SUSTAINABLE AGGREGATES SOUTH AUSTRALIA

CO_2 Emission Factor Study

AUGUST 2010

Founding Partners

Government of South Australia Zero Waste SA

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Sustainable aggregates – CO_2 emission factor study

Final Report

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Executive summary

This study has been commissioned by Zero Waste SA and is part of a wider project aiming to increase the market acceptance of recycled aggregates for use by the construction sector. RMCG has been sub-contracted to provide professional input to the project in the areas of greenhouse gas emissions and environmental/social impact considerations around recycled aggregates.

The project collected process energy usage data from the recycling industry to develop an emission factor for recycled aggregate. An average emission factor of almost 4 kg CO_2-e/t has been calculated from the data provided. This represents between 22% and 46% fewer emissions than an equivalent quarried or primary aggregate (based on limited Australian data on primary aggregates). Similarly US studies have found recycled aggregate to have around 30% less embodied carbon emissions than primary aggregates.

The spreadsheet tool can be used to compare the sustainability of materials choices for a range of construction projects. For example, replacement of 50% of primary aggregates with recycled aggregates in a road construction project could reduce the embodied energy (and resulting GhG emissions) of the materials component of the construction, by around 23%.

Recycling and reuse of recycled aggregates brings substantial environmental gains (RMCG 2008). There will usually be gain in the following areas:

- **Reduced resource consumption** – substitution of new products for recycled means conserving primary aggregates for future generations.
- **Diversion of waste materials from landfill** – which can mean less biodiversity, amenity and transport emissions costs.
- **Reduced quarrying** – means less amenity and biodiversity costs.
- **Reduced GhG emissions** - recycled aggregates can have lower embodied energy in addition to reduced transport emissions where recycled materials are reused in close proximity to the site of reprocessing.

These environmental gains are dependent on an efficient recycled aggregates collection and reuse supply chain.

Future data collection should focus on quantifying offsite environmental and social impacts of quarrying, recycling and landfill.

1 Introduction

This study has been commissioned by Zero Waste SA and is part of a wider project aiming to increase the market acceptance of recycled aggregates for use by the construction sector. RMCG has been sub-contracted to provide professional input to the project in the areas of greenhouse gas emissions and environmental/social impact considerations around recycled aggregates.

The production of recycled aggregates and other construction materials provide a sustainable material source for construction and redevelopment projects across Australia. The findings from this project provide valuable energy and emissions accounting information relevant to the construction sector that will assist them make more sustainable materials choices.

The relative greenhouse gas impacts of different waste disposal and recycling options requires on-going data collection and is essentially work in progress. An earlier study conducted in conjunction with Resourceco (an Adelaide based recycling company) began to collect required data and develop a suitable framework relevant to an environmental assessment of aggregates recycled from construction and demolition (C&D) waste (RMCG/ARRB Group 2009).

The objective of this project is to build on earlier work and investigate the main sources of process energy usage and greenhouse gas (GhG) emissions arising from winning, collection and processing of both primary and recycled aggregates. More specifically, the project is focused on measuring the total embodied energy of recycled aggregates, which include road base and sub base products.

There are difficulties in comparing greenhouse emission figures between published studies due to differences in the accounting methodologies used and local electricity generation factors between jurisdictions, both across Australia and worldwide. This project aims to collect local and current data so that an Australian emission factor for recycled aggregates can be determined that can be applied to local construction projects.

A Sustainable Aggregates CO_2 Emissions Estimator tool has also been developed as part of this project. The tool calculates the emissions and financial implications of materials choices (recycled and primary aggregates) on a project basis. It is intended that practitioners involved in planning road construction projects use the tool.

2 Project methodology

2.1 Background

At the project outset, both recyclers and quarrying companies were invited to provide energy usage data to the project. Two quarrying businesses declined this invitation, which has meant that the outcomes have relied on published figures on the embodied energy of primary or quarried aggregates. Energy usage data to develop an emission factor for recycled aggregates has been collected from four recycling companies. These companies are currently operating in Adelaide (two businesses), Perth (one business) and Melbourne (one business) and are amongst the major providers of recycled aggregates within Australia.

