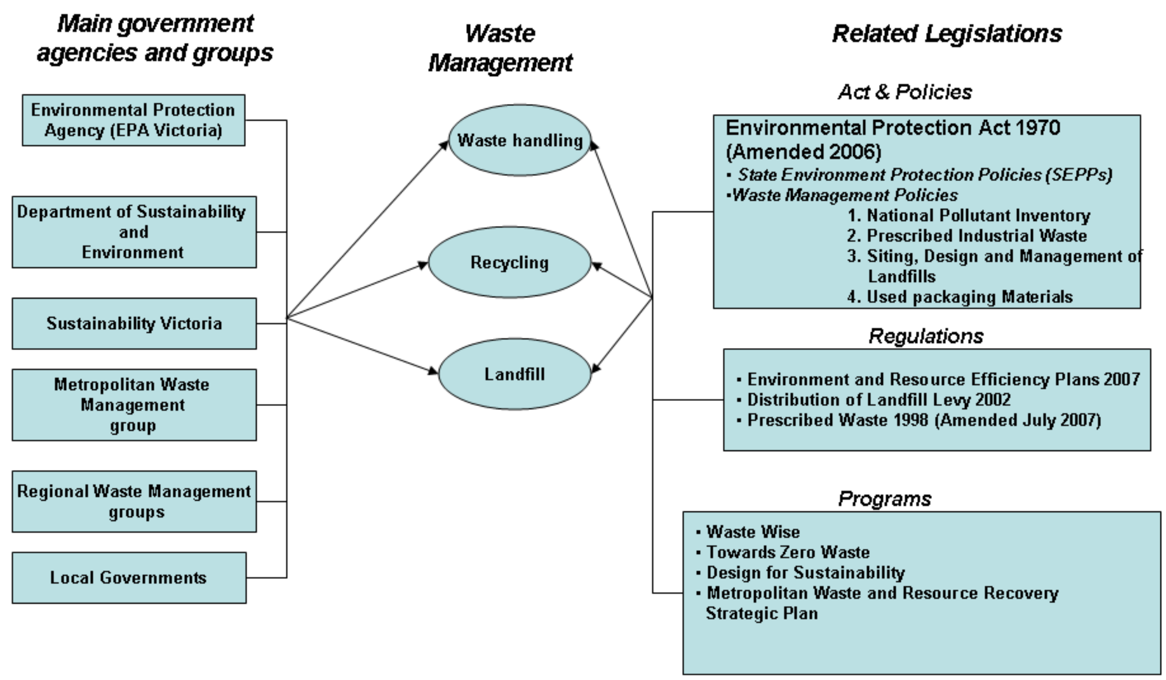

Figure 9.1: Major policies, regulations and waste management programmes in Victoria

(Source: EPA, 2008c)

Chapters 2 and 8 discussed legislation currently available as a guide for waste management implementation. In advocating for changes in practices, certain adjustments should be made to current legislation to incorporate effective waste management plans, which clearly outline the environmental, social, and economic benefits to recyclers and users within the C&D industry. For example, currently, legislation is generalized for recycled materials, and does not necessarily target the specific issues (such as product endorsement) associated with C&D recycled materials, as discussed in Chapter 8.

Victoria's waste minimisation strategy is well underway, and some major achievements have been made. However, every C&D material requires a different type of classification, and specific recycling requirements. General regulations exist for C&D waste classification, which is also sometimes classified as industrial/commercial waste. Such generalization does not allow for proper classifications, since each material quantity differs. For example, bricks are not recycled as much as concrete in the building industry. Once shortfalls for each C&D waste material are identified, the material quantity flows in the system can be targeted and improved. Incorporating waste specific mechanisms into waste legislation will ensure that all waste streams are properly classified, disposed of, and recycled. The mechanisms should take into account transport, energy, material quantities, demand and cost, as considered in this study.

In reviewing most recycling literature, the terms ‘recovery rate’, ‘diversion rate’ and ‘recycling rate’ were sometimes interchangeably used to refer to the recycling rate. In the United Kingdom, a study by Thomas (2001), based on the European Recovery and Recycling Association, has shown that to set performance indicators and improve stakeholders’ participation in recycling rates, there needs to be a clear definition of these terms. Thomas (2001) defined the recovery, diversion and recycling rates as the following:

- *“Recovery rate is the ratio of the amount of targeted material recovered from the generators served to the total amount of targeted material available in the waste stream from the generators served ×100”*
- *“Diversion rate is the amount of material recovered from the generators served/total amount of available waste from the generators served ×100”*
- *“Recycling rate is the quantity of materials sent for recycling (materials recycling)/total quantity of waste available ×100”*

The defined terms show three different meanings. The amount recovered and diverted might not necessarily be recycled. Using any of these terms, according to Thomas (2001), will depend on the definitions of indicators used. Therefore, to achieve a good recycling rate, other indicators are necessary to build a clearer picture of overall effectiveness of waste management.

9.4.2 Product endorsements

To sustainably manage C&D waste materials such as RC and bricks, they should be recyclable. C&D materials recyclability could be increased if a sustainable provision is made for its end-of-life. It is essential to advocate for sustainable products through endorsements, to allow for an effective recyclability at the end-of-life stage. There has also been some discussion about merging the various building materials rating tools, based on LCA, to achieve a uniform rating system through the Building Assembly and Materials Scorecard (BAMS[51]). The success of programmes like BAMS is key to improving the quality and durability of recycled materials, and ultimately increasing demand.

Regulatory instruments such as the Building Code of Australia, Product Stewardship, National Packaging Covenant, Green Procurement, landfill pricing, and Eco-efficiency design, have been used to promote C&D waste recycling, and the optimised use of C&D recycled materials. The recent introduction of the Buy Recycled Business Alliance (BRBA)[52] as a nationwide directory responsible for promoting recycled materials purchase and use has been welcomed as a good avenue for creating awareness for consumers within the building industry.

Currently, the Victorian programme for promoting sustainable products like C&D waste recycled products is ECO-Buy[53]. C&D recycled materials are endorsed on their environmental sustainability merits, with issues such as reduction in carbon emissions and recyclability high on the list of priorities. The ELCA of the recycling RC and brick waste materials considered environmental factors that could be endorsed, based on the reduced effects on the environment. AFG is currently listed on the ECO-Buy site, along side other supporters of good practice. The programme has drawn together local governments and waste management groups, to promote green products and suppliers.

[51] BAMS is an initiative to provide a common basis of assessment and comparison of the whole-of-life environmental performance of building materials. There are 2 scorecards; namely, the assembly and materials scorecards. This is to create a tool similar to LEEDS, MRPI, Eco-Quantum and BRE (RMIT, 2008).

[52] The Buy Recycled Business Alliance (BRBA) is a non-profit alliance of businesses, united by a commitment to promote the purchase and use of Recycled Content Products (RCPs) and materials. The BRBA was formally launched by the NSW Minister for the Environment, the Hon. Bob Debus MLA, in August 1999. It is the first online directory of its kind for RCPs and materials in Australia. It was re-launched in April 2008 (BRBA, 2008).

[53] ECO-Buy is running a programme for the Victorian state government to assist departments and agencies to green their purchasing practices, by positively influencing procurement processes, and providing tools and resources to assist in decision-making. This is funded by the Department of Sustainability & Environment (DSE), and will initially work with a small group of departments and agencies to pilot existing ECO-Buy services to develop an adapted programme for roll out (ECO-Buy, 2006).

Table 9.3 shows some of the organisations, websites, and regulations that seek to endorse the use of C&D recycled materials.

Table 9.3: Waste regulations, organisations involved and the promotion of C&D recycled products

Building Materials	Waste regulations/ Legislation (voluntary & compulsory)	Organisations involved	Websites promoting C&D recycled materials	Endorsed products examples
Concrete and brick waste	• Towards Zero Waste • Section 820 (RCC specifications) • Green Building Office Deign v3 (Materials section) • WMAA Best Practice Guidelines for Waste Processing • ISO 14020 series	• Sustainability Victoria • EPA • GBCA • Vic Roads • Waste Management Association of Australia (WMAA) • Green Environmental Choice Australia (GECA)	• Buy Recycled Business Alliance (Work in Progress) • Australian Green Procurement database • ECO-Buy • Ecospecifier	• E-Crete • Envirocrete • Eco-bricks

As the Victorian Government has announced that it is still on track to achieving the TZW targets by 2014, maintaining those targets is critical. For the achievements of the TZW to be maintained, there needs to be a demand for C&D recycled materials. With the increasing drive towards sustainability in the building industry, using endorsed materials could increase the C&D waste material quantities recycled. The demand for endorsed C&D recycled materials will require a change in the environmental and economic benefits of recycling, perceptions, preferences and behaviours, which are likely to be driven by a consumer influenced market. On the other hand, sole reliance on consumer preferences does not always result in the desired outcome, hence, there should be a joint effort from all stakeholders, with the environment at the forefront of decision-making in C&D recycled materials use.

9.5 Contribution of the TBL+1 aspects to the Study

The findings of this study were consistent with the EU study findings by Rasmussen et al. (2005). The problems identified by the EU study in Section 2.1, make a persuasive case for policy-makers and decision-makers to rethink the use of the principles in the waste hierarchy. The three main issues identified are outlined below:

- **Social cost-benefit studies cast doubts on the validity of the waste hierarchy as the sole ranking principle in waste management strategies** – this study analysed the social impacts as well as the cost and benefits of recycling, compared to landfill and virgin gravel production. Though recycling forms part of the waste management hierarchy, the hierarchy is mainly based on the environmental options of waste management. Thus, analysing the social and the economic aspects highlights other important factors discussed in this study.
- **There are inefficiencies in fixed recycling targets in the European Union** – the study of the 25 EU member countries revealed that countries had different economies, thus recycling targets had varying results based on income levels, size and composition of waste streams, proximity to markets for recycled materials, costs, and convenience of disposal options (Rasmussen et al., 2005). Victoria's TZW target is set to be achieved, but the Australian Government has raised concerns about the likelihood of most states achieving recycling targets (Parliament of Australia, 2008). The EU study advocates for a price-based policies.
- **European legislation on waste suggests a move towards more economic regulation, such as green taxes or tradable quotas, which are price-based policies** – this study has discussed the implications of applying subsidies and taxes that has been successful in Europe and the United States, and should be adopted in Australia.

The waste hierarchy serves as a guide to the available options for waste management for Victoria, but cannot be solely relied on, to provide the effective waste management strategy desperately needed in the building industry (Section 2.1). Recycling remains the preferred waste management option of the waste management hierarchy, when C&D waste cannot be reduced or re-used. Thus, recycling can only become sustainable, and the demand for C&D materials increased, when the four TBL+1 aspects in this study are applied.

The four TBL + 1 aspects of recycling contribute both theoretically and practically to the building industry and recycling plants. Theoretically, the four aspects of recycling advance both theory and knowledge about the overall impacts of recycling, compared to virgin materials, by highlighting the significant, but often ignored, aspects of recycling. The integration of the environmental, social, economic, and governance aspects, improves the industry's understanding of the dynamics of recycling. These four aspects of recycling, therefore, provide a complete assessment of C&D waste materials recycling. The proposed framework (Figure 9.2) has the potential to be used by other researchers as a guide to measure the optimised use of C&D waste materials.

In practice, the four TBL+1 aspects of recycling present the building industry with a sustainable method of managing C&D waste within a waste management plan. Hence, the four aspects of recycling have the potential to be used in both policy and practice related to C&D waste reduction, planning, and management. Effectively combining recycling with all four aspects, reduces the possibility of underestimating some of the inadequacies of C&D waste management, and substantiates implementation of a sustainable waste management plan for recycling purposes. For instance, discussions in Chapter 8 revealed that the impacts of legislation and product endorsements on recycling, and use of C&D recycled waste materials, had been underestimated. Underestimation of recycling benefits puts pressure on virgin non-renewable materials resources, and can also have serious unintended consequences, including increasing the overall cost and time of C&D projects. Therefore, the four aspects of recycling provide an effective framework that can enable the building industry and all other stakeholders to develop sustainable waste management plans.

Previous sections of this chapter discussed improvements to recycling, and highlighted some benefits of using C&D recycled materials. It is important that, irrespective of the approach adopted, all TBL+1 aspects are considered, although the contributory factors might differ from those discussed in this study. These factors should be considered on a project by project basis, and should serve as a guide when investigating waste management issues. Figure 9.2 shows the proposed framework that should be adopted to optimise the use of C&D recycled materials.

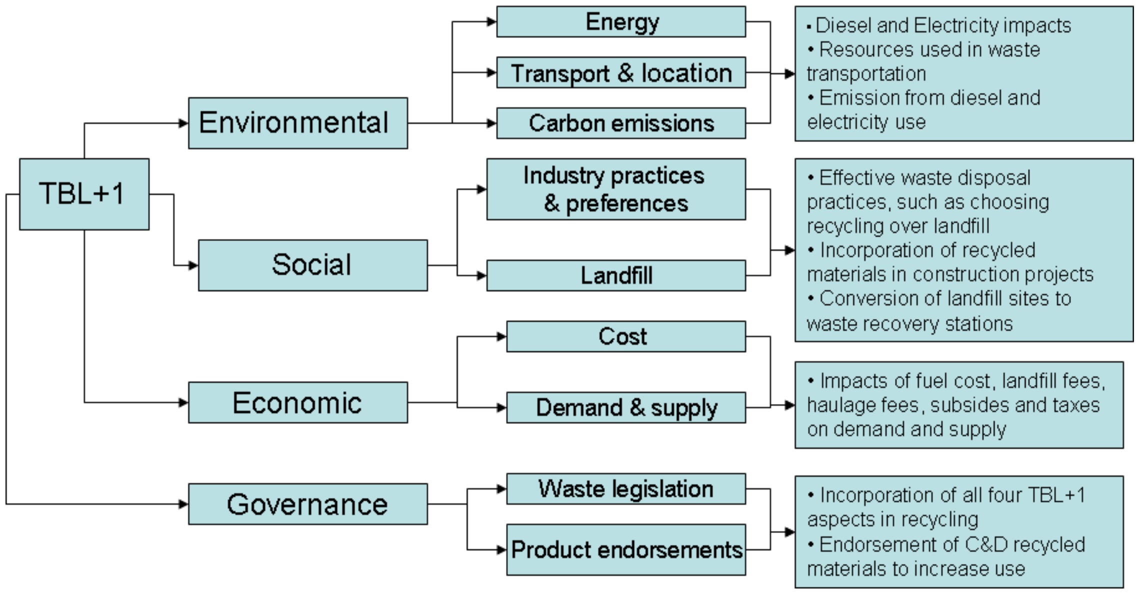

Figure 9.2: Proposed framework to optimise the use of C&D recycled materials

9.6 Overall contribution of the Study

The extent, to which the building industry can apply recycling practices, is an important component in assessing effective waste management plans. The assessment of recycling benefits is critical in improving the optimised use of C&D waste materials. Unfortunately, before this research, an examination of waste recycling literature indicated that little attention had been given to the integration of recycling with the TBL+1 aspects, to assess overall impacts. The lack of integration of recycling, with the TBL+1 aspects, presents a gap in the literature about recycling, and the amount of recycled materials used within the building industry. The contribution of this study, both to the research community and the building industry, is the introduction of the TBL+1 framework for recycling. These aspects bridge the gap between recycling and optimised use of C&D recycled materials, and highlights the fact that any one aspect, especially the environmental aspect, cannot be solely responsible for the evaluation and assessment of recycling impacts. The social, economic and governance impacts are very much an integral part of the C&D waste management process. This study, therefore, provides a significant contribution to recycling, and for future recycling and waste management researchers.

9.7 Limitations of the Study

This research, like many others, is not without limitations.

The first limitation relates to project specific applications of the four TBL+1 aspects of recycling. The framework was developed, based on the assertion that waste management practices work together with all aspects, to define the overall impacts of a project. Therefore, the TBL+1 framework of recycling, is applicable in most commercially funded projects that experience inadequacies in waste management practices, which can be mitigated with improvements to recycling. Better recycling practices can reduce the impacts from landfill disposal (high haulage cost, fuel cost, and landfill fees), lengthy travel distances, carbon emissions, and subsequently, reduce overall impacts. The identified impacts can be reduced, and effectively assessed, with improvements in recycling practices. However, the use of the four TBL+1 aspects of recycling in smaller budget projects is limited, since the overall waste management plan might be affected by cost and time factors. In such projects, the most significant TBL+1 aspect(s) of the project should be considered.

The second limitation relates to the application of this study to other C&D waste materials. Two areas of concern identified, include the number of C&D waste materials studied, and the C&D waste material types considered. This study was conducted on a small scale, with two C&D waste materials however, there are a vast number of C&D waste materials that can be studied using the TBL+1 aspects of recycling. It is therefore difficult to generalize the results obtained from this study, as directly applicable to other C&D waste materials such as timber, steel and asphalt. Each material type requires a different recycling process, and impacts realised are also quite diverse. The framework for the TBL+1 aspects of recycling has not been tested for how different material types can affect the final impact figures. Therefore, generalization of the study results should be made with caution.

