

Calculating Greenhouse Gas Emissions in the Construction Industry

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ABSTRACT

Greenhouse gas emissions within the civil construction industry are becoming a major issue due to the eventual implementation of the Carbon Pollution Reduction Scheme. This paper examines existing methods for calculating greenhouse emissions associated with construction projects before establishing a more effective and comprehensive way to monitor, analyse and report greenhouse emissions. Existing literature relating to construction industry greenhouse emissions is reviewed. The paper investigates the information sources used by VicRoads, Australian Greenhouse Office and the Australian Government Department of Climate Change, especially the National Greenhouse Accounts Factors document. Given the weaknesses identified in existing methods, a modified calculator was then developed to estimate greenhouse gas emissions from all elements of a construction project, from energy consumed to materials used to vegetation cleared and the associated transport of these. Using the data from an actual rail project, the VicRoads' Calculator is compared against the modified calculator. Support for the use of a modified calculator is found through differences in the calculation of some aspects and in emission factors. The importance of continual updating of information is stressed, particularly due to the large scale of construction projects and the changing nature of the various energy and emissions factors involved. Small differences can create large errors in calculation. It is found that the simple yet comprehensive modified calculator provides more accurate results in a more user friendly manner, making it easily applicable to civil construction projects of any scale.

1. INTRODUCTION

Presently the Australian Government is planning on phasing in a Carbon Pollution Reduction Scheme (CPRS) (DCC, 2008a) into the Australian economy. The CPRS will have a major effect on all industries and workplaces throughout Australia. All companies who produce more than 250,000 tonnes (as CO_{2-e}) of carbon pollution each year (DCC, 2008a) will need to report their greenhouse emissions in order to purchase permits to allow them to produce and trade in greenhouse emissions. This will become a major issue for the construction industry, particularly how they will report the amount of greenhouse emissions that will be produced from their various construction projects.

Presently there are very few tools and literature sources available for companies to use to accurately quantify their emissions associated with their construction projects. To establish a simple and comprehensive way for these companies to report their project-related emissions several different avenues need to be investigated.

Firstly the sources and processes from which the construction projects emit their emissions need to be established. This can be broken down into several sections: onsite impacts, vegetation clearing, embodied energy in materials and the transportation of materials to and from site. After establishing these elements the following methodology can be implemented

to determine an effective and comprehensive way to monitor, analyse and report greenhouse emissions from construction projects:

- Application of the existing VicRoads Greenhouse Gas Calculator v2 (NetBalance, 2008) to an actual Rail Project (site confidential) as a case study to determine if there are any information gaps between the tool and required information;
- Analysis of this case study to determine the accuracy of the results and the data within the VicRoads Calculator via a review of the current literature;
- An investigation into the possible alternative methods that could be used to bridge any gaps or uncertainties within the calculator and data; and,
- Development of a Modified Greenhouse Emissions Calculator that incorporates new aspects and methodology;
- Comparison of the two calculators to determine which is more accurate, comprehensive and simpler to use; and
- Discussion of key findings from the project.

2. ESTABLISHING THE GAPS

The first step of this project was to apply the existing VicRoads Greenhouse Gas Calculator (NetBalance, 2008) to an anonymous actual road project. This calculator is set out as an Excel spreadsheet, allowing for the input of information into three main sheets; onsite impacts, transport of materials and material embodied energy. 'Onsite impacts' cover electricity usage, vegetation clearing and fuel consumption. The 'Transport of Materials' section calculates the amount of emissions produced from the transport of project materials to and from the project site. Lastly, 'Material Embodied Energy' calculates the amount of greenhouse emissions that are produced during the production of the materials used. The majority of these calculations use emission factors that have been either established by the Australian Government Department of Climate Change or their specified industry. Thus it is important for the development of a greenhouse calculator to ensure that these factors mimic the findings of current literature. The application of the calculator was done to establish if there were any information gaps between the tool and the information supplied.

By applying this calculator to the rail construction project a number of information gaps were established. The major gap established from this application was within the onsite impacts section of the calculator. 'Onsite impacts' is one of the main areas requiring information within the calculator. It contains 3 sub-sections: electricity, fuel usage and vegetation clearing. The first 2 sub-sections; electricity and fuel consumption, are relatively straightforward as this information is easily sourced from bills, invoices and site management. The third section, 'Vegetation Clearing', has proven to be more difficult to populate as it requires information to calculate both the forgone sequestration and the greenhouse emissions already stored within the vegetation (refer to Figure 1 highlighted in purple). To calculate this, the Calculator requires information on the age of the cleared vegetation, the predicted weight of the vegetation and the 'Area' (vegetation type) in which the vegetation belongs to (refer to Figure 1 highlighted sections blue and green).