2.2 Framework for the determination of an aggregates emission factor

A principle element of the study is to compare the embodied greenhouse emissions within recycled aggregates with an equivalent new quarry product (20 mm minus crushed rock) on a project basis. A simple tool has been developed that will calculate the potential greenhouse emissions and financial implications for different aggregates choices in a construction project.

The study comprises four main parameters:

1. Process energy use and emissions

C&D recycled aggregates: energy use and emissions arising from processing including crushing, screening and blending of recycled aggregates.

Quarried aggregates: energy use and emissions arising from winning, handling, crushing, screening and blending of primary aggregates (quarrying).

- Diesel fuel usage – litres (MJ/L) kg $CO_{2\text{-}e}$ per MJ or litre of fuel.

- Electricity usage – kWh (MJ/kWh) kg $CO_{2\text{-}e}$ per MJ or kWh of electricity.

Note: emission factors for electricity usage vary between states in Australia.

2. Material production quantities

- Amount of material produced per unit of time.

3. Transport energy use and emissions

- Transport of materials between points of origin and delivery to construction site.

- Average tonne-kilometres travelled and resulting emissions.

4. Cost of materials and transport

- Cost of each material selected ($/tonne or m^3 delivered).

3 Recyclers energy usage

Energy usage and production data on recycled aggregates has been collected from four recycling companies operating in Australia. Table 3-1 summarises the results of a survey of energy use in relation to monthly production from the four participating businesses.

Table 3-1 Summary of recyclers energy usage and production

Recyclers' aggregated monthly production and energy usage			
Total t recycled aggregate	**MJ diesel**	**MJ electricity**	**Total MJ energy/month**
107,270	4,067,819	450,120	4,517,939
	Diesel	**Electricity**	**Average MJ/t**
Total embodied energy MJ/t	38	4	42
			Total t CO_2-e/month
Total t CO_2-e/month	283	143	425
	Total kg CO_2-e/t		
Emission factor recycled aggregate (average)	3.97		

An average emission factor of 3.97 kg CO_2-e/t has been calculated from the data provided. It should be noted that the efficiency of businesses varied considerably. Those with the greater production levels had higher efficiency levels (in terms of energy use per unit of output) than smaller production businesses.

The landfill diversion rate of the surveyed recycling facilities is between 96% and almost 100%. Typically the vast majority of waste delivered is brick rubble and concrete, with a few percent of scrap steel, combustibles and organics. The typical composition of C&D waste delivered to recycling facilities is illustrated in Figure 1 (over page).

Australian data on emission factors for quarry or primary aggregates is limited. A literature search found two published figures. A figure of 5.1 kg CO_2-e/t for quarried aggregates in WA (Stratagen 2008) and a figure of 7.6 kg CO_2-e/t was extrapolated from energy use data provided in a consultants presentation on a Victorian study of a quarry operation (ERM 2006).

The relative emissions between products will vary according to the combination of energy or fuel sources used. In Australia, electricity is usually more emissions intensive than diesel fuel. Electricity generated from coal is greenhouse emissions intensive due to large efficiency losses: high levels of energy are required in heating during generation and there are substantial losses during transmission, for example.

There are inherent difficulties in comparing published figures in relation to carbon emissions from aggregates, both quarried rock and recycled. Depending on the geographical location (between states within Australia or between countries) and methodology used in each study, there will be variations in emission factors by fuel source depending on the scope of the emissions sources included.[1]

[1] Under Australia's Greenhouse Gas Protocol, Scope 1 Direct Emissions are defined as those generated directly by an organisation, from sources that are owned or controlled by the company, for example, emissions from fuel consumption by

A US study of life-cycle GhG emission factors (EPA-USA 2003) for clay brick reuse and concrete recycling also found GhG savings arising from reduced process energies between primary aggregates manufacture and recycled manufacture. Savings in the order of 30% were reported. The study also considered the impact of transportation distances of materials and concluded that the use of the recycled product will result in GhG savings as long as it is transported no more than 5 km further than the quarried aggregate.