The third limitation to the study relates to the method used to measure the environmental impacts of recycling, compared to landfill disposal. As indicated earlier, several factors affect the recycling process. These factors included transportation to the recycling plant; quantity of C&D materials recycled, and required input and output variables for recycling. In this study, SIMAPRO (developed by the PReConsultants in the Netherlands) was used to measure the environmental impact of recycling. SIMAPRO uses nine impact categories to evaluate the unit processes of recycling. Four relevant impact categories (global warming, water use, solid waste and embodied energy) were chosen for this study. While SIMAPRO provides a framework for understanding the impacts of recycling at a crushing plant like AFG, it does not fully account for all the other external factors that might affect the unit processes. However, in spite of the limitations, the study maximized the available results from the environmental TBL+1 aspect, to answer the research questions as best as possible.

Finally, AFG was very instrumental in providing the cost data for this study. However, the confidentiality issues across the industry meant that the full extent of costs and benefits could not be revealed. Data such as staff, administration, infrastructure, and overhead costs was not readily available, as it was confidential. However, this study made efforts to acquire best case data, which was representative of the AFG recycling plant, but acknowledges that the study of the AFG recycling plant is not necessarily a general representation of all recycling plant practices. Similarities and differences to other plants in areas such as technology used, capital invested, recycled aggregates types, material prices, and resource use may exist.

9.8 Future projections

This section attempts to predict future trends, based on the research undertaken.

9.8.1 Future environmental trends

Water, fuel (diesel) and electricity use are still likely to cause environmental impact in years to come through increased emissions and decreased resources. However, a shift towards more sustainable input options, such as renewable energy and other sustainable fuel sources is likely to occur.

Diesel is the main fuel for all kinds of commercial and industrial on and off-road vehicles. Caltex (fuel retailer) projects that demand will increase by around 4% per annum on trend. Governments in Australia have implemented a range of measures aimed at reducing CO_2 emissions from transport, including National Average Fuel Consumption targets, the Alternative Fuels Conversion Programme, and government bio-fuels measures. The impact savings from these measures are estimated to be 1.8 $MtCO_2$-e per annum over the Kyoto period and 5.0 $MtCO_2$-e in 2020. However, as a percentage of total road transport emissions, these projected savings are small, representing 2% in 2010, and 4% in 2020 (Caltex Australia Limited - CAL, 2009). For now, investments and research in other sustainable fuel alternatives are needed to help improve fuel impacts, as the research done in this study.

Gross electricity generation in Australia is projected to rise from 257 TWh[54] in 2005-06 to 415 TWh in 2029-30. This represents an increase of 62% over the projection period, and an average rate of growth of 2% a year (Syed et al., 2007). In Victoria, electricity generation is predicted to increase from 59.3TWh (2005-06), to 68.7TWh (2011-12), and 80.2TWh by 2019-20. The next step to improve recycling impacts in the future could see the introduction of renewable energy for commercial purposes. The Victorian Government's Renewable Energy Target scheme (VRET), which commenced on 1 January 2007, requires that 10% of total electricity generation be sourced from renewable energy sources by 2016 (Syed et al., 2007). For Australia, there is currently a mandatory renewable energy target of 25% by 2020.

[54] T – tera (10^{12}) and Wh watt-hours means Terawatt hours

Projections suggest that across Australia, the number of drought months will increase by up to 20% by 2030 (ABS, 2010). Water demand in Victoria is likely to increase by 2.3% per annum from 1996 to 2020 and 2050, whilst industrial/commercial use will increase by about 2.8% per annum, for the same period. Water use is likely to increase from 5,980 GL/a (in 1996), to 6,295 GL/a in 2020, and 6,422 GL/a in 2050. Forecast estimates suggest that water use in the industrial/commercial sector will increase to 11% by 2050 (Australian Natural Resources Atlas - ANRA, 2000). With the currents efforts to conserve water use in Australia, the use of recycled water in C&D waste recycling should become standard practice across the building industry.

9.8.2 Future economic trends

In the past, electricity and water prices have not increased as much as fuel prices. However, the trends in water and electricity use will result in higher prices, and directly impact on the costs associated with recycling production.

The Essential Services Commission (ESC, 2009) predicts that in the next pricing period (2013-2018), there will be an increase in water prices, and related services for Melbourne. Table 9.4 shows the price increases from 2007 -2013 for City West water, which was the water service provider used in this study. The increase in water prices over the five-year period is predicted to be about 23%. The ESC study projections reveal that the demand for water will determine the price consumers pay, hence, the forecasted low demand will increase prices, and vice-versa.

Table 9.4: Percentage increase in water prices from 2007-2013

	Price increases by the metropolitan retail businesses (%, in January 2009 prices**) – Final Decision**		
City West water	Average annual increase, 2008-09 to 2012-13	Total four-year increase 2008-09 to 2012-13	Total five-year increase 2007-08 to 2012-13
	12.2	53	76

(Source: ESC, 2009)

Electricity price increase has been predicted to fluctuate at $0.05 per MWh between 2010 and 2014 for four Australian states, as shown in Figure 9.3. The trend for Victoria (dark blue line), indicates that the fluctuations will continue to occur over the five-year period (2010-2014). Electricity price fluctuations will subsequently affect the overall cost of recycling.

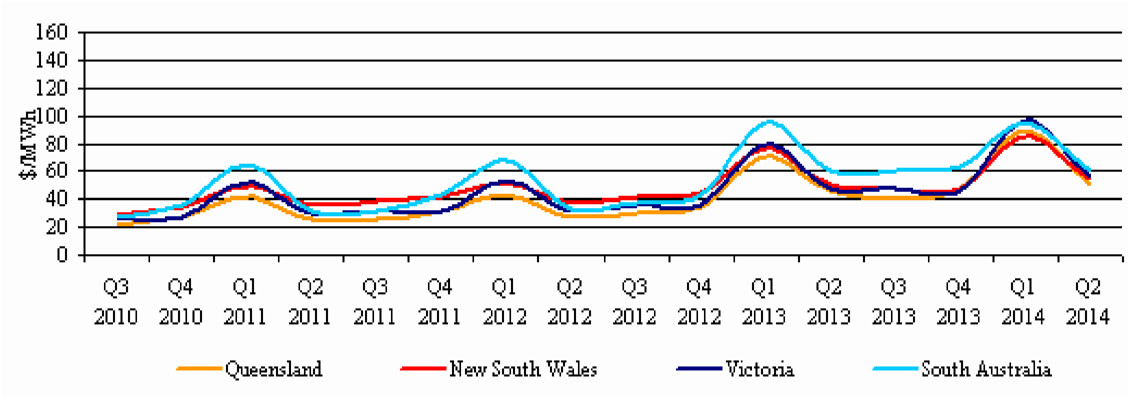

Figure 9.3: D-CyphaTrade regional quarterly base futures prices (Electricity)
(Source: Australian Energy Regulator - AER, 2009)

Fluctuating fuel prices strongly influence the overall recycling costs. Emerging diesel substitutes such as the Liquefied Natural Gas (LNG), bio-diesel, and other sustainable fuel options, are some of the government's initiatives to lower the price of fuel. Undoubtedly, opportunities for the use of cheaper sustainable electricity and fuel substitutes are needed, to continuously ensure reduction in the overall cost of recycling.

9.8.3 Future social and governance trends

The next five years are likely to see the adoption of recycling at C&D sites. However, this will need to be facilitated by modified legislation, and regulations in waste management, which focuses on improving industry practices. The diffusion of best practice is likely to occur, but only if it becomes standard practice across the whole building industry.

Recycled material quality improvements are likely to create an increase in demand, assuming all market forces are in place. There is the potential for increased use of RCC and RCB hence, future trends are likely to move towards improving RCC and RCB quality. RCC and RCB could replace virgin gravel entirely, if the issue of quality is adequately addressed.

As most landfill sites are predicted to be closed or converted to recovery facilities, C&D waste material quantities could increase beyond the capacity to recycle. The increased upgrade and development of buildings in Victoria is the reason for the likely increase in the quantities of C&D waste. This will create the opportunity for more recycling plants and transfer stations to be established. It is in the interest of waste management planners to use this as an opportunity to increase recycling, and create an effective system of waste management for Victoria.

Construction site practices will continue to influence the distance traveled, cost, time, and the waste quantities disposed. The adoption of good waste management practices should encourage the creation of more recycling plants and waste recovery facilities, and increase the trend towards sustainable waste practices.

Several relevant milestones have been identified and discussed in this study. Figure 9.4 outlines the Federal Government's proposed milestones to improve markets for recycled waste materials, whilst Figure 9.5 shows the milestones in pursuing sustainability in the next five years. These form part of the National Waste Policy, outlined in 2010 (Appendix A13, Table A13.1). Chapter 10 outlines conclusions and recommendations based on the research findings in this thesis.

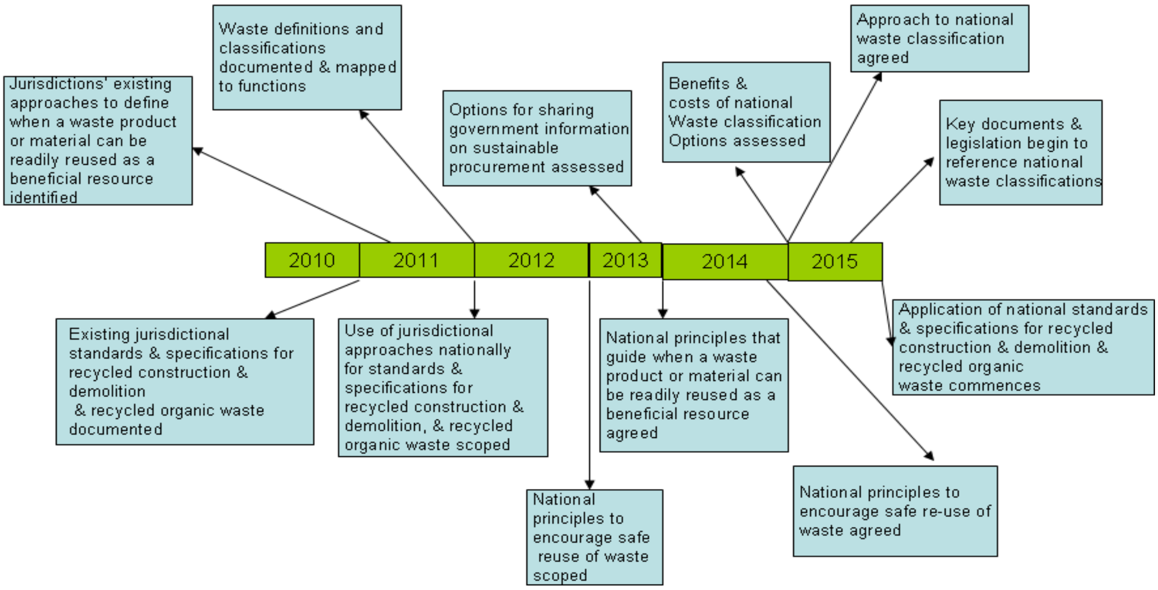

Figure 9.4: Selected milestones for National Waste Policy 'improving the market' direction

(Source: Environmental Protection and Heritage Council - EPHC, 2010)

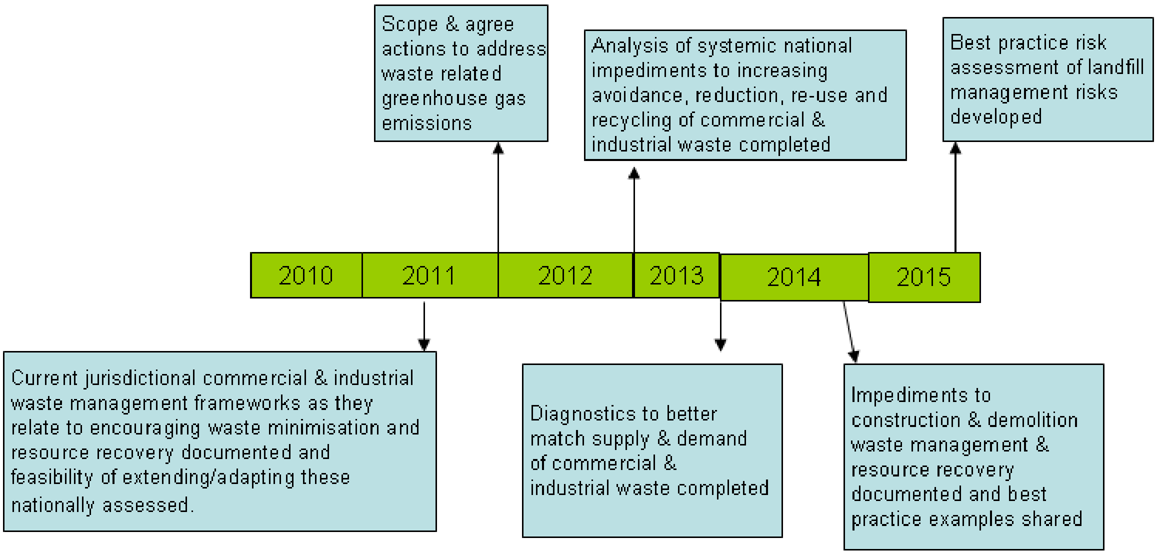

Figure 9.5: Selected milestones for National Waste Policy 'pursuing sustainability' direction

(Source: EPHC, 2010)

9.9 Chapter summary

The key findings identified in this chapter are summarized as follows:

- Section 9.1 – Adoption of sustainable fuel options to reduce the impacts of energy and transport
- Section 9.2 – Incorporate waste management plans in the entire planning stages of projects
- Section 9.3 – Establish reasonable landfill charges
    - To encourage contractors to deliver waste to recyclers
    - Allow recyclers to charge more for the acceptance of C&D waste
- Section 9.3 – Increase the downstream market for recycled products, for example, RCC and RCB use for other purposes, other than road bases
    - Incorporating of C&D recycled materials use into construction projects, as an alternative to virgin raw materials
    - Providing subsidies for recycled products whilst increasing taxes on virgin materials, and landfill prices
- Section 9.4 – Modify waste legislation to incorporate all the above

The interrelated nature of this discussion chapter makes it quite difficult to single out any TBL+1 aspect as the major driver to increased use of recycled C&D waste materials. This section, therefore, applies all four TBL+1 principles of the study.

Environmentally, the TBL+1 applied the 'Precautionary Principle'. Emissions from energy and transport are still a major part of environmental impacts. Recycling, though relatively sustainable, should use as many renewable resources as possible. The Precautionary Principle should be applied in resource use. Since developments are inevitable, this principle seeks to find the harmony between developments and the environment. Incorporating this principle into the study of carbon emissions, transport and energy means that precautionary measures can be applied. The use of transport and energy sustainably, would ensure that emissions were better controlled, when recycling took place and landfill was avoided. The adoption of sustainable alternatives requires a joint responsibility of all stakeholders, and effective management of recycling activities. Carbon emissions are inevitable, but can be considerably reduced during recycling.

Socially, the TBL+1 principle most appropriate for this study was the UN Global Compact sub-section (Section 3.2.2.1) on environment, which included the following three principles:

- Principle 7: support a precautionary approach to environmental challenges
- Principle 8: undertake initiatives to promote greater environmental responsibility
- Principle 9 : encourage the development and diffusion of environmentally friendly technologies

In recycling, these principles are needed to shape the attitudes, behaviours, and preferences within the construction and demolition industry. Adopting a precautionary approach to environmental challenges enables the industry to find a balance between developments and sustainability. Waste management practices and choices determine the level of responsibility on the part of both producers and consumers therefore, the adoption of the right practices and technologies across the industry is important. The waste management responsibilities should begin at the design stage (where recyclable materials should be used), through to the recycling and use of C&D recycled materials. At the construction and demolition sites where C&D waste materials are generated, source separation and provisions for recycling are very important to the recycling process. At the recycling plants, the main focus should be on how to recycle these materials, with less emissions and costs as possible, whilst aiming to improve quality. This will increase the recycled material benefits, compared to alternatives such as landfill disposal and virgin gravel production.

Economically, the TBL+1 best describe the dynamics of the supply and demand phenomenon, as Supply Chain Economics (RMIT, 2009). Supply Chain Economics considers environmental impact, which is hard to quantify in monetary terms. The costs and benefit results identified in the ELCC were calculated based on the results of the ELCA, to determine the environmental impact. Environmental impact occurs throughout a product's Life-Cycle, but such impact may be reduced during recycling, compared to the production of new products. Incorporating environmental impacts into supply chain management means that prices, taste and preferences should only be considered, after environmental conditions have been satisfied.

The TBL+1 Governance concept brings together the environmental, social, and economic aspects. The Australian Governance operates on both a national and state level. At the national level, the Commonwealth Government has assigned major priority to environmental governance, through some institutions such as Environment Australia, and the Department of Industry, Science and Resources (RMIT, 2009). On a State level, the Victorian Government works with organisations such as EPA, Sustainability Victoria, Metropolitan Waste Management Group, and some other organisations discussed in Chapter 8. The building industry should be accountable for the Commonwealth and State legislation, to enable clear guidelines for waste management to be established. Ideally, an effective waste legislation should answer the following four questions:

(a) What type of C&D waste materials can be recycled?
Most C&D waste can be recycled, for example:

- Concrete
- Bricks
- Asphalt
- Wood
- Steel
- Plastics
- Plasterboards etc

(b) Who is responsible for recycling?
All stakeholders, for example:

- Contractors
- Sub-contractors
- Site workers etc

(c) Why should C&D waste materials be recycled?

- To reduce environmental impact such as carbon emissions
- To save the depletion of finite resources, used in virgin materials production

(d) What will be gained by recycling these C&D waste materials?