Vegetation						
Trees removed	Predicted Age of Tree (years)	Predicted Weight of Tree (tonnes)	Tree Growth Area	Forgone Sequestration (t CO ₂ -e)	Decomposition GHG release (t CO ₂ -e)	Total tree GHG Emissions (t CO ₂ -e)
Tree 1	2	2	Area 6	181.1	5.4	186.5
Tree 2	5	4	Area 6	184.0	10.8	194.8
Tree 3	10	6	Area 6	204.0	16.2	220.2
Tree 4	15	8	Area 6	232.0	21.6	253.6
Tree 5	20	10	Area 6	264.4	27.0	291.4
Tree 6	2	12	Area 7	149.1	32.4	181.5
Tree 7	5	14	Area 7	154.2	37.8	192.0
Tree 8	10	16	Area 7	174.2	43.2	217.4
Tree 9	15	18	Area 7	202.2	48.6	250.8
Tree 10	20	20	Area 7	234.6	54.0	288.6

Figure 1: Vegetation clearing table (NetBalance, 2008)

For the type of vegetation cleared, the VicRoads Calculator allows for two separate areas in Victoria to be chosen to represent the type of vegetation prominent within the project area, Areas 6 and 7. There is a significant difference between the two areas at 180 and 150 tonnes CO_{2-e} per tree respectively. These values precede the incorporation of the age or weight of the specified tree. Hence it is important that this information is accurate and true as it would effect the overall CO_{2-e} emissions of a given project, especially if the project involves significant vegetation clearing. Areas 6 and 7 refer to vegetation types within the South Western Victoria and Northern Central Victoria respectively (e.g. see Figure 2, page 3, of AGO, 2006a) – neither of which should be used for this specific project as it is not located within either of these regions. Thus an investigation into the possibility of establishing values for specific vegetation types rather than areas is required. This would enable the production of more accurate results.

3. LITERATURE REVIEW

This section outlines the various literature reviews that were undertaken during the project. However before any reviews can be undertaken it first must be established how or from what sources construction projects produce their emissions. Once this has been established reviews can be undertaken in these areas to establish ways in which to quantify the emissions. Project emission sources can be broken down into several sections such as onsite impacts, vegetation clearing, embodied energy in materials and the transport of materials to and from site. Breaking this down further, the main producers of greenhouse emissions from construction projects are as follows:

- Onsite fuel consumption in vehicles, machinery, equipment, generators and plant operation;
- Electricity consumption;
- Decomposition of vegetation and the foregone sequestration as a result of clearing the site;
- Materials such as concrete, steel, wood, asphalt, PVC piping, aggregate and cement treated crushed rock; and
- Transportation of materials to and from site.

Now that the sources of greenhouse emissions have been established literature reviews can be undertaken on these various sections to establish ways in which they can be quantified and hence reported. It should be noted that the main way to calculate the greenhouse emissions from the majority of the mentioned elements is from the products specific emissions factor. The following reviews include documentation from the Intergovernmental Panel on Climate Change (IPCC), Australian Greenhouse Office (AGO), the Department of Climate Change (DCC) and National Pollution Inventory (NPI).

The literature review section is split into two main sub-sections. One relating to vegetation clearing and the other to sourcing the information for the emissions factors for the varying types of materials used on site.

3.1 Vegetation Clearing

3.1.1. General – Vegetation Groupings

One of the main areas under investigation is the classing of vegetation into specified groupings or classes, to correctly identify their store of greenhouse emissions and the foregone sequestration of the vegetation. To ensure that this section of the calculator is as accurate and relevant as possible, it is important to establish the correct carbon storage and foregone sequestration of the particular vegetation within the project area. The National Vegetation Information System (AGO, 2002; NGGIC, 2004) groups Australia's vegetation into 23 major groups, namely:

- Group 1: Rainforest and Vine Thickets
- Group 2: Eucalyptus Tall Open Forests
- Group 3: Eucalyptus Open Forests
- Group 4: Eucalyptus Low Open Forests
- Group 5: Eucalyptus Woodlands
- Group 6: Acacia Forests and Woodlands
- Group 7: Callitris Forests and Woodlands
- Group 8: Casuarina Forest and