The UK Quarry Products Association (QPA 2008) reports overall sector emissions averaging 6 kg $CO_{2\text{-}e}$ per tonne. Emission factors are reported for sand and gravel (3.98 kg), crushed rock (4.02 kg) and asphalt (26.82 kg - process emissions only). These figures are not directly comparable to Australia given that a substantial proportion of electricity generation in the UK is nuclear which is deemed a zero carbon emission energy source. Recycled aggregates in the UK are likely to have comparatively lower embodied energy than Australian products, given their lower emission factors for electricity usage (for example, an equivalent emission factor for UK electricity use is in the order of 0.4 kg$CO_{2\text{-}e}$/kWh compared with 1.1 kg$CO_{2\text{-}e}$/kWh for South Australia).

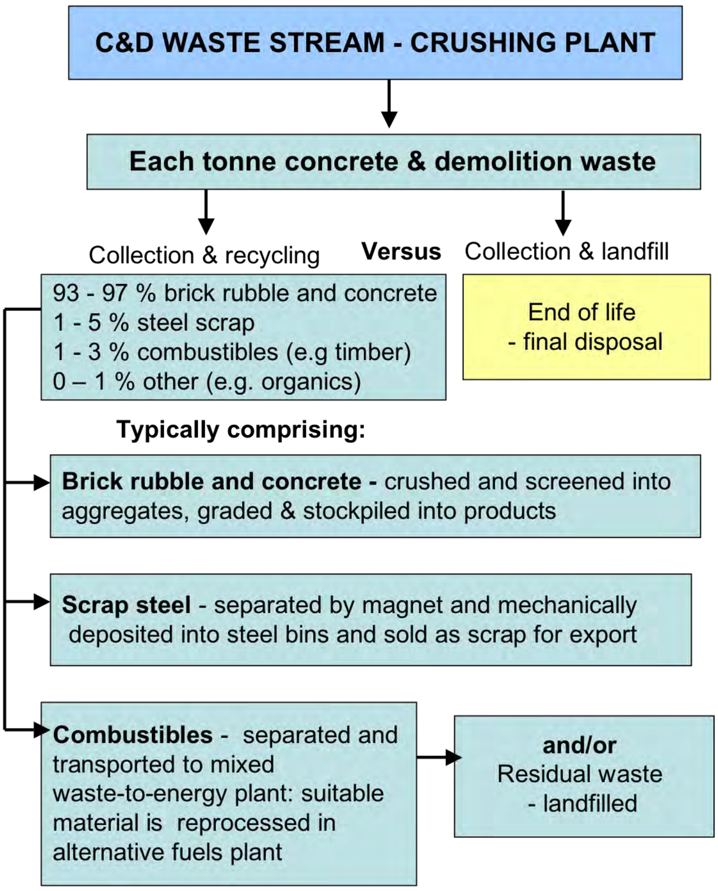

Figure 1 Construction and demolition waste stream – crushing plant

mobile sources. Scope 2 Indirect Emissions are defined as those generated indirectly from use of electricity, purchased and consumed by the reporting organisation. Scope 3 Various Emissions are other, non-electricity related emissions, generated indirectly. Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company. Scope 3 emissions include those coming from disposal of wastes, use of products sold, extraction and transport of purchased materials and fuels etc (National Greenhouse Accounting Factors Workbook Jan'08).

4 Sustainable aggregates CO_2 emissions estimator

The project has developed a user-friendly spreadsheet tool that calculates the emissions and financial implications of materials choices (recycled and primary aggregates) on a project basis.

The tool uses emission factors based on both primary research (as described in the previous section) and published values. The tool uses values of energy use and CO_2 emissions produced from a range of activities, including:

- Winning, handling, crushing, screening and blending of primary aggregates (quarrying).
- Crushing, screening and blending of recycled aggregates (recycling).
- Transport of materials between points of origin and delivery to construction site.

This section provides a guide to using the Sustainable Aggregates CO_2 Emissions Estimator tool. The objective of the spreadsheet tool is as follows:

- To enable an estimate of the CO_2 savings arising from substituting primary or quarry aggregates for recycled aggregates into a construction job (in terms of embodied energy and direct energy usage in transport of materials).