- Environmental benefits from the avoided production of virgin materials
- Cost savings and increased income from recycling
- Downstream market opportunities for C&D recycled materials

So far, the industry is aware of 'what to recycle' and 'who should recycle'. Once the questions of 'why recycle' and 'what will be gained' are addressed, improvements to ensure increased recycling and use of C&D recycled materials can be achieved.

The implementation of TBL+1 in recycling requires actions such as:

- An in-depth environmental assessment of recycling
- An adoption of effective waste management practices
- An increase in landfill fees, and introduction of subsidies and taxes
- A modification of waste management legislation

10 CONCLUSION AND RECOMMENDATIONS

This chapter concludes the study and makes recommendations for further improvements to the optimised use of C&D recycled materials. Conclusions answer the first research question *"What are the major factors that could increase recycling of C&D waste materials?"*, whilst recommendations answer the second question *"How best can these factors be incorporated into existing practices to facilitate increased demand for RC and brick recycled materials?"* Conclusions are drawn from the research findings in Chapter 9, and fourteen recommendations are made.

10.1 Conclusion

This section outlines the conclusions for this study by advocating a carbon emissions reduction (10.1.1), adoption of effective waste management practices (10.1.2), driving demand and supply (10.1.3), and endorsing C&D recycled materials (10.1.4). Conclusions highlighting the major factors to increase recycling are important to achieve an optimised use of C&D recycled materials.

10.1.1 Carbon emissions reduction

Carbon emissions are currently a pressing issue in Australia. In this study, electricity and diesel use were the two major contributors to carbon emissions. Carbon emissions taxes (when introduced) will cause the industry to rethink recycling emission levels. It is important that waste management legislation, is modified to factor in the anticipated fuel tax cuts, such as the government's proposed CPRS. Unfortunately, this study concludes that carbon emissions during recycling are inevitable, but the measures to contain and considerably reduce emissions, are possible and very crucial. Comparatively, the options of landfill disposal and virgin gravel production had far more adverse environmental consequences. There were significant CO_2 emissions reduction for both RCC and RCB production. Opportunities for carbon emission reduction measures through the use of sustainable renewable energy resources should be utilized within the C&D industry.

10.1.2 Adoption of effective waste management practices

The choices made within the C&D industry affect the recycling and use of C&D waste recycled materials. Whilst encouraging good waste management practices, it is also important that the industry spearheads the demand for C&D recycled materials. A trickle down effect of best practice should be enforced through the current waste regulations. That said, not all regulations have achieved effective results, so a hands-on approach is needed within the C&D industry. Various C&D companies mentioned in Chapter 6 have taken the first steps toward sustainable waste management practices. It is important that individual companies share case-studies from their successes across the building industry. Cost and time still remain the two most important considerations for every project. Currently, the C&D industry is still skeptical about adopting new waste management practices, due to the uncertainty about their implementation effects on cost and time of projects. The adoption of effective waste management practices require that these two elements be considered in every waste management plan.

10.1.3 Driving demand and supply

The cost calculations in this study have shown the costs savings of recycling. The cost analysis for C&D recycled materials prices helped define cost and benefit accounting, desperately needed within the C&D industry. In the short term, price transparency might not seem beneficial, especially when recycling costs initially appear higher, compared to virgin gravel production. However, recycling cost savings add up in the long-term. The eagerness of C&D companies, in recent times, to sell themselves as sustainable in all projects, could increase demand for C&D recycled materials. Industry awareness of C&D waste recycling benefits creates avenues to engage best practice solutions, for good out comes. This is important for establishing an effective demand and supply system for both producers/recyclers and consumers. The cost and benefits of recycling are key to driving C&D recycled material demand and supply.

10.1.4 Endorsing C&D recycled materials

Current legislation should take into consideration the issue of endorsing more C&D recycled materials through a uniform channel. Organisations discussed in various sections of this study, have initiated several endorsement systems. The endorsement of a product assures producers and consumers of less impact on the environment. Consumer choices currently influence the building material preferences of builders seeking a competitive edge on sustainable building materials used in projects. This implies that consumers are dictating the building materials markets. It is a step in the right direction, that recycled building materials like concrete and bricks are finally being endorsed in Victoria. The next step in this sustainable development will be for the State Government to advocate the promotion of more C&D recycled products. Since this programme is still in its early stages, it should be reviewed in a few years, to determine if the endorsement of recycled materials has increased consumer demand in Victoria. This could be an avenue for further investigation in a future study.

10.2 Recommendations

Recommendations are made according to findings on both the construction and recycling sites. The recommendations focus on construction and recycling site improvements. These recommendations were also submitted to the BICC. From the recommendations, future practices for recycling and the use of C&D waste materials, could be improved for target groups such as:

- Construction and Demolition Industry
- Recyclers
- Waste Management planners/ Regulators
- Product Specifiers

The critical barriers to best practice in C&D waste recycling and C&D recycled materials use outlined in the recommendations are summarized into the following four sections:

- Poor worker awareness
- Slow diffusion of best practice to the wider industry

- Lack of detailed information on the economics of recycling
- Adjustment of current state waste management legislations

Several creative and innovative measures are required to overcome different aspects of the barriers identified in this study. Increased use of these measures across the industry, and a programme ensuring continuous improvement are critical. Based on better understanding of the technical processes and the economics of each stage of recycling, disposal chains have the potential to put into practice the actions recommended by this study.

The recommendations cover actions that could be pursued by individual building developers, C&D companies, the industry as a whole, government, and jointly by industry, and government. BICC could have an overarching responsibility for the programme, and seek agreement with relevant government agencies or industry associations, to supervise specific initiatives.

10.2.1 Poor worker awareness - changing worker behaviour

- At a simpler level, companies in a variety of industries have engaged workers by setting site performance targets, and keeping workers apprised of progress through signage (this is now almost standard practice in OHS). Teams that achieve the best performance may also be rewarded – ranging from cash rewards and simple prizes, to celebratory functions, such as group barbecues or lunches.

Recommendation 1: Balance the 'stick' approach, by rewarding workers and sub-contractors that achieve or exceed recycling targets, or exhibit creativity and innovation in waste minimisation.

- As a first practical step to convey a consistent message that promotes innovations in waste minimisation, a short video could be made available to employers to use with the worker induction that conveys the social, environmental and economic benefits imperative for effective recycling, and shows the simple steps involved. This could ensure a consistent message goes out to workers about the importance of recycling.

Recommendation 2: As part of site inductions, develop a short video presentation or appropriate signage, illustrating best practices in waste minimisation and recycling, conveying the benefits for the overall projects and the workers' companies.

10.2.2 Diffusion of best practice to accelerate wider industry uptake

- Keeping waste streams separate at the source is the biggest opportunity for industry to gain a business benefit from improved environmental practice. Better documentation of this economic opportunity will also assist industry change, and the steps needed to do this are outlined in Section 10.2.3. However, there is already enough information to mount a persuasive case for industry change.

Recommendation 3: Industry and government should jointly develop an information programme aimed at conveying the imperative benefits of C&D waste recycling. The programme should build on the C&D aspect of the current Waste Wise programme being delivered by Sustainability Victoria.

- To support the information campaign, an incentive programme would help motivate companies to develop creative strategies to increase recycling, or to offset some of the initial cost of implementing new business systems and practices.

Recommendation 4: Establish an incentive programme that will provide financial support for construction projects, to facilitate the development of on-site recycling strategies, or to fund innovative recycling programmes.

- The incentive programme could be modelled on Sustainability Victoria's COBEI (Commercial Office Building Energy Initiative), in which

Sustainability Victoria matches a company's financial allocation for projects aimed at achieving sustainable building design and practice. This could be managed under Sustainability Victoria's Waste Wise programme.

Recommendation 5: Use case-studies from new projects to replenish and advance the information campaign on best practice.

10.2.3 Establish the economics of recycling

- It could well be that construction projects would improve their recycling practices if there are subsidies as well as taxes on virgin alternatives, since this will clearly outline the financial benefits of recycling C&D waste materials. Alternatively, a high landfill dumping fee would drive behavioural change.

Recommendation 6: Implement subsidies and taxes, whilst increasing landfill cost to drive recycling across the building industry.

Recommendation 7: Identify incentives and disincentives to waste minimisation within the rebate system, and recommend changes that will drive best practice.

- The potential for materials suppliers to assume responsibility for their waste, could be further explored with the materials supply companies, developing further initiatives such as that between CSR and Grocon at the AXA site, for recycling gypsum from plasterboard. Importantly, well researched information on the costs and benefits of recycling would provide a good basis for companies to review their waste management practices.

Recommendation 8: Conduct a cost-benefit analysis of recycling, building on this study, which tracks the path of C&D waste leaving a project site, and includes transport and other costs involved.

10.2.4 Adjustment of current state waste management legislation

- The government has initiated some developments in sustainable fuels. Though these initiatives are still in the initial stages, they have been successfully used in other sectors of production. Hence, the recycling industry could incorporate these sustainable alternatives. This would further improve the energy and transport impacts of recycling, such as those realised in this study. The adoption of alternative fuel uses like bio-diesel and LNG is a good starting point, to reduce current contributions to carbon emissions.

Recommendation 9: Sustainable fuel alternatives should be adopted in C&D waste recycling, especially in terms of energy and transport use, to reduce carbon emissions.

- This study indicated that the preferred option, to recycle 100% of RC and brick waste, should be encouraged across the state, with a total landfill disposal ban. Many European countries such as the Netherlands and the United Kingdom have enforced this ban, by imposing heavy penalties for dumping.

Recommendation 10: A total ban for dumping concrete and brick waste in landfill should be enforced in Australia, with heavy penalties imposed.

- The government's plan to close landfill sites in Victoria could create more land area for other uses such as C&D materials recovery facilities and recycling plants. This would reduce the travel impacts on cost and the environment. Recovery plants (collection points) located between waste creation points and recycling plants, would allow for a bulk transportation of waste, and a constant supply of C&D waste for recycling. In this way, an effective waste material management could be ensured.

Recommendation 11: Recovery and recycling plants should work in close co-ordination with each other to ensure a constant supply of C&D waste materials to the recycling industry.

- Penalties and fines are currently not clearly defined. Projects that want to encourage best practice, could adopt fines to deter unsustainable waste management practices during the course of a project. This was the case with some of the construction sites studied. Penalties and fines should be fully enforced, not just at project levels, but also at the industry level. This should become common practice across the industry.

Recommendation 12: Apply penalties and fines for construction and demolition projects that do not conform to waste management plans.

- The rebate system mentioned in recommendation 7 should also be applied to projects that use C&D recycled materials. Currently, the GBCA points system remains the main form of recognition for projects that use C&D recycled materials. A financial payback would encourage demand, and promote an injection of C&D recycled materials back into the building industry.

Recommendation 13: Financially reward projects that use C&D recycled materials through rebates.

- There are several tools used to certify recycled materials in general. The industry needs to be more specific in the classification of C&D recycled materials. Some producers certify products based on the various stages of the product's Life-Cycle. Though Life-Cycle can be used for certification of C&D recycled materials, the certification procedure should be uniform across the C&D industry. ECO-Buy is a good starting point for this in Victoria.

Recommendation 14: Create a uniform certification system for C&D recycled products that are widely recognised across the building industry.

Finally, the drivers and barriers are numerous, but the drivers that shape the C&D industry should eliminate barriers through the adoption of best practice within the industry. Best practice diffusion is the key to increased recycling, backed by appropriate legislation, and increased landfill fees.

10.3 Future research recommendations

Recommendations for future research are outlined in this section. Areas that could facilitate the optimisation of C&D recycled materials use include

- **Investigating the quality of C&D recycled materials within the building industry:** RCC and RCB quality affects its use in the building industry. Further research is needed to investigate areas for further improvements in quality, and other avenues for C&D recycled material use, particularly in structural applications. Product certification for C&D recycled materials could assist in initiating this process.

- **Investigating the lack of space for sorting waste:** Most commercial construction sites in Melbourne are currently located in the central business district. This study has highlighted some of the best practices that could be adopted, but acknowledges that different sites might require different waste management strategies. Innovations in relation to waste sorting, and prevention of contaminants on construction sites, are key to increasing recycling.

- **Correctly quantifying recovered and recycled C&D waste materials:** The quantity of recovered waste recycled is critical. The industry sometimes assumes that all waste recovered materials are recycled, but this is not always the case. It is important that future studies clearly differentiate between the figures recovered and recycled, to correctly identify waste flow quantities. This will allow for a better quantification of C&D recycled materials.

- **Identifying measures to effectively apply a total ban on landfill:** Study the successes achieved in the total ban of concrete disposal in European countries such as the Netherlands and the United Kingdom. This could identify how such a ban could be applied to the current situation in Australia. Investigate measures to prevent waste from being sent to landfill, for example, the impact of landfill fees on waste disposal. The effective implementation of landfill fees in NSW could serve as a case-study, with critical drivers adopted across other Australian states like Victoria. Could higher fees eliminate landfill disposal?

- **Effectively classifying C&D waste types through legislation:** Victoria's waste minimisation strategy is well underway, and some major achievements have been made. C&D waste like concrete, bricks and asphalt, are generally classified as rubble (Section 9.4.1). A proper classification of individual C&D waste quantities is needed. A future study could investigate the various waste legislations on specific waste types, to identify how specific material end-of-life options could be improved. Waste specific mechanisms incorporated into waste legislation would ensure that all waste streams were properly classified, disposed of, and recycled. The mechanisms should take into account transport, energy, technology, quantities, demand, and cost. A proposed legislative framework for specific material types could initiate the process.

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APPENDICES

Appendix A1: WasteWise Phase II Summary Report 2001

This summary report covers the full year of 2001, and builds on the previous WasteWise Phase II report for 2000. WasteWise began in 1995 as a demonstration programme between ANZECC and five leading construction companies to pioneer best practice waste reduction in the industry. Partners committed to a 50% waste reduction target by the year 2000 against 1990 per capita levels. Following the success of the initial 3-year WasteWise programme, a second phase of the programme began in 1998 with an expanded membership of 14 organisations. WasteWise Phase II officially concluded in December 2001. Waste Wise was discussed in Chapter 2 (Section 2.1.2)

The final phase of WasteWise involved fourteen Partners, from industry associations (7), construction companies (6) and an architecture firm.

Construction Companies

- Barclay Mowlem Construction Ltd;
- Bovis Lend Lease Pty Ltd;
- John Holland Group Pty Ltd;
- Multiplex Constructions Pty Ltd;
- Project Co-ordination (Australia) Pty Ltd;
- Thiess Pty Ltd.

Industry Associations

- The Australian Institute of Building;
- The Australian Institute of Landscape Architects;
- The Civil Contractors Federation;
- The Housing Industry Association;
- The Institute of Public Works Engineering Australia;
- The Institution of Engineers, Australia
- Master Builders Australia;

Architecture

- Taylor Oppenheim Architects;

Source:
www.environment.gov.au/settlements/industry/construction/wastewise/phase2001.html
(May 2007)

Appendix A2: Interview Guide – Research on C&D Waste Recycling Practices

The structured open-ended questionnaire used in the six construction sites study is outlined below. The responses from the interviews are discussed in the site findings in Chapter 6 (Section 6.2)

<u>Project planning (corporate philosophy and attitude)</u>

1. Did the project brief have specifications on recycling of construction waste?
2. If so, who decided to include recycling and what was the reason? (Question is designed to tease out if the initiative came from the project owner or the contractor)
3. Was a waste management plan developed during the design process?
4. If so, what are the key features?
5. Was there provision for staff input, feedback and continuous improvement/innovation?
6. Who enforced the plan on-site?
7. Were there incentives for contractors and workers to follow the waste management plan?

<u>Site operations</u>

1. How well-informed were workers on-site about waste recycling? Was the plan part of site induction?
2. What materials were recycled?
3. Could you give a sense of the recycled volume for each material?
4. Were the materials sorted on-site, or just mixed together to be sorted by the recycling company?
5. If sorted, did this add time to the project schedule?
6. Did you find that some materials were not worth recycling and better disposed off? Why?
7. Were some of the recycled materials used for the project?
8. Are there interesting on-site experiences with workers illustrating barriers to implementing the recycling plan, or conversely, illustrating innovation on-site.
9. Were there progress meetings to determine how well the plan was being implemented?
10. If so, who were involved in the meetings?

11. Were lessons from the project reported and codified to be incorporated in future projects?

Supply chain

1. Did you find recycling services to be readily available?

2. Do you think there is a ready-market for recycled construction materials?

Economics of recycling

1. Did recycling increase the cost of construction?
2. What were the major costs, for example, skips, and haulage, etc
3. Did you earn anything from recycling?
4. If so, which materials were profitable and which were costly to recycle?

Appendix A3: Waste Generation, Disposal and Recycling Rates

The four tables below show the waste generation, disposed recycled and composition trends for 2002-03 in Australia. In Victoria, the total waste generated was over 8.5 million tonnes (Tables A3.1). Half of the waste was disposed (Table A3.2), whilst the other half was recycled (Table A3.3). Concrete made up about 82% of the waste quantities for the same year (Table A3.4). Chapter 2 (Section 2.3.2) explained further.

Table A3.1: Waste Generation 2002- 03

State / Territory	Municipal '000 tonnes	C&I '000 tonnes	C&D '000 tonnes	Total '000 tonnes
New South Wales	3,326	4,196	4,649	**12,171**
Victoria	2,291	2,743	3,575	**8,609**
Queensland	1,742	959	1,166	**3,973**
Western Australia	833	744	1,945	**3,522**
South Australia	600	677	2,156	**3,433**
Tasmania	na	na	na	**na**
ACT	111	150	250	**674**
Northern Territory	na	na	na	**na**
Australia	**8,903**	**9,469**	**13,741**	**32,382**

(a) Excludes Tasmania and the Northern Territory.
Source: Department of the Environment and Heritage, 2006 Submission to the Productivity Commission Inquiry into Waste Generation and Resource Efficiency.

Table A3.2: Waste Disposed 2002-03

State / Territory	Municipal '000 tonnes	C&I '000 tonnes	C&D '000 tonnes	Total '000 tonnes
New South Wales	2,170	2,831	1,340	**6,341**
Victoria	1,547	1,003	1,630	**4,180**
Queensland	1,297	747	678	**2,722**
Western Australia	741	420	1,535	**2,696**
South Australia	365	208	704	**1,277**
Tasmania	na	na	na	**na**
ACT	82	98	27	**207**
Northern Territory	na	na	na	**na**
Australia	**6,202**	**5,307**	**5,914**	**17,423**

(a) Excludes Tasmania and the Northern Territory.
Source: Department of the Environment and Heritage, 2006 Submission to the Productivity Commission Inquiry into Waste Generation and Resource Efficiency.

Table A3.3: Waste Recycled 2002-03

State / Territory	Municipal '000 tonnes	C&I '000 tonnes	C&D '000 tonnes	Total '000 tonnes
New South Wales	1,156	1,365	3,309	**5,830**
Victoria	744	1,740	1,945	**4,429**
Queensland	445	212	488	**1,251**
Western Australia	92	324	410	**826**
South Australia	235	469	1,452	**2,156**
Tasmania	na	na	na	**na**
ACT	29	52	223	**467**
Northern Territory	na	na	na	**na**
Australia	**2 701**	**4,162**	**7,827**	**14,959**

(a) Excludes Tasmania and the Northern Territory.
Source: Department of the Environment and Heritage, 2006 Submission to the Productivity Commission Inquiry into Waste Generation and Resource Efficiency.

Table A3.4: Solid Waste composition 2002-03

Composition	Municipal (%)	Commercial and Industrial (%)	Construction and Demolition (%)
Organics (Food and garden)	47	13	1
Paper	23	22	–
Plastics	4	6	–
Glass	7	2	–
Metals	5	22	7
Concrete	3	3	82
Timber	1	9	4

- is nil or rounded to zero.
Note: Municipal waste includes domestic waste and other council waste (e.g. beach, parks and gardens, street litter bins).
Source: Productivity Commission, (DEH 2006), Inquiry into Waste Generation and Resource Efficiency, Draft Report.

Appendix A4: Sample of a Recycling Report

Table A4.1 shows a sample of a recycling report obtained from the MCC and CBW sits during the data collection period. Chapter 6 (Section 6.2.3) explains the benefits of recycling reports.

Table A4.1: MCC and CBW Recycling Reports

Bricks and roof tiles		Metre^3		tonnes		tonnes		tonnes	
Virgin Excavated Natural Material		Metre^3		tonnes		tonnes		tonnes	
Concrete	**26.00**	Metre^3	**39.00**	tonnes	**39.00**	tonnes	**39.00**	tonnes	NATIONAL RECYCLING
Asphalt		Metre^3		tonnes		tonnes		tonnes	
Vegetation Waste		Metre^3		tonnes		tonnes		tonnes	
Timber	**58.00**	Metre^3	**17.40**	tonnes	**17.40**	tonnes	**17.40**	tonnes	NATIONAL RECYCLING
Fill (Demo and Inert)	**10.00**	Metre^3	**16.00**	tonnes	**16.00**	tonnes	**16.00**	tonnes	NATIONAL RECYCLING
Glass		Metre^3		tonnes		tonnes		tonnes	
Plasterboard		Metre^3		tonnes		tonnes		tonnes	
Plastic	**37.00**	Metre^3	**6.40**	tonnes	**6.40**	tonnes	**6.40**	tonnes	NATIONAL RECYCLING
Metal	**38.00**	Metre^3	**34.20**	tonnes	**34.20**	tonnes	**34.20**	tonnes	NATIONAL RECYCLING
Cardboard	**49.00**	Metre^3	**4.90**	tonnes	**4.90**	tonnes	**4.90**	tonnes	NATIONAL RECYCLING
Polystyrene		Metre^3		tonnes		tonnes		tonnes	
Insulation		Metre^3		tonnes		tonnes		tonnes	
Mixed Waste	**18.00**	Metre^3	**5.40**	tonnes		tonnes	**5.40**	tonnes	BORAL LANDFILL
Total	**236.00**	Metre^3	**123.30**	tonnes	**117.90**	tonnes	**123.30**	tonnes	
Recycle %	95.62%								

Waste Recycling Report **Multiplex CBW** **April 2007**

Material	Total quantity generated		Total quantity generated		Total recycled		Total disposed of		Method & location of disposal
Bricks and roof tiles		Metre^3		tonnes		tonnes		tonnes	
Virgin Excavated Natural Material		Metre^3		tonnes		tonnes		tonnes	
Concrete	**42.00**	Metre^3	**63.00**	tonnes	**63.00**	tonnes		tonnes	NATIONAL RECYCLING
Asphalt		Metre^3		tonnes		tonnes		tonnes	
Vegetation Waste		Metre^3		tonnes		tonnes		tonnes	
Timber	**240.00**	Metre^3	**72.00**	tonnes	**72.00**	tonnes		tonnes	NATIONAL RECYCLING
Fill (Demo and Inert)		Metre^3		tonnes		tonnes		tonnes	
Glass		Metre^3		tonnes		tonnes		tonnes	
Plasterboard		Metre^3		tonnes		tonnes		tonnes	
Plastic	**48.00**	Metre^3	**9.60**	tonnes	**9.60**	tonnes		tonnes	NATIONAL RECYCLING
Metal	**16.00**	Metre^3	**14.40**	tonnes	**14.40**	tonnes		tonnes	NATIONAL RECYCLING
Cardboard	**34.00**	Metre^3	**3.40**	tonnes	**3.40**	tonnes		tonnes	NATIONAL RECYCLING
Polystyrene		Metre^3		tonnes		tonnes		tonnes	
Insulation		Metre^3		tonnes		tonnes		tonnes	
Mixed Waste	**40.00**	Metre^3	**12.00**	tonnes		tonnes	**12.00**	tonnes	BORAL LANDFILL
Total	**420.00**	Metre^3	**174.40**	tonnes	**162.40**	tonnes	**12.00**	tonnes	
Recycle % Total	93.12%								

Appendix A5: Site Visit and Inspection of Operations

Colleja Waste Management and Recycling
20-30 Baldwin Rd Altona North

The site visit took place on the 23rd August, 2006. Chapter 6 (Section 6.2.3) discusses the relevance of such visits to the recycling process.

Operations were inspected in the presence of;
- Dean Colleja – Colleja Waste Management and Recycling
- Peter Dudley - Colleja Waste Management and Recycling
- Simon Pinwill – Collex Pty Limited (now Veolia)
- Alan Ker – Grocon

The group observed the delivery of construction site waste from a variety of sources, including Collex (Veolia) vehicles.

Material from the trucks passes over a weighbridge where total load is weighed. The volumes of the various components of the load include bricks, concrete, metals, soil timber, plasterboard.

Figure A5.1: Weighbridge

The truck is then unloaded within the confined space of a concrete floored warehouse where wind blown litter is able to be controlled. Once in this position, the material are sorted using a variety of mechanical and manual operations. Bricks, concrete, metals, soil timber and plasterboard is extracted and placed into separate piles. They are then moved to larger stockpiles or bins for delivery to a range of other recyclers.

Figure A5.2: Off loading centre

Destination of Recovered Materials

- Bricks - stockpiled until they can be cleaned off and resold.
- Concrete – sent to Alex Fraser Recycling or Recovery and Recycling Industries for crushing and resale as aggregate.
- Soil is re-used at the company's Bacchus Marsh coal mine for perimeter screening.

Figure A5.3: Piles of C&D waste

- Metals – sold to Sims or Norstar Recyclers.

Figure A5.4: Pile of extracted metal

- Timber – all mdf, plywood, painted and contaminated timber is removed. All other timber is sent to mossrock for chipping and re-use as mulch.

Figure A5.5: Pile of recovered timber

- Plasterboard – sent to Recovery and Recycling Industries for crushing and resale as gypsum.

Figure A5.6: Bins for plasterboard

Appendix A6: Waste Minimisation and Recycling Agreements with Workers (Multiplex example)

This section shows an example of a waste minimisation and recycling agreement. Construction site workers are informed by using these agreements as explained in Chapter 6 (Section 6.2.4).

Site Induction for Waste Minimisation & Recycling

SITE INDUCTION FOR
WASTE MINIMISATION & RECYCLING AGREEMENT

Multiplex is committed to 80% Waste Minimisation for the Melbourne Convention Centre Development Project.

All **products that can be recycled will be recycled, and shall be placed in approximately marked containers supplied by Multiplex.**

1. Material for Recycling

- Metal (including aluminium);
- Concrete / tiles / bricks;
- Timber;
- Plasterboard; and
- Cardboard.

All recyclable waste above shall be placed in appropriately marked bins by the subcontractor.

2. All other General Waste

- PVC;
- Insulation;
- Plastics;
- Strapping.

All general waste above shall be placed in appropriately marked bins by the subcontractor.

3. Putrescible Waste/Food Waste & Glass/Aluminium/Plastic (Lunchroom)

All food waste/lunchroom litter and glass, aluminium & plastic drinking bottles and *cans* must be placed in appropriately marked bins inside/outside lunchrooms.

4. Flammable / EPA Waste (Dry only)

- Sealants (silicon/polyurethane);
- Sealant containers;
- Empty paint tins (both acrylic & oil);
- Oily rags;
- Empty varnish tins;
- Empty petrol containers;
- Empty oil containers;
- Empty aerosol tins.

This waste must be placed in marked <u>EPA Hazard Bins</u> for disposal. This conforms to EPA (Vic) & OHS Legislation.

5. Flammable / EPA Waste (Wet only)

- Liquid paint/varnishes
- Washing out of brushes (acrylic & oil based paints, and varnishes).

EPA states that all washing out of brushes (acrylic, oil based paints and varnishes) shall not be rinsed into stormwater ***or*** sewer drains. The Painter will provide two marked 1000L ISO containers for this purpose. One for water washing and another with turpentine.

Subcontractors must adhere to Multiplex Waste Minimisation commitment. All recyclable waste above shall be placed in appropriately marked bins by the Subcontractor. Multiplex will impose on subcontractors substantial fines for waste that has been placed incorrectly in recycle bins.

Subcontractor agrees to participate in all efforts to achieve the recyclable target of 80% on the Melbourne Convention Centre Development project.

I have read and understood the above and will comply with the above waste minimisation and recycling agreement.

Signed for an on behalf of Subcontractor	Witnessed on behalf of Multiplex
________________________	________________________
Name: Title: Dated:	Name: Title: Dated:

Figure A6.1: Waste Minimisation and recycling agreement

Appendix A7: Waste Management Plans

Figures A7.1 to A7.3 show the three waste management plans for the MCC, 55 St. Andrews Place and CBW construction sites studied. Chapter 6 (Section 6.2.1) discussed the obligation of contractors and sub-contractors to the waste management process.

MULTIPLEX
Melbourne Convention Centre Development

24.0 THE ENVIRONMENT

All Sub-contractors are required to comply with the Multiplex Environmental Management Plan. This plan outlines how each sub-contractor will meet their legal obligations and Multiplex requirements in regard to Waste minimisation and Protection of the Environment. Your cooperation in this issue is required. Some key environmental issues include:-
The development is required to achieve a 6-star Green Star rating which is the highest possible obligation to be imposed.

The imposed 6-star rating requires the construction process to recycle 80% of building waste products. As such the appropriate bins for timber, concrete, steel, plasterboard, cardboard must be used. If the recycle bins are found to be polluted the sub-contractor will be back charged. You must ensure that rubbish is placed in the correct bins as signed.

After having completed an audit on the site it was found previous use of the area has contributed to contamination of the soil and groundwater. Should you be required to excavate any soil it...is necessary that you undergo a site specific "Earthworks" induction also.

Storm water drains are for clean rainwater only, no paint, sand, cement, chemicals can be put into the drains. Do not hose anything into storm water drains

Make sure that paint and other chemicals do not soak into the ground or get into storm water drains

Immediately notify your Supervisor or the Site Manager of any chemical spills or substance release to ensure effective clean up.

The planning permit on site has restrictions on "Noisy Works". As such before starting any activity that could be considered "noisy" contact your employer OJ Site Management to confirm the requirements.

Regularly check and maintain noisy equipment
Do not light any fires on-site

Maximum penalty for most pollution offences have been doubled for companies and individuals.
Report any environmental concerns to your supervisor or the Site Manager

S:\M.C.C.D\9.0 QMS OHS EMS\9.11 Induction & Declarations\MCCD - FOO6_Induction Training Handout - Revision #O3.docPage 17 of 19

Figure A7.1: Melbourne Convention Centre (MCC)

RUBBISH AND DEBRIS

The Contractor shall provide all necessary bins for their own use and ESD requirements for use by all trade and sub-contractors. The Contractor is responsible for maintaining a clean and safe site.

(a) Waste Management
Green Star gives credit points for management systems that facilitate the reduction of construction waste going to landfill. To achieve the points, the contractor must:

- Provide and implement a comprehensive waste management plan.
- Provide a copy of the waste management plan prior to commencement of work on-site for approval by the Superintendent
- Re-use and/or recycle 80% of waste by weight
- Provide to the Superintendent: Monthly reports showing the percentage waste recycled or re-used (by weight)

The contractor is also responsible for:

- The removal of all dirt and debris attributable to the Works from adjacent roads, paths and properties in accordance with the requirements of the relevant authorities
- The appearance and operation of the site not creating issues with neighbours, and the contractor is required to allow for remedying any appearance issues raised by neighbours
- The contractor is responsible for preventing any dust, leakage, seepage or leaching from the site during the works or during a period 90 days after practical completion.

Various wastes may be reported as co-mingled weight. A sample report should be prepared for approval by the Superintendent. The report format shall be as indicated below:

- Sub-Contractor certification confirming that the waste re-use/recycling target was achieved for this site

(b) Vehicles and transportation
Use trucks that will not spill or deposit dirt or debris on adjacent public roads, paths or properties.

(c) Completion
Before arranging handover inspections, finish, clean, and make good the Works including:

- Clear and remove surplus materials, dirt, debris and the like
- Repair damage and defects to adjacent properties resulting from the Works
- Repair damage, stains and blemishes, or replace work where required
- Clean all finished surfaces
- Commission, lubricate and adjust all installations
- Commission, test and ensure services and equipment are connected and operating properly

Figure A7.2: 55 St Andrews Place

5.11 WASTE MINIMISATION AND MANAGEMENT

OBJECTIVES

- To reduce waste sent to landfill by reduction, redirection and management of waste materials. Waste can be avoided through design, reducing waste at the source, reusing waste both on and off site and to recycle waste on-site through separation.

RESPONSIBILITIES

- Subcontractor / Site Team

PROCEDURE

- Provide a waste minimisation and management plan to council where required by council conditions.
- Sub-contractors to develop a waste minimisation plan for their scope of work.
- Sub-contractors will undertake as part of their contract to minimise the packaging they bring onto the site and to reuse off-cuts where possible.
- Pallets and reels will be returned with reusable packaging to the suppliers.
- Stockpile materials (clean fill) on site will be reused for back fill or landscaping preventing disposal at landfill wherever possible.
- On-site separation for recycling will focus on five main materials with a separate bin for mixed waste remaining. These materials are metal; concrete; timber; plasterboard and cardboard.
- Regular auditing and reporting of the waste programme will be conducted by Site Management and a data base maintained monitoring recycling, reuse and reduction data over the life of the project.
- Supplies and deliveries will be monitored to reduce overestimating.
- The target set for waste reduction on the project is at least 60%of material generated on the site will be recycled.
- Complete Monthly Waste and Resource Recovery Report.

PERFORMANCE INDICATORS

- Meeting waste minimisation objectives.

RECORDS

- Site Environmental Inspection Checklist Form EMP 032

Reference:	Victoria ▪ State Industrial Waste Management Policies ▪ Environment Protection (Resource Efficiency) Act 2002 ▪ Environment Protection Act 1970

Litter

OBJECTIVES

- Multiplex will reduce or eliminate littering on site through the Waste Minimisation and Management program to best practice standards.

RESPONSIBILITIES

- Subcontractor / Site Team

PROCEDURE

- Stormwater drainage systems will be constructed so as to filter out litter from the storm water drains.
- Litter bins with clear signage and symbols will be placed at strategic locations around the site where litter is generated:
  - Lunch sheds;
  - Offices;
  - Canteens;
  - Supply reception area; and

Figure A7.3: Corner of Bourke and William Street (CBW)

Appendix A 8: Veolia's Waste Collection Management Strategies

Figure A8.1 shows the colour coded bin initiative by Veolia to ensure proper disposal practices on site for all workers. These signs were clearly displayed at the construction sites. The colour-coded bin system facilitated waste sorting and ultimately recycling as explained in Chapter 6 (Section 6.2.2).

RUBBISH TYPE/BIN COLOUR

PLASTER	BLUE
CONCRETE	YELLOW
TIMBER	RED
CARDBOARD	GREEN
STEEL	BLACK
GENERAL	GREEN
PLASTIC	GREEN

Figure A8.1: Colour coded bin allocation

Veolia also arranged for the easy collection of bins at accessible collection points known to all workers at the site also ensuring safety and proper disposal practices as shown in Figure A8.2.