The potential areas for CO_2 savings are:

- Differences in material density and freight distance between construction job and recycling facility or quarry i.e. reduced transport emissions.
- Differences in embodied energy of recycled and new quarry aggregates i.e. reduced embodied emissions.

The tool also provides an opportunity for the user to broadly determine any financial cost differences between jobs with different materials choices. This will vary from job to job depending on proximity of the material source to the project site and the actual cost of materials.

The tool uses Microsoft Excel worksheets. These are as follows:

- *Instructions worksheet* – describing the six steps in the analysis.
- *Input and calculation worksheet* – containing input cells and default data .
- *Default project worksheet* – shows outcomes with a 0% recycled component.
- *Output summary worksheet* – displays results of selected unbound pavement designs.
- *Formulae and assumptions worksheet* – displays emission factors, other default values and their sources.
- *References worksheet* – describing data sources.

Data sources

There is a scarcity of suitable data in Australia. The worksheet uses embodied energy data generated from this project involving a survey of four recyclers in different capital cities across Australia, as discussed in section 3. Australian data on emission factors for quarry products is limited. Data has been sourced from a WA study on a quarry operation and a consultants report on a quarry operation in Victoria (as discussed in Section 3).

Assumptions

The tool's main objective is to provide an estimate of the potential savings in CO_2 emissions when choosing recycled materials for a construction job.

There are a number of underlying factors in the development of this tool. These include:

- The emissions from road transport assume a one-way loaded trip. Given that the return trip will usually be empty and will not differ between materials chosen, it is not included in the analysis.
- The worksheet allows for the user to customise a number of parameters, including pavement dimensions, percentage recycled component in each pavement layer, price of materials, transport distances and freight vehicle type (rigid or articulated).
- The user has access to all formula used in the worksheet and the user can customise both formulae and input data.

Guide to entering data

An outline of each of the steps in using the tool is provided in Appendix 1.

The main steps are:

- Enter the dimensions of the construction job for each base layer i.e. pavement width, depth, length.
- Enter the percentage recycled aggregates within each base layer.
- Enter cost of recycled and new quarry product.
- Worksheet calculates: m^2 of pavement, m^3 and t of material and a cost of material for each layer.
- Enter the transport distances in km (one way) i.e. recycling facility to construction job and quarry to construction job.
- Worksheet calculates the amount in tonnes of material to be transported in tonne km, accounting for their different densities.
- Observe the outputs in the calculations and output sheets for CO_2-e savings between alternative recycled: primary aggregate mixes.

Results

The user can input a range of figures into the spreadsheet tool with regard to: percentages of recycled aggregates for each pavement layer; transport distance of material to project site; and cost of materials; to observe the impact on emissions and financial cost.

Assuming all other factors are equal by substituting 50% of primary aggregates with recycled will mean a reduction in emissions of 23% i.e. 2.59 kg CO_2-e/m^2 reduced to 1.99 kg CO_2-e/m^2, assuming a pavement of 300mm depth and 10 m width (as illustrated in Appendix 2).

Emissions can be further reduced where the transport distance from the recycling facility to the construction project is less than the nearest quarry.

5 Conclusions

The study collected process energy usage data from the recycling industry to develop an emission factor for recycled aggregate. An average emission factor of almost 4 kg CO_2-e/t has been calculated from the data provided. This represents between 22% and 46% fewer emissions than an equivalent quarried or primary aggregate (based on limited Australian data on primary aggregates). Similarly US studies have found recycled aggregate to have around 30% less embodied carbon emissions than primary aggregates.

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ERM (2006). *Greenhouse Gas & Energy Assessment for your Operation.* IQA-CCAA Construction Materials Industry Conference 2006. Presented by Tony Powell. Environmental Resources Management Australia.

Quarry Products Association (2008). *Sustainable Development Report 2008.* United Kingdom. http://www.qpa.org/sus_report01.htm

RMCG (2008). *Process energy emissions – Resourceco recycled aggregates.* Report prepared for ARRB Group and Resourceco. RM Consulting Group, Bendigo, Vic.