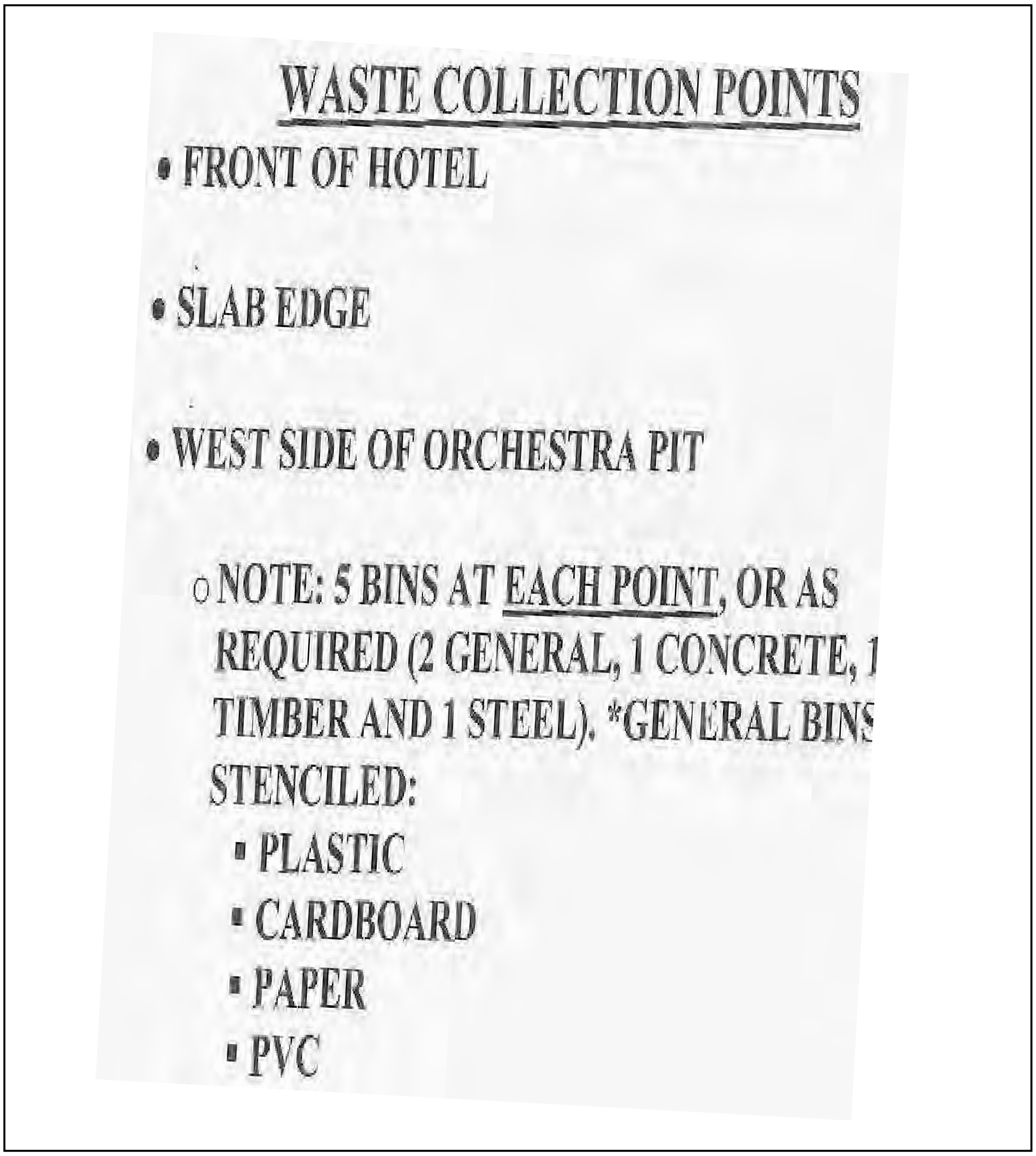

Figure A8.2: Strategic waste collection points

Appendix A9: RC and Bricks Data Sources

This section outlines the data sources that were used for the End-of-Life-Cycle Analysis (ELCA). Data Quality Indicators used in the ELCA calculations are also listed in the section. The data collected for RC during the six month period was over 770 tonnes, whilst the total quantity of bricks was 30,680 tonnes for the 2008 production year. However, figures were scaled to a 1000 tonnes for calculating a unit rate. Chapters 4 and 5 show the inventory data used in the ELCA calculations for RC and bricks.

A9.1 RC data

The total figures for Table A9.1 include bricks and asphalt. That total number of bins used for the rounds was 104. Table A9.1 summarizes the data for RC collected between the periods of March and September 2008. With the original data collected, scaled to 1000 tonnes, the number of trips and subsequent input data was calculated based on 1000 tonnes.

Table A9.1: AFG Recycle Bin Resource Recovery Report

Material Recovered	Period	Quantity This month	Quantity to Date	Bins this month	Bins To Date	Destination
Concrete, Brick and Asphalt	March -May 2008	403.15	473.71	34	41	AFG Laverton
Concrete, Brick and Asphalt	June - July 2008	496.40	970.11	35	76	AFG Laverton
Concrete, Brick and Asphalt	August - September 2008	392.44	1,362.55	28	104	AFG Laverton

In Table A9.1 RC figures also included bricks and asphalt. Figure A9.1 is a breakdown of figures for RC only. RC data was calculated from the "inconc" data. The data sheet in Figure A9.1 was obtained from the weighbridge where the quantities were measured and registered.

RECYCLING INDUSTRIES PTY LTD
RECYCLING INDS - LAVERTON
TICKET REGISTER

From 01/06/08 To 30/06/08 Cust. CR01 Order WESTGATE ALL

Date 05/08/08 Time 15:52

Docket Number	--Delivery-- Date	Time	Truck Rego	Customer Code	Order Number	Job Address	Prod Code	Qty M3	Qty Tonnes	Product Price	Cartage	TOTAL Price
613826	02/06/08	13:31	UNU220	CR01	WESTGATE ALL	PORT MELBOUR	INMIXED		20.02 I	0.00	0.00	0.00
614215	03/06/08	16:14	UNU220G	CR01	WESTGATE ALL	PORT MELBOUR	INMIXED		30.84 I	0.00	0.00	0.00
615738	12/06/08	08:01	WJH552	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		12.24 I	0.00	0.00	0.00
616092	13/06/08	10:20	UNU220	CR01	WESTGATE ALL	PORT MELBOUR	INMIXED		7.34 I	0.00	0.00	0.00
616526	16/06/08	14:46	UNU220	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		14.20 I	0.00	0.00	0.00
616554	16/06/08	16:18	UNU220	CR01	WESTGATE ALL	PORT MELBOUR	INMIXED		17.50 I	0.00	0.00	0.00
617118	18/06/08	11:01	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		16.08 I	0.00	0.00	0.00
617178	18/06/08	12:25	UNU220	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		15.18 I	0.00	0.00	0.00
617898	20/06/08	16:26	TWP739	CR01	WESTGATE ALL	SOUTH BANK	INCONC		13.06 I	0.00	0.00	0.00
618300	23/06/08	16:39	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		12.72M I	0.00	0.00	0.00
618870	26/06/08	09:23	UNU220	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		15.18 I	0.00	0.00	0.00

End Of Report .....

-INWARD M3--	-OUTWARD M3-	--INWARD T--	-OUTWARD T--			
0.00	0.00	174.36	0.00	$ 0.00	$ 0.00	$ 0.00

Page 1 17.2

RECYCLING INDUSTRIES PTY LTD
RECYCLING INDS - LAVERTON
TICKET REGISTER

From 01/07/08 To 31/07/08 Cust. CR01 Order WESTGATE ALL

Date 01/08/08 Time 08:40

Docket Number	--Delivery-- Date	Time	Truck Rego	Customer Code	Order Number	Job Address	Prod Code	Qty M3	Qty Tonnes	Product Price	Cartage	TOTAL Price
619854	02/07/08	10:22	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		13.72 I	0.00	0.00	0.00
619925	02/07/08	12:46	RDO672	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		12.14 I	0.00	0.00	0.00
619978	02/07/08	14:18	RDO672	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		12.48 I	0.00	0.00	0.00
620270	03/07/08	15:20	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INASPHALT1		17.02 I	0.00	0.00	0.00
620296	03/07/08	16:43	TWP739H	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		15.20 I	0.00	0.00	0.00
620436	04/07/08	11:21	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INASPHALT1		12.94 I	0.00	0.00	0.00
620469	04/07/08	12:29	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		4.16 I	0.00	0.00	0.00
620516	04/07/08	14:24	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		12.86 I	0.00	0.00	0.00
620774	07/07/08	11:10	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		11.56 I	0.00	0.00	0.00
621126	08/07/08	15:13	UNU220	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		12.64 I	0.00	0.00	0.00
621365	09/07/08	15:36	WJH552	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		15.88 I	0.00	0.00	0.00
622199	15/07/08	11:05	SBF882	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		11.22 I	0.00	0.00	0.00
622526	16/07/08	14:09	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		8.60 I	0.00	0.00	0.00
622555	16/07/08	15:17	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		9.10 I	0.00	0.00	0.00
622577	16/07/08	16:16	WJH552	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		12.90 I	0.00	0.00	0.00
622579	16/07/08	16:23	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		12.58 I	0.00	0.00	0.00
623748	24/07/08	08:35	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		10.82M I	0.00	0.00	0.00
623840	24/07/08	13:09	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		12.12 I	0.00	0.00	0.00
624382	29/07/08	09:35	WJH552	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		13.66 I	0.00	0.00	0.00
624411	29/07/08	10:49	TWP739	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		9.28 I	0.00	0.00	0.00
624458	29/07/08	12:45	WJH552	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		8.46 I	0.00	0.00	0.00
624696	30/07/08	14:58	UNU220	CR01	WESTGATE ALL	PORT MELBOUR	INASPHALT1		16.32 I	0.00	0.00	0.00
624726	30/07/08	16:20	UNU220	CR01	WESTGATE ALL	PORT MELBOUR	INCONC		14.68 I	0.00	0.00	0.00
624883	31/07/08	12:23	TWP739A	CR01	WESTGATE ALL	PORT MELBOUR	INASPHALT1		8.86 I	0.00	0.00	0.00

End Of Report .....

-INWARD M3--	-OUTWARD M3-	--INWARD T--	-OUTWARD T--			
0.00	0.00	289.20	0.00	$ 0.00	$ 0.00	$ 0.00

Figure A9.1: Ticket register for incoming RC waste at AFG

Table A9.2 shows the quantity of inputs and outputs per tonne required to recycle 1000 tonnes of RC.

Table A9.2: Process Input and Output table for baseline (C_1)

Processes (Inputs and Outputs)	Crushed Concrete (Total production)	Unit	Crushed Concrete (Per tonne production)	Unit
Transport of waste material to crushing plant	20	km	1.6	t/km
Heavy vehicle fuel consumption within plant • Cracking large boulders • Loading of crusher • Water spreading • Other uses to site	809	l	0.8	l/t production
Electricity usage on-site	2,734	kWh	2.7	kWh/t production
Water usage on-site	100	l	0.1	l/t production
Waste generated by recycling process	10	t	-	-
Transport of waste not recycled to landfill	4	km per trip	0.75	t/km
Total number of trips from waste collection site to landfill	4	trips	3.3	t per trip
<u>**Avoided Products**</u>				
Steel	20	t		
Virgin gravel Production	950	t		

(Source: AFG, 2008b)

A9.2 Bricks data

Table A9.3 shows the quantity of inputs and outputs per tonne required to recycle 1000 tonnes of bricks.

Table A9.3: Process Input and Output table for baseline (B_1)

Processes (Inputs and Outputs)	Crushed Bricks (Total production)	Unit	Crushed Bricks (Per tonne production)	Unit
Transport of waste material to crushing plant	15	km (Average)	1.3	t/km
Heavy vehicle fuel consumption within plant • Water spreading • Other uses to site	809	litres	1.2	l/t production
Electricity on-site	2,734	kWh	2.7	kWh/t production
Water use on-site	100	litres	0.1	l/t production
Waste generated by recycling process	-	-	-	-
Total number of trips from waste collection site to landfill	-	-	-	-
Avoided Products				
Virgin gravel production	950	t		
Transport and landfill of demolition bricks waste	333	t		

(Source: AFG, 2008b)

A9.3 Data Quality Indicators (DQI)

The Data Quality Indicators (DQI) are requirements used in SIMAPRO for a Life-Cycle assessment. DQI values are allocated according to the importance of each impact category to the overall ELCA study, and are summarized in Table A9.4. In SIMAPRO, the 5 DQI requirements namely time, geography, type, allocation, and system boundaries have 8 sub-sections. The DQI differs from project to project and are assigned values ranging from 1 to 11, based on relevance of data to the ELCA study.

Table A9.4: Data Quality Indicators (DQI)

DQI requirements	Selections	DQI Weightings
Time Period	• 1990-1994 • 1995-1999 • 2000-2004 • 2005-2009	3
Geography	• Australia • Mixed data	1
Type • Technology	• Mixed data • Average technology • Modern Technology • Best Available technology	3
• Representativeness	• Mixed Data • Average from processes with similar outputs • Average of all suppliers • Theoretical calculations • Data based on input-output tables	3
Allocation • Multiple output allocation	• • Physical causality	11
• Substitution allocation	• Actual substitution • Substitution by close proxy (similar process)	11
• Waste treatment allocation	• Closed loop assumption • Full substitution by close proxy (similar process)	11
System Boundaries • Cut-off rules	• Less than 1% (physical criteria) • Less than 1% (socio economic) • Less than 1% (environmental relevance)	3
• System boundary	• Second order (material, energy flows including operations)	4
• Boundary with nature	• Unspecified • Unknown • Not applicable	11

Appendix A10: Results Tables and Figures for ELCA Study

This section shows the results tables and figures for the ELCA study for virgin gravel, RC, and Bricks, whilst Chapters 4 and 5 show the results for the ELCA calculations.

A10.1 Virgin Gravel Production

Table A10.1 shows the impacts of producing virgin gravel.

Table A10.1: Impact assessment characterization for virgin Gravel production

Impact category	Unit	Total	Gravel/AU U	Articulated TruckAU U	Electricity, high voltage AU U
Global Warming	kg CO2	17679.713	0	13321.774	4357.9385
Photochemical oxidat	kg C2H2	8.1333231	0	7.50778	0.62554307
Eutrophication	kg PO4--- eq	9.0339442	0	7.5836288	1.4503155
Carcinogens	DALY	3.82E-05	0	2.09E-05	1.73E-05
Land use	Ha a	0.001427523	0	2.53E-05	0.00140224
Water Use	KL H2O	2007.0067	2000	0.13518469	6.8715244
Solid waste	kg	80184.364	80000	11.029016	173.33522
Embodied energy LHV	MJ LHV	134965.31	0	89700.406	45264.907
Minerals	MJ Surplus	1.3083822	0	0.023105608	1.2852766

A10.2 Reinforced Concrete

Tables A10.2 and A10.3 show the recycling and landfill scenarios of RC (C_0 and C_1),

Table A10.2: Characterization results summary on impact areas for landfilling 1000 tonnes of RC (C_0, 100%)

Impact category	Unit	Total	Landfill of	Truck 12t AU	Landfill inert waste/AU U
Global Warming	tonnes CO2	70	0	66	4
Water Use	KL	1.9420485	0	0.67010864	1.2719398
Solid waste	Tonnes	1000	0	0.1	1000
Embodied energy LHV	GJ	474	0	445	30

Table A10.3: Characterization results summary on impact areas for recycling 1000 tonnes of RC (C_1, 100%)

Impact category	Unit	Total	RC,C1	Truck 12t AU	Water, Vic/	Electricity	Diesel used AU	Gravel/AU U	Pig iron/AU U	Landfill RC
Global Warming	tonnes CO2	-13	0	13	0	3	3	-17	-14	1
Water Use	KL	-1.927	0	0.13541779	0.116422	4.1524164	0.026964533	-1888.3926	72.418394	0.01883787
Solid waste	Tonnes	-108	0	0	0	0.1	0	-75	-8	10
Embodied energy LHV	GJ	-328	0	90	0	31	16	-127	-315	5

Figures A10.1 and A10.2 are the corresponding figures to Tables A10.2 and A10.3 respectively. The characterization tables show the individual contribution of each activity to the total impacts of each scenario.

Figures A10.1 and A10.2, show the contribution analysis for the recycling of RC (C_1) and landfill disposal (C_0) scenarios. Unlike the C_1 scenario, the C_0 did not have any negative values (benefits).

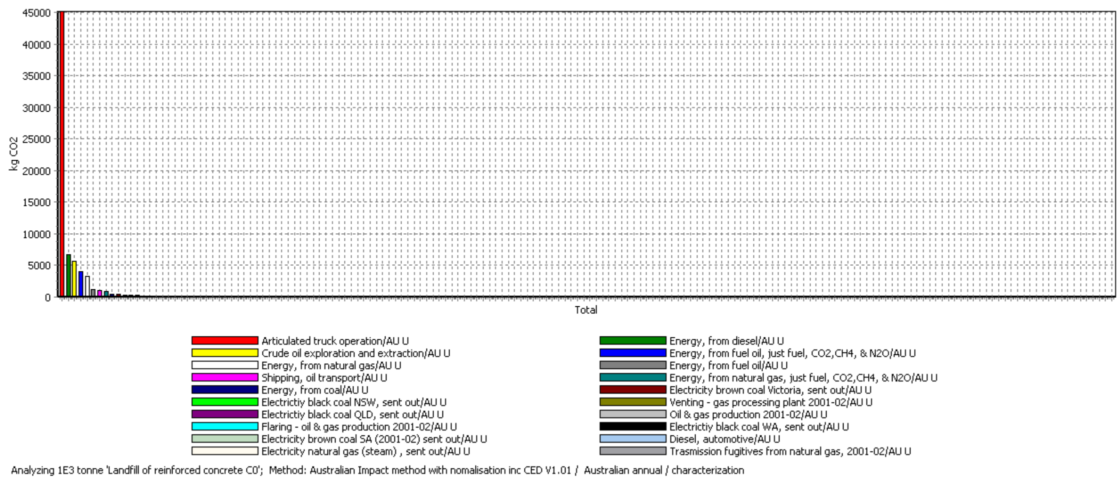

Figure A10.1: Contribution analysis with Characterization indicator (Process contribution) for landfill (C_0)

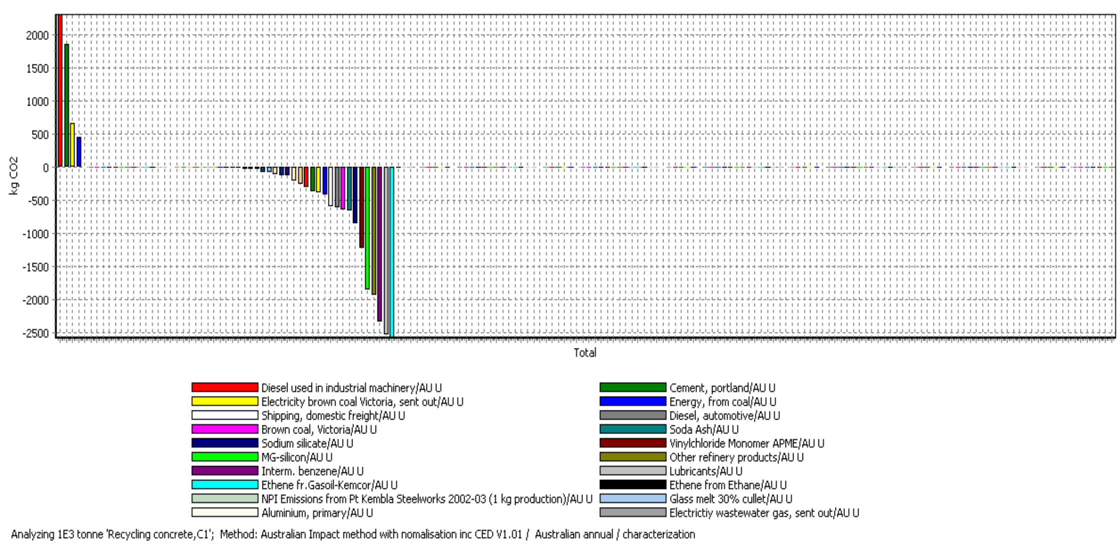

Figure A10.2: Contribution analysis with Characterization indicator (Process contribution) for recycling (C_1)

Tables A10.4 to A10.7 provides a d etailed breakdown of the v arious p arameters contributing to each of the four impact categories (global warming, water use, solid waste and embodied energy) chosen for the four RC scenarios

Table A10.4: Global warming (CO_2) impact for four RC scenarios

Substance	Compartment	Unit	Landfill RC C0 (100%)	RC,C1 (100%)	RC,C2 (97%)	RC C3 (80%)
Total of all compartments		kg CO2	70038.269	-13048.064	-10104.029	2485.2439
Carbon dioxid	Air	kg CO2	66435.726	-7205.139	-4682.4068	8181.313
Carbon dioxid	Air	kg CO2	2140.9822	-4715.3078	-4381.1183	-5101.4398
Chlorinated fl	Air	kg CO2	5.40E-10	-3.71E-09	-3.52E-09	-2.58E-09
Chloroform	Air	kg CO2	0.000222936	0.000105227	0.000109871	0.000131313
Dinitrogen mo	Air	kg CO2	309.45201	-27.556162	-15.559935	33.831571
Ethane, 1,1,1	Air	kg CO2	111.37944	-1.4579865	2.4807124	22.390568
Ethane, hexa	Air	kg CO2	0.000755778	-0.004161363	-0.00393288	-0.003453614
Methane	Air	kg CO2	1040.2143	-1097.3593	-1026.2886	-648.59688
Methane, bio	Air	kg CO2	0.50854042	-1.2110455	-1.1049785	-2.2273015
Methane, dicl	Air	kg CO2	0.000677724	0.000348053	0.000361325	0.000421723
Methane, tetr	Air	kg CO2	0.005339739	-0.029400932	-0.02778667	-0.024400536

Table A10.5: Water use Impact for four RC scenarios

Substance	Compartment	Unit	Landfill RC C0 (100%)	RC,C1 (100%)	RC,C2 (97%)	RC C3 (80%)
Total of all compartments		KL H2O	1.9420485	-1927.8191	-1811.5242	-1191.7245
Water, coolin	Raw	KL H2O	0.072188195	0.11999511	0.12629435	-0.29273587
Water, coolin	Raw	KL H2O	1.23E-09	-8.47E-09	-8.05E-09	-5.89E-09
Water, coolin	Raw	KL H2O	2.20E-11	-1.51E-10	-1.44E-10	-1.05E-10
Water, coolin	Raw	KL H2O	0.008193178	58.458298	56.705672	46.763114
Water, coolin	Raw	KL H2O	1.696578	-8.3280447	-7.8455532	-7.8269565
Water, proce	Raw	KL H2O	1.60E-10	-1.10E-09	-1.05E-09	-7.66E-10
Water, proce	Raw	KL H2O	0.15479712	-2.5267642	-2.4356365	-1.9288555
Water, proce	Raw	KL H2O	4.93E-12	-3.39E-11	-3.22E-11	-2.36E-11
Water, proce	Raw	KL H2O	1.93E-11	-1.33E-10	-1.26E-10	-9.23E-11
Water, proce	Raw	KL H2O	0.004515663	24.366027	23.635666	19.491077
Water, proce	Raw	KL H2O	0.001054855	-0.004861059	-0.0045706	-0.004827794
Water, proce	Raw	KL H2O	8.01E-12	-5.50E-11	-5.23E-11	-3.83E-11
Water, unspe	Raw	KL H2O	0.004721502	-1999.9038	-1881.706	-1247.9253
Water, unspe	Raw	KL H2O	4.90E-17	7.31E-09	7.09E-09	5.85E-09

Table A10.6: Solid waste impact for four RC scenarios

Substance	Compartment	Unit	Landfill RC C0 (100%)	RC,C1 (100%)	RC,C2 (97%)	RC C3 (80%)
Total of all compartments		kg	1000086.8	-108285.68	-73601.223	103457.13
ash	Waste	kg	46.57569	-37.849205	-34.334427	-22.342553
Chemical waste, inert	Waste	kg	2.30E-10	-1.58E-09	-1.50E-09	-1.10E-09
Chemical waste, regulated	Waste	kg	1.83E-10	-1.26E-09	-1.19E-09	-8.73E-10
Dross	Waste	kg	8.21E-05	-0.000452322	-0.000427487	-0.000375393
Metal waste	Waste	kg	5.63E-13	-3.87E-12	-3.67E-12	-2.69E-12
Mineral waste	Waste	kg	0.3438916	-79932.04	-75206.032	-49865.802
Oil waste	Waste	kg	3.22E-09	-1.15E-08	-1.07E-08	-1.40E-08
Packaging waste, paper and board	Waste	kg	4.30E-27	-2.96E-26	-2.81E-26	-2.06E-26
Packaging waste, plastic	Waste	kg	1.52E-12	-1.04E-11	-9.89E-12	-7.24E-12
Packaging waste, wood	Waste	kg	6.79E-14	-4.66E-13	-4.43E-13	-3.24E-13
Production waste	Waste	kg	1.50E-07	-8.23E-07	-7.78E-07	-6.83E-07
Slags and ashes	Waste	kg	2.80E-10	-1.93E-09	-1.83E-09	-1.34E-09
Waste, final, inert	Waste	kg	1000000	-20000.097	9699.9086	159999.9
Waste, fly ash	Waste	kg	39.62943	-230.9591	-218.59598	-186.7013
Waste, from construction	Waste	kg	8.99E-13	-6.18E-12	-5.87E-12	-4.30E-12
Waste, industrial	Waste	kg	2.01E-10	-1.38E-09	-1.31E-09	-9.59E-10
Waste, Shedder dust	Waste	kg	1.64E-06	-7.54E-06	-7.09E-06	-7.49E-06
Waste, solid	Waste	kg	0.13545926	-5179.5011	-5024.0975	-4143.6954
Waste, to incineration	Waste	kg	1.22E-12	-8.39E-12	-7.97E-12	-5.84E-12
Waste, unspecified	Waste	kg	0.054131553	-2905.2358	-2818.0713	-2324.2365

Table A10.7: Embodied energy impacts for four RC scenarios

Substance	Compartment	Unit	Landfill RC C0 (100%)	RC,C1 (100%)	RC,C2 (97%)	RC C3 (80%)
Total of all compartments		MJ LHV	474208.74	-327616.78	-300061.31	-177717.25
bagasse	Raw	MJ LHV	41.384467	-271.30741	-257.49318	-182.74103
Carbon	Raw	MJ LHV	0.001955166	-0.010765264	-0.010174196	-0.00893435
Coal, 13.3 MJ per kg, in ground	Raw	MJ LHV	262.48308	-1857.2867	-1765.5741	-1268.2908
Coal, 18.5 MJ per kg, in ground	Raw	MJ LHV	566.16231	-3698.7092	-3510.1107	-2489.6536
Coal, 20.5 MJ per kg, in ground	Raw	MJ LHV	2700.7954	-19110.175	-18166.512	-13049.927
Coal, 21.5 MJ per kg, in ground	Raw	MJ LHV	3726.2982	-169693.51	-164091.72	-132671.09
Coal, 28.0 MJ per kg, in ground	Raw	MJ LHV	5928.11	-2593.6316	-2308.3853	-821.72802
Coal, brown, 8.1 MJ per kg, in ground	Raw	MJ LHV	3495.8023	5810.911	6115.9597	-14176.096
Energy, from biomass	Raw	MJ LHV	104.2184	-240.97588	-219.45523	-456.39292
Energy, from coal	Raw	MJ LHV	1.20E-07	-8.23E-07	-7.82E-07	-5.73E-07
Energy, from coal, brown	Raw	MJ LHV	2.13E-08	-1.47E-07	-1.39E-07	-1.02E-07
Energy, from gas, natural	Raw	MJ LHV	9.60E-07	-6.59E-06	-6.26E-06	-4.59E-06
Energy, from hydro power	Raw	MJ LHV	369.79882	-2018.5255	-1907.2596	-1642.0899
Energy, from hydrogen	Raw	MJ LHV	2.36E-08	-1.62E-07	-1.54E-07	-1.13E-07
Energy, from oil	Raw	MJ LHV	6.06E-07	-4.16E-06	-3.96E-06	-2.90E-06
Energy, from peat	Raw	MJ LHV	5.84E-11	-4.01E-10	-3.81E-10	-2.79E-10
Energy, from solar	Raw	MJ LHV	0.13452273	-0.92412036	-0.87794978	-0.6427859
Energy, from sulfur	Raw	MJ LHV	4.18E-09	-2.87E-08	-2.73E-08	-2.00E-08
Energy, from uranium	Raw	MJ LHV	1.62E-07	-1.11E-06	-1.05E-06	-7.72E-07
Energy, from wood	Raw	MJ LHV	3.12E-11	-2.15E-10	-2.04E-10	-1.49E-10
Energy, kinetic, flow, in wind	Raw	MJ LHV	5.1013525	-18.295148	-17.04675	-22.152448
Energy, recovered	Raw	MJ LHV	-4.16E-08	2.86E-07	2.71E-07	1.99E-07
Energy, unspecified	Raw	MJ LHV	2.91E-09	-2.00E-08	-1.90E-08	-1.39E-08
Gas, natural, 35.9 MJ per m3, in ground	Raw	MJ LHV	83768.986	-105569.73	-99368.863	-66499.779
Graphite, from technosphere	Raw	MJ LHV	9.21E-05	-0.00048492	-0.000457745	-0.000414291
Oil, crude, 42.8 MJ per kg, in ground	Raw	MJ LHV	53669.776	-3877.1111	-1900.0589	8149.9222
Oil, crude, 43.4 MJ per kg, in ground	Raw	MJ LHV	319569.69	-24477.5	-12663.905	47413.419

The u ncertainty an alysis w as carried o ut t o i dentify t he reliability o f d ata u sed. The uncertainty analysis for the 100% RC landfill disposal and 100% RC recycling (***C₀*** and ***C₁***) scenarios are shown in Figures A10.3 and A10.4 respectively.

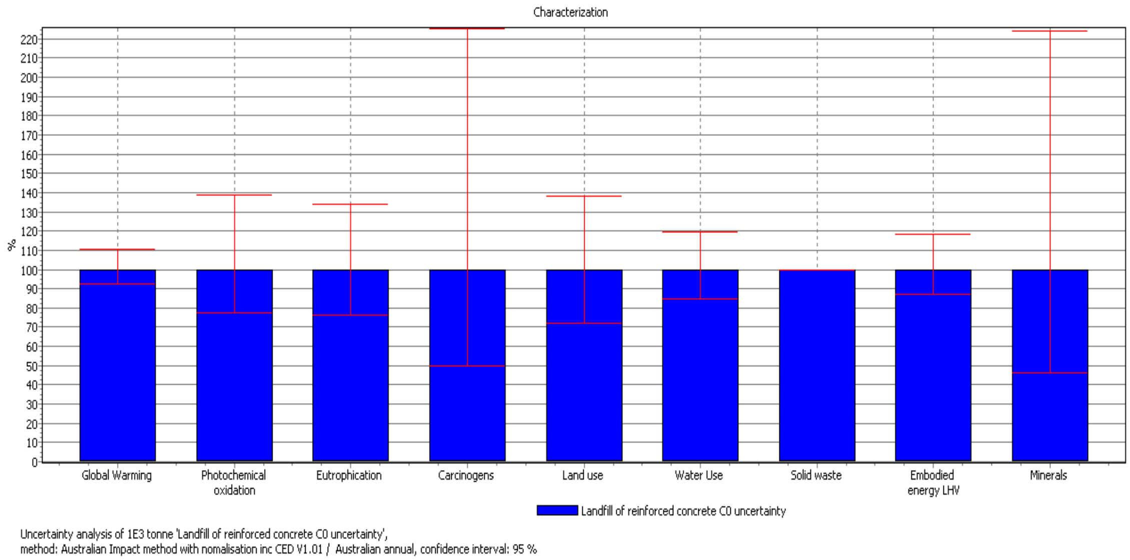

Figure A10.3: Uncertainty analysis for RC landfill disposal scenario (C_0)

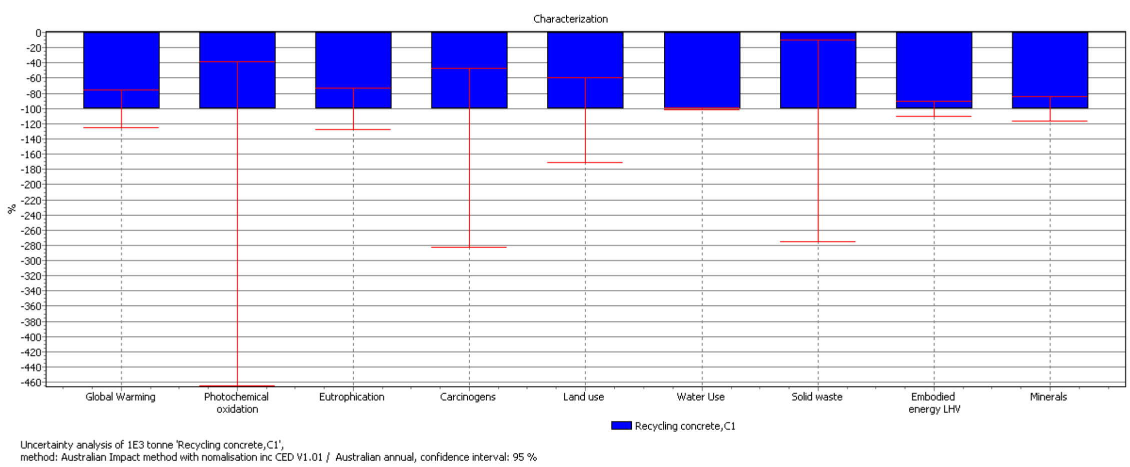

Figure A10.4: Uncertainty analysis for the RC recycling scenario (C_1)

A10.3 Bricks

Tables A10.8 and A10.9, represents the results data for the two bricks scenarios. Table A10.8 shows the major impacts of disposing bricks to landfill was the use of transport. Table A10.9 shows virgin gravel, sand and kaoline as the "'avoided processes'" and the major benefits of the B_1 scenario. These benefits offset the impacts from the articulated truck and diesel use.