Strategen (2008). *Red Hill quarry development proposal. Public Environmental Review.* Prepared for Hanson Construction Materials Pty. Ltd. Western Australia

Appendix 1: Instructions worksheet

Sustainable aggregates SA CO_2 emissions estimator - INSTRUCTIONS

Grey cells	Input cell - enter data
Orange cells	Set figure - cannot change
Green cells	Calculated figure

Default Calculation (0% Recycled content) | **Output Summary** | **MAIN MENU**

STEP 1:	RECYCLED CONTENT	a. Select % recycled content in base layer b. Enter pavement dimensions: width, thickness, length of base layer c. Select % recycled content in subbase layer d. Enter pavement dimensions: width, thickness, length of subbase layer
STEP 2:	COST OF MATERIALS	a. Enter cost of recycled and quarry materials b. Tool calculates: m^2 pavement, m^3 & t of material and cost of materials
STEP 3:	TRANSPORT DISTANCE	a. Select heavy vehicle type: articulated or rigid b. Enter estimated km of oneway trip - recycling depot to project site c. Enter estimated km of oneway trip - quarry to project site d. Tool calculates tonne-kms and cost for recycled and quarry materials
STEP 4:	EMBODIED ENERGY & EMISSIONS	a. Tool calculates base and subbase materials emissions
STEP 5:	TRANSPORT ENERGY USE & EMISSIONS	a. Tool calculates total tonnage hauled and transport emissions by heavy vehicle type
STEP 6:	GRAND TOTAL CO_2 EMISSIONS	a. Tool summarises total embodied materials emissions and transport emissions for the project b. Tool provides a total cost of materials c. Go to default worksheet (0% recycled for the same project) d. Go to output summary worksheet - for results for actual project and default (0% recyced content)

Appendix 2: Example summary outputs

PROJECT SUMMARY — 50% recycled base material — MAIN MENU

	Default	Current Project	Units
Material selection			
Road base material	3,450	3,165	tonnes
Select recycled content %	0%	50%	
Road subbase material	3,450	3,165	tonnes
Select recycled content %	0%	50%	
Materials cost	$96,600	$91,500	
Transport cost	$41,400	$37,980	
Total costs	$138,000	$129,480	
Materials emissions			
Base materials emissions	22,080	16,411	kg CO_{2-e}
Subbase materials emissions	22,080	16,411	kg CO_{2-e}
Transport energy use and emissions			
Transport emissions - Articulated	7,673	7,039	kg CO_{2-e}
Transport emissions - Rigid	24,937	22,877	kg CO_{2-e}
(Note: total emissions uses freight vehicle selected)			
Summary - total emissions and cost			
Grand total emissions	51,833	39,860	Total kg CO_{2-e}
Emissions per m^2 of road	2.59	1.99	kg CO_{2-e}/m^2
Percentage change in emissions		23%	

PROJECT SUMMARY

50% recycled base material
25 km less transport distance

MAIN MENU

	Default	Current Project	Units
Material selection			
Road base material	3,450	3,165	tonnes
Select recycled content %	0%	50%	
Road subbase material	3,450	3,165	tonnes
Select recycled content %	0%	50%	
Materials cost	$96,600	$91,500	
Transport cost	$51,750	$35,606	
Total costs	$148,350	$127,106	
Materials emissions			
Base materials emissions	22,080	16,411	kg $CO_{2\text{-}e}$
Subbase materials emissions	22,080	16,411	kg $CO_{2\text{-}e}$
Transport energy use and emissions			
Transport emissions - Articulated	11,509	6,159	kg $CO_{2\text{-}e}$
Transport emissions - Rigid	37,405	20,017	kg $CO_{2\text{-}e}$
(Note: total emissions uses freight vehicle selected)			
Summary - total emissions and cost			
Grand total emissions	55,669	38,980	Total kg $CO_{2\text{-}e}$
Emissions per m^2 of road	2.78	1.95	kg $CO_{2\text{-}e}/m^2$
Percentage change in emissions		30%	