Table A10.8: Characterization results summary on impact areas for 100% landfill (B_0)

Impact category	Unit	Total	Landfill B0	Articulated Truck,12t
Global Warming	tonnes CO2	18	0	118
Water Use	KL	0.1781205	0	0.1781205
Solid waste	Tonnes	1000	1000	0
Embodied energy LHV	GJ	118	0	118

Table 10.9: Characterization results summary on impact areas for 100% recycling (B_1)

Impact category	Unit	Total	Recycling Bricks B1	Truck, 12t/AU U	Water	Electricity	Diesel used	Gravel/AU U	Kaoline	Sand
Global Warming	tonnes CO2	-6.5	0	3	0.01	3	5	-18	-70	-42
Water Use	KL	2	0	0.027831328	153.02893	4.122292	0.045190546	-2007.0067	-254.11325	-2000.4174
Solid waste	Tonnes	-76	0	0	0	0.1	0	-80	-1	0
Embodied energy LHV	GJ	-54	0	18	0.2	31	28	-135	-989	-295

Tables A 10.10 t o A 10.13 pr ovides a de tailed br eakdown of t he va rious pa rameters contributing to each of the four impact categories (global warming, water use, solid waste and embodied energy) chosen for the two brick scenarios

Table A10.10: Global warming (CO_2) impacts for two brick scenarios

Substance	Compartment	Sub-compartment	Unit	Landfill B0	Recycling Bricks B1
Total of all compartments			kg CO2	17552.883	-6477.7275
Carbon dioxide	Air		kg CO2	16835.882	-5514.0613
Carbon dioxide,	Air		kg CO2	99.90558	-659.71153
Chlorinated fluo	Air		kg CO2	4.66E-11	-1.80E-09
Chloroform	Air		kg CO2	5.92E-05	-3.50E-05
Dinitrogen mon	Air		kg CO2	77.117973	-41.023172
Ethane, 1,1,1,2-	Air		kg CO2	29.602204	-17.128854
Ethane, hexaflu	Air		kg CO2	6.53E-05	-0.001621298
Methane	Air		kg CO2	73.845586	-107.195
Methane, bioge	Air		kg CO2	0.043928078	0.4997859
Methane, dichlo	Air		kg CO2	0.0001801	-0.000106435
Methane, tetrafl	Air		kg CO2	0.00046125	-0.011454819
Carbon dioxide,	Air	low. pop.	kg CO2	247.53259	-78.16753
Dinitrogen mon	Air	low. pop.	kg CO2	1.9770492	-1.3438086
Ethane, 1,1,1,2-	Air	low. pop.	kg CO2		-0.32098405
Methane	Air	low. pop.	kg CO2	186.97495	-59.261913

Table A10.11: Water use impacts for two brick scenarios

Substance	Compartment	Sub-compartment	Unit	Landfill B0	Recycling Bricks B1
Total of all compartments			KL H2O	0.1781205	-1749.4656
Water, process	Raw		KL H2O	9.11E-05	-0.001226742
Water, process	Raw		KL H2O	x	153
Water, cooling,	Raw	in ground	KL H2O	0.14655159	-2.4410813
Water, cooling,	Raw	in water	KL H2O	0.006235667	0.35544324
Water, cooling,	Raw	in water	KL H2O	1.07E-10	-4.12E-09
Water, cooling,	Raw	in water	KL H2O	1.90E-12	-7.35E-11
Water, cooling,	Raw	in water	KL H2O	0.000707732	-0.014631348
Water, cooling,	Raw	in water	KL H2O	2.38E-14	-9.20E-13
Water, process	Raw	in water	KL H2O	1.38E-11	-5.35E-10
Water, process	Raw	in water	KL H2O	0.023736477	-0.34761532
Water, process	Raw	in water	KL H2O	4.26E-13	-1.65E-11
Water, process	Raw	in water	KL H2O	1.67E-12	-6.45E-11
Water, process	Raw	in water	KL H2O	0.000390066	-0.008330852
Water, process	Raw	in water	KL H2O	6.08E-17	-7.40E-16
Water, process	Raw	in water	KL H2O	6.92E-13	-2.68E-11
Water, unspecif	Raw	in water	KL H2O	0.000407847	-1900.0081
Water, unspecif	Raw	in water	KL H2O	4.23E-18	-5.15E-17

Table A10.12: Solid waste impacts for two brick scenarios

Substance	Compartment	Sub-compartment	Unit	Landfill B0	Recycling Bricks B1
Total of all compartments			kg	1000014.5	-76115.159
ash	Waste		kg	11.060795	-23.057861
Chemical waste	Waste		kg	1.99E-11	-7.68E-10
Chemical waste	Waste		kg	1.58E-11	-6.10E-10
Dross	Waste		kg	7.10E-06	-0.000176228
Metal waste	Waste		kg	4.86E-14	-1.88E-12
Mineral waste	Waste		kg	0.029705597	-76000.584
Oil waste	Waste		kg	2.78E-10	-1.20E-09
Packaging wast	Waste		kg	3.72E-28	-1.44E-26
Packaging wast	Waste		kg	1.31E-13	-5.06E-12
Packaging wast	Waste		kg	5.86E-15	-2.27E-13
Production wast	Waste		kg	1.29E-08	-3.21E-07
Slags and ashe	Waste		kg	2.42E-11	-9.36E-10
Waste, final, ine	Waste		kg	0.001822383	-0.024534846
Waste, fly ash	Waste		kg	3.4232179	-91.236114
Waste, from co	Waste		kg	7.77E-14	-3.00E-12
Waste, industri	Waste		kg	1.73E-11	-6.70E-10
Waste, Inert	Waste		kg	1000000	x
Waste, Shedde	Waste		kg	1.41E-07	-1.90E-06
Waste, solid	Waste		kg	0.011701066	-0.19277372
Waste, to incin	Waste		kg	1.05E-13	-4.08E-12
Waste, unspeci	Waste		kg	0.004675922	-0.063297988

Table A10.13: Embodied energy impacts for two brick scenarios

Substance	Compartment	Sub-compartment	Unit	Landfill B0	Recycling Bricks B1
Total of all compartments			MJ LHV	118190.02	-54203.516
Carbon	Raw		MJ LHV	0.000168889	-0.004194226
Energy, from so	Raw		MJ LHV	0.011620167	-0.44928379
Energy, recover	Raw		MJ LHV	-3.59E-09	1.39E-07
Energy, unspec	Raw		MJ LHV	2.51E-10	-9.71E-09
Graphite, from t	Raw		MJ LHV	7.95E-06	-0.000182405
bagasse	Raw	biotic	MJ LHV	3.5748192	-144.46613
Energy, from bi	Raw	biotic	MJ LHV	9.0024581	110.15256
Energy, kinetic,	Raw	in air	MJ LHV	0.4406584	-1.9032639
Coal, 13.3 MJ p	Raw	in ground	MJ LHV	22.673473	-916.22692
Coal, 18.5 MJ p	Raw	in ground	MJ LHV	48.905497	-1976.3816
Coal, 20.5 MJ p	Raw	in ground	MJ LHV	233.2966	-9427.2564
Coal, 21.5 MJ p	Raw	in ground	MJ LHV	321.88025	-13000.921
Coal, 28.0 MJ p	Raw	in ground	MJ LHV	1575.3325	-931.09087
Coal, brown, 8.1	Raw	in ground	MJ LHV	301.96986	17212.777
Energy, from co	Raw	in ground	MJ LHV	1.04E-08	-4.00E-07
Energy, from co	Raw	in ground	MJ LHV	1.84E-09	-7.12E-08
Energy, from ga	Raw	in ground	MJ LHV	8.29E-08	-3.21E-06
Energy, from hy	Raw	in ground	MJ LHV	2.04E-09	-7.87E-08
Energy, from oil	Raw	in ground	MJ LHV	5.24E-08	-2.02E-06
Energy, from pe	Raw	in ground	MJ LHV	5.05E-12	-1.95E-10
Energy, from su	Raw	in ground	MJ LHV	3.61E-10	-1.39E-08
Energy, from ur	Raw	in ground	MJ LHV	1.40E-08	-5.40E-07
Energy, from wo	Raw	in ground	MJ LHV	2.70E-12	-1.04E-10
Gas, natural, 35	Raw	in ground	MJ LHV	21813.209	-14784.493
Oil, crude, 42.8	Raw	in ground	MJ LHV	13492.137	-4244.9335
Oil, crude, 43.4	Raw	in ground	MJ LHV	80335.642	-25259.446
Energy, from hy	Raw	in water	MJ LHV	31.943481	-838.87385

Figure A10.5 and A10.6 show the uncertainty analysis for the landfill scenario (B_0) and the recycling scenario (B_1).

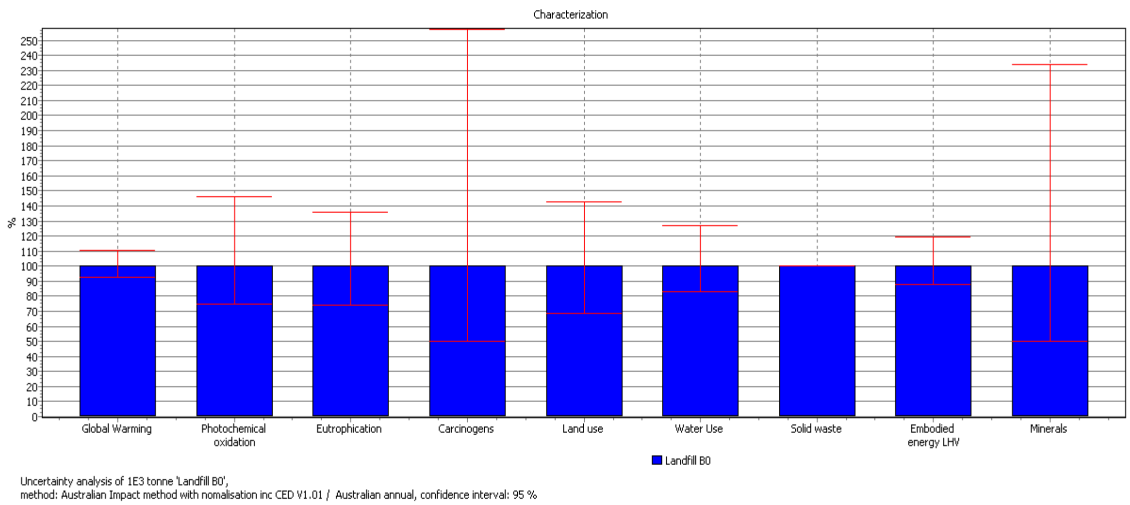

Figure A10.5: Uncertainty analysis for Brick landfill disposal scenario (B_0)

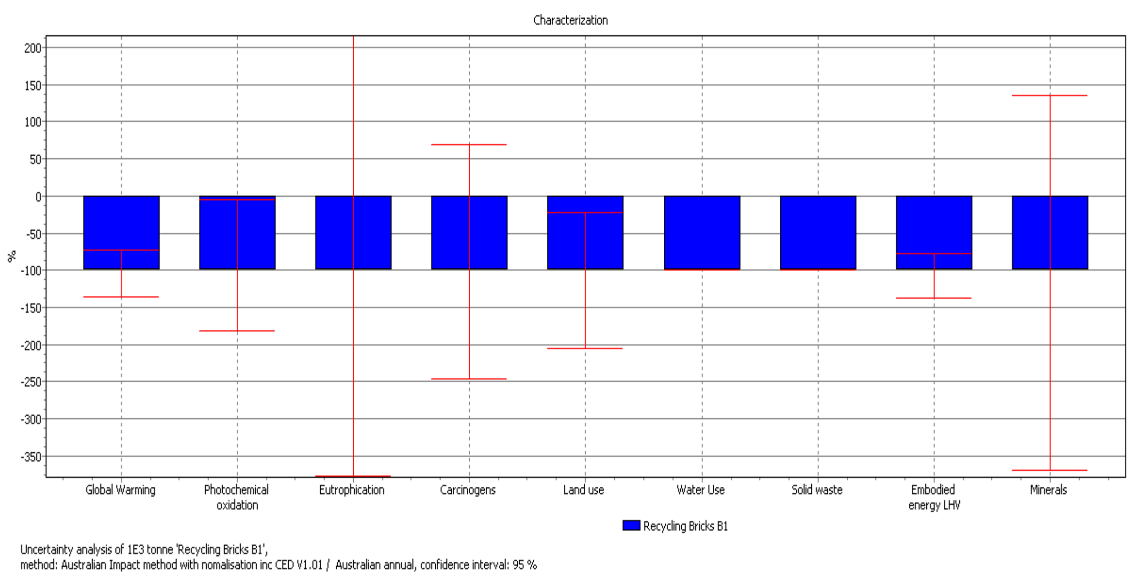

Figure A10.6: Uncertainty analysis for Brick recycling scenario (B_1)

Appendix A11: Cost Analysis Data

Recycling and landfill cost are calculated in this section. Electricity and Water data were taken from the service providers within the Laverton area where the recycling plant is located, whilst all calculations were done through close consultation with AFG. The prices and assumptions used in the calculations for the costs and benefits of the RC recycling, brick recycling, and landfill disposal scenarios summarized in Chapter 7 are discussed in this appendix.

Prices used in cost calculations

- Electricity – \$0.29 per kWh
- Cost of Diesel – \$1.112 per litre
- Diesel used – 1.96 litres per km
- Water – \$1.14 per kilolitre
- Truck and Labour cost – about \$6 per km
- Haulage fee per 12-tonne truck – \$300
- Landfill tipping fee – \$67 per tonne or \$804 per 12-tonne truck
- All cost calculations are based on 1000 tonnes of RC and brick waste material recycled

Cost assumptions

- All costs and prices quoted are valid for the data collection period between March and September 2008
- All prices quoted exclude GST and are valid for Melbourne.
- All prices exclude capital cost for setting up the crushing plant

A11.1 Cost analysis for RC

Electricity figures used were calculated as Kilowatt hours (kWh) for each scenario. AFG works from Monday to Friday peak period and so the commercial D tariffs for peak periods are used. Table A11.1 shows the electricity usage and cost calculated for the four RC scenarios.

Table A11.1: Electricity usage and cost for four RC scenarios (1000t)

Scenarios	Kilowatt hours(kWh)	Cost (\$)
Landfill – 100% (C_0)	-	-
Recycling – 100% (C_1)	2,734	793
Recycling – 97% (C_2)	2,652	769
Recycling – 80% (C_3)	2,187	634

Diesel cost was calculated at $1.112 per litre which is the average diesel price for two years from August 2006 to 2008 as stated by the Victoria Transport Association (VTA). Table A11.2 shows the fuel use and cost for both machinery and transport.

Table A11.2: Machinery and Transport fuel cost for RC scenarios (1000t)

Scenarios	Trips	Transport (Litres)	Transport ($)	Machinery (Litres)	Machinery ($)
Landfill – 100% *(C_0)*	83	651	724	-	-
Recycling – 100% (C_1)	83	3,254	3,618	809	900
Recycling – 97% *(C_2)*	81	3,150	3,531	785	873
Recycling – 80% *(C_3)*	67	2,626	2,920	647	719

Water usage charges used in this price analysis are based on a 19.67% increase that took effect in July 2008 and prices exclude GST. Table A11.3 shows the water usage and costs for the four RC scenarios.

City West Water Service charges used in the calculations

- Water usage charge per kilolitre - $1.1376

Source: http://www.citywestwater.com.au/business/about_your_account.htm

Table A11.3: Water usage and cost for four RC scenarios (1000t)

Scenarios	Tonnes Recycled	Kilolitres used	$ Water use charge
Landfill – 100% *(C_0)*	-	-	-
Recycling – 100% (C_1)	1,000	100	113
Recycling – 97% *(C_2)*	970	97	110
Recycling – 80% *(C_3)*	800	80	91

Other costs included in the calculation were truck and labour cost and the haulage fee shown in Tables A11.4 and A11.5 respectively. The truck labour cost was calculated at $6 per km, which has been allocated as shown in Table A11.4. In Table A11.5 the haulage fee for C_0 and C_1 were same because even though the waste might be hauled to different locations, the cost of taking waste off the site was the same in both cases, based on the quantity hauled.

Table A11.4: Truck and labour cost allocations per km

Area of Allocation	Allocation (%)
Drivers Wages Wages Overhead • Bin dispatcher • Manager • Allocator	45
Repair & Maintenance	12
Fuel/Oil	17
• Consumables by workers • Motor Vehicle Expenses • Motor Vehicle Registration • Insurance and Miscellaneous	1
Depreciation	20

(Source: AFG, 2008b – recycling Industry estimation)

Table A11.5: Haulage waste quantity and cost for the four RC scenarios

Quantity/Fees	Waste Quantity (tonnes)	Number of trips (per 12-tonne truck)	Haulage fee per 12-tonne truck ($)	Cost ($)
Landfill 100% (C_0)	1,000	83	300	24,900
Recycling 100% (C_1)	1,000	83	300	24,900
Recycling 97% (C_2)	970	81	300	24,300
Recycling 80% (C_3)	800	67	300	20,100

A11.2 Cost analysis for Bricks

The study of bricks was considered for the 2008 production year. The two main scenarios were for landfill (B_0) and recycling (B_1), where 100% C&D waste was assumed to be recycled or disposed to landfill. Table A11.6 summarizes the usage and cost for fuel, electricity, haul and landfill.

- Price of tipping at landfill per 12-tonne bin - $804
- Price of diesel per trip to landfill - $8.72
- Distance traveled – 4km

Table A11.6: Summary table for usage and cost for two Brick scenarios

	Landfill 100% (B_0)	*Recycling 100% (B_1)*
Fuel (Litres)	651	2,440
Fuel ($)	724	2,713
Electricity (kWh)	0	2,734
Electricity ($)	0	793
Trips (Haul)	83	83
Haulage ($)	24,900	24,900
Trips (Landfill)	83	0
Landfill fee ($)	66,732	0
Machinery (Litres)	0	809
Machinery ($)	0	900
Water (Kilolitres)	0	100
Water ($)	0	113

A11.3 Landfill cost

Landfill cost was calculated for the RC and Brick scenarios. The tipping fee cost based on a rate of $67 a tonne was higher than fuel cost for both RC and Bricks, as shown in Table A11.7.

Table A11.7: Tipping fee and fuel cost for RC and Brick waste to landfill

Scenarios	Quantity to landfill (tonnes)	Number of trips to landfill (12-tonne truck)	Distance to landfill site (km)	Tipping fee ($)	Fuel cost ($)
RC					
Landfill 100% RC (C_0)	1000	83	4	66,732	724
Recycling 100% RC (C_1)	10	1	4	804	9
Recycling 97% RC (C_2)	39.7	3	4	2,412	29
Recycling 80% RC (C_3)	208	17	4	13,668	151
Bricks					
Landfill 100% Bricks (B_0)	1000	83	4	66,732	724
Recycling 100% RC (B_1)	-	-	-	-	-

A11.4 Capital cost of crusher

This section calculates the annualized capital cost of the crusher.

Cost of crusher – $10 million
Interest payable on cost of crusher – 8%
Number of years for repayment – 10 years

$M = P [i(1 + i)^n] / [(1 + i)^n - 1]$ (http://www.fonerbooks.com/interest.htm)

Where M = Monthly repayments, P = Principal, i = Interest 0.08/12, n = number of years 10 by 12 months (120 months)

$M = 10{,}000{,}000 [0.0067 (1.0067)^{120}] / [(1.0067)^{120} – 1]$

$M = 10{,}000{,}000 [0.0067 (2.23)] / [2.23 -1]$

$M = 10{,}000{,}000 [0.015] / [1.23]$

$M = 150{,}000 / 1.23$

M =$121,951 Therefore annual repayment is 121,951 * 12 = $1,463,415million

Total annualized cost of equipment per annum – $1,463,415million

Estimated total RC per annum at AFG – 400,000 tonnes

Estimated total bricks per annum at AFG – 250,000 tonnes

Total production tonnage for RC and bricks per annum – 650,000 tonnes

Capital cost of crusher – $\dfrac{\text{Total annualized cost of equipment}}{\text{Total production tonnage per annum}}$

Therefore $\dfrac{\$1,463,415}{650,000 \text{ tonnes}} = \$2.25$ per tonne

Hence, the capital cost of using the crusher to recycle a 1000 tonnes of RC is

$2.25 * 1000 tonnes = $2,250

Hence, the capital cost of using the crusher to recycle a 1000 tonnes of Bricks is

$2.25 * 1000 tonnes = $2,250

Appendix A12: VicRoads Specification Standards

The VicRoads specification (Section 820) for the use of "recycled crushed concrete for pavement sub-base and light duty base" discussed in Chapter 8 (Section 8.7) is presented in this appendix.

SECTION 820 -RECYCLED CRUSHED CONCRETE FOR PAVEMENT SUBBASE AND LIGHT DUTY BASE

820.01 DESCRIPTION

This section covers the requirements of 20mm nominal size, recycled crushed concrete and plant mixed wet-mix crushed concrete for Class CC3 subbase, and Class CC4 subbase of various nominal sizes and 20mm nominal size Class CC2 light duty base. Recycled crushed concrete products may include a nominated percentage of Reclaimed Asphalt Pavement (RAP).

820.02 DEFINITIONS

Crushed Concrete

Crushed concrete is composed of rock fragments coated with cement with or without RAP, sands and/or filter, produced in an enrolled manner to close tolerances of grading and minimum foreign material content.

Light Duty Base Pavement

Light duty base pavement is the layer directly beneath the bituminous surfacing on lightly trafficked roads with a Design Traffic Loading of up to $1*10^6$ Equivalent Standard Axles.

Plant Mixed Wet-Mix crushed concrete is a mixture of recycled crushed concrete, RAP, any granular additives and water, produced at a controlled mixing plant to close tolerances of grading and moisture content based on the modified optimum moisture content of the material.

Reclaimed Asphalt Pavement (RAP)

Asphalt removed from an existing asphalt pavement, re-processed by crushing and/or screening for recycling into new asphalt.

820.03 COMPONENTS

(a) Crushed concrete fragments shall consist of clean, hard, durable, angular fragments of concrete.

The use of crusher fines passing the 4.75mm sieve which are not produced from crushing concrete, shall be subject to approval in writing by the Superintendent to the proposed source and nature of the materials and the proposed amounts to be added. Unless otherwise specified, crusher fines which have been produced from an igneous or metamorphic rock source shall have a Degradation Factor – Crusher Fines of not less than 60.

(b) RAP is permitted to be used in combination with crushed concrete. The percentage of RAP in any product shall not exceed 20% unless otherwise approved by the Superintendent. Reclaimed asphalt pavement shall not contain tar.

(c) The use of sands and/or filler shall be subject to approval in writing by the Superintendent. Details regarding the proposed source, the nature of the additives, the proposed amounts to be added and the proposed method of incorporating such materials in the product must be submitted with the request for approval.

Where the Contractor elects to use an additive component with the crushed concrete, the additive shall:

(i) be derived from sound and durable material;

(ii) not be cementitious in nature;

(iii) be free of vegetable matter, lumps and balls of clay and oversize particles of rock;

(iv) be sized such that it can be effectively and uniformly distributed throughout the crushed concrete;

(v) be kept dry to ensure that a free-flowing additive is incorporated into the mixture;

(vi) be blended in the base and subbase finished products and shall not be greater than 15% by mass, unless approved otherwise in writing by the Superintendent.

820.04 PRODUCT

(a) The crushed concrete mix shall comply with the relevant requirements of Table 820.041.

Table 820.041 - Physical Properties

Test Value			
Test	Class CC2	Class CC3	Class CC4
Liquid Limit % (max)	35	35	40
Plasticity Index (max)	6	10	20
California Bearing Ratio (%) (min) (1)	100	80	15
Los Angeles Abrasion Loss (max) (2)	30	35	40
Flakiness Index	35	-	-

Notes: (1) Value applicable to material passing 19.0 mm sieve: initially at optimum moisture content and 98% of maximum dry density as determined by test using Modified compactive effort, but then soaked for 4 days prior to the CBR test.

(2) Material used for the Los Angeles test shall be washed in solution of three parts water to one part hydrochloric acid for 10 minutes to remove cement paste from the aggregates and then washed again in water prior to the test.

(b) Foreign materials in that fraction of the product retained on a 4.75 mm sieve shall not exceed the percentages by mass specified in Table 820.042.

Table 820.042 - Foreign Material (Max Allowable %)

Foreign Material Type	Class CC2	Class CC3	Class CC4
High density materials such as metal, glass and brick	2	3	5
Low density materials such as plastic, rubber, plaster, clay lumps and other friable material	0.5	1	3
Wood and other vegetable or decomposable matter	0.1	0.2	0.5

Any material which may contain asbestos must be managed and tested in accordance with the requirements of WorkSafe Victoria including the current Occupational Health and Safety (Asbestos) Regulations.

(c) For PMWMCC, the aggregates and water shall be mixed at a mixing plant by continuous or batch mixing.

820.05 WATER

Water used for producing PMWMCC or where water is added to the crushed concrete prior to delivery, such water shall be clear and substantially free from detrimental impurities such as oils, salts, acids, alkalis and vegetable substances. Water supplied from sources where dissolved salts are known or likely to be present shall be tested for electrical conductivity prior to use. The electrical conductivity shall not be more than 3500 µS/cm. Water sources classified by the relevant Water Authority as potable water shall be exempt from this requirement.

820.06 GRADING OF UNCOMPACTED CRUSHED CONCRETE AND PMWMCC LIGHT DUTY BASE

After completion of production, but before compaction, crushed concrete and PMWMCC light duty base shall comply with the relevant grading requirements of Tables 820.061.

The Contractor shall aim to produce the crushed concrete and PMWMCC in such a way that the grading coincides with the relevant target grading specified in Table 820.061.

Table 820.061 - Grading Requirements for Class CC2, 20 mm Light Duty Base

Sieve Size AS (mm)	Target Grading (% Passing)	Test Value before Compaction	
		Limits of Grading (% Passing)	% Retained between Sieves
26.5	100	100	
			0 - 5
19.0	100	95 - 100	
			7 - 18
13.2	85	78 - 92	
			10 - 16
9.5	73	63 - 83	
			14 - 24
4.75	54	44 - 64	
			10 - 20
2.36	39	30 - 48	
			15 - 29
0.425	17	13 - 21	
			7 - 14
0.075	7	5 - 9	

The Superintendent may revise the target grading requirements for the 2.36 mm, 0.425 mm and 0.075 mm sieves specified in Table 812.061. The magnitude of the range of the limits of grading shall remain unchanged for the revised target grading and the range shall remain centred on the target grading. Changes made to the target grading shall be limited to a maximum of two percentage units for the 2.36 mm and 0.425 mm sieves and one percentage unit for the 0.075 mm sieve.

820.07 GRADING OF UNCOMPACTED CRUSHED CONCRETE SUBBASE

(a) Class CC3 Crushed Concrete

After completion of production, but before compaction, Class CC3 crushed concrete and PMWMCC shall comply with the grading requirements of Table 820.071.

The Contractor shall aim to produce the crushed concrete in such a way that the grading coincides with the relevant target grading specified in Table 820.071. The permitted ranges of grading in these tables provide for random fluctuations in the production process.

The crushed concrete shall not be graded from near the coarse limit on one sieve to near the fine limit on the following sieve or vice versa.

Table 820.071 - Grading Requirements for 20 mm Class CC3 Crushed Concrete

Sieve Size AS (mm)	Target Grading (% Passing)	Limits of Grading Test Value before Compaction (% Passing)
26.5	100	100
19.0	100	95 - 100
13.2	85	75 - 95
9.5	75	60 - 90
4.75	59	42 - 76
2.36	44	28 - 60
0.425	19	10 - 28
0.075	6	2 - 10

The Superintendent may revise the target grading requirements for the 2.36 mm, 0.425 mm and 0.075 mm sieves specified in Tables 812.071. The magnitude of the range of the limits of grading shall remain unchanged for the revised target grading and the range shall remain centred on the target grading. Changes made to the target grading shall be limited to a maximum of two percentage units for the 2.36 mm and 0.425 mm sieves and one percentage unit for the 0.075 mm sieve.

(b) Class CC4 Crushed Concrete

After completion of production, but before compaction, Class CC4 crushed concrete shall comply with the relevant grading requirements of Table 820.072. The crushed concrete shall not be graded from near the coarse limit on one sieve to near the fine limit on the following sieve or vice versa.

Class CC4 crushed concrete of nominal size differing from that specified may be accepted by the Superintendent provided it meets the grading requirement of Table 820.072 corresponding to a nominal size adjacent to that specified.

Table 820.072 - Grading Requirements for Class CC4 Crushed Concrete

Sieve Size AS (mm)	Limits of Grading - Test Value before Compaction (% Passing)					
	Nominal Size (mm)					
	50	40	30	25	20	14
75.0	100					
53.0		100				
37.5			100	100		
26.5					100	
19.0	54 - 75	64 - 90				100
9.50			48 - 70	54 - 75		
4.75					42 - 76	54 - 75
0.425	7 - 21	7 - 23	9 - 24	10 - 26	10 - 28	15 – 32
0.075	2 - 10	2 - 12	2 - 12	2 - 13	2 - 14	6 – 17

820.08 MOISTURE CONTENT

(a) Crushed Concrete

Where payment is to be made on a mass basis, the average moisture content of crushed concrete at the plant shall not exceed 8.5% by mass unless otherwise specified or unless the Contractor has, at the time of tendering, nominated an upper limit of average moisture content greater than 8.5%. In the latter case the difference between the nominated value and the specified value will be taken into account when tenders are being considered. The average moisture content of crushed concrete supplied on any one day will be determined from three samples taken at random from that days supply. If the average moisture content is greater than that specified or nominated, the material may be rejected. If at the discretion of the Superintendent the material is accepted, payment will be made for the mass determined by deducting the calculated mass of excess moisture from the net mass shown on the delivery dockets.

(b) PMWMCC

Where the work of the Contract includes supply and delivery only, the moisture content of the mixture at the point of delivery, expressed as a percentage by mass, shall be within plus 0.5 to minus 1.0 of the target nominated from time to time by the Superintendent.

820.09 STOCKPILING PRIOR TO DELIVERY

If the Contractor elects or is required to supply PMWMCC or crushed concrete to stockpile prior to delivery to the roadbed the following requirements shall be met:

(a) the product, after recovery from the stockpile, complies with this specification;

(b) the stockpile site is clean, adequately paved, and well drained;

(c) if a stockpile is constructed in more than one layer, each layer is fully contained within the area occupied by the upper surface of the preceding layer;

(d) unless otherwise specified or approved by the Superintendent, all crushed concrete supplied to stockpile shall have a minimum moisture content of 3.5% by mass unless the stockpile is located at the supply point for producing PMWMCC;

(e) all PMWMCC delivered to stockpile shall be supplied at a moisture content of not less than the optimum moisture content unless the material is to be wet mixed again prior to delivery to the roadbed where the minimum moisture content in stockpile shall be not less than 3.5% by mass;

(f) the surface of the stockpile shall be kept damp to prevent a net loss of moisture and to minimise the generation of airborne dust;

(g) no cementitious filler is used.

820.10 HANDLING OF CRUSHED CONCRETE

Handling of crushed concrete, including the loading of trucks and stockpiling, shall be effected in such a manner as to minimise segregation.

820.11 MINIMUM TESTING REQUIRMENTS

The contractor shall test the crushed concrete and PMWMCC at such a frequency to ensure that the material consistently complies with specified requirements. The test frequency shall initially not be less than that shown in Table 820.111, except that the test frequency for Grading, foreign Material Content, Moisture Content and Degradation Factor, may be halved where the most recent 10 test results in succession have me specification requirements. If any subsequent test result fails to meet specification requirements, another test shall be immediately undertaken. If the second test fails the test frequency shall revert to the minimum test frequency specified in Table 820.111 and the Contractor shall not return to half the test frequency until further 10 successive test results comply with specification requirements.

Table 820.111 – Minimum Frequency Testing

Test	Minimum Frequency of Testing
Grading	On each day – one per 500 tonnes or part thereof
Foreign Material Content	On each day – one per 500 tonnes or part thereof
Moisture Content • Crushed Concrete • PMWMCC	 On each day – 3 No. One per 200 tonnes or part thereof on each day
Plasticity Index	In each day – one per 500 tonnes or part thereof
California Bearing Ration for Class CC2, CC3 and CC4	Prior to the commencement of work and when in the opinion of the Superintendent the nature of the material has changed significantly
Degradation Factor of any Imported Crusher Fines	One per day
Flakiness Index (Class CC2)	Prior to the commencement of work and one per 10,000 tonne and when in the opinion of the Superintendent the nature of the material has changed significantly
Los Angeles Abrasion	Once per month or when in the opinion of the Superintendent the nature of the material has changed significantly

Appendix A13: National Waste Policy 2010

Table A13.1 presents the National Waste Policy and government's intended improvement for the next five years discussed in Chapter 9 (Section 9.8.3).

Table A13.1: Timeframe for delivery of EPHC priorities and commitments mapped against the six directions of the National Waste Policy

National Waste Policy Direction	Year	Environment Protection and Heritage Council Commitment
1. Taking responsibility	2010	• That the Australian Packaging Covenant replace the National Packaging Covenant • Release the final choice modelling survey report on packaging to the stakeholder reference group • Australian Standard for biodegradable plastics in home composting finalized • To establish partnerships with industry to increase recycling of mercury containing lamps in Australia
	2011	• Commonwealth National Product Stewardship Framework legislation enacted • Co-regulatory television & computer product stewardship scheme commences under the national framework • Industry led voluntary tyre product stewardship scheme commences
	2014	• A number of voluntary product stewardship schemes are accredited and reporting under the national product stewardship framework • Guidance on sustainable procurement such as standard specifications and model contract clauses are available to procurement officials
2. Improving the market	2013	• National principles to encourage safe re-use of waste are agreed and national specification for use of recycled construction & demolition waste in pavements & fit for purpose use of organics & bio-solids derived from organic waste commenced
	2014	• Existing classification arrangements are assessed, options developed for where national harmonisation is appropriate together with their costs and benefits and an approach agreed
3. Pursuing sustainability	2011	• Strategies for addressing and/or offsetting emissions from landfill that complement the approach to resource recovery from organic waste released
4. Reducing hazard and risk	2012	• New standard setting body for chemicals in the environment established hazard and risk
	2013	• Assessment of the approach best suited to Australia to reduce hazardous substances in products & articles sold in Australia completed and a decision made
5. Tailoring solutions	2012	• Audit of existing waste infrastructure and local capability in selected remote Indigenous communities completed and recommendations provided
6. Providing the evidence	2010	• First National Waste Report released (completed)
	2013	• Second National Waste Report published
	2015	• The basic national dataset and how best to improve data collection and streamline business reporting requirements and administration, to align with national directions is scoped and developed

(Source: EPHC, 2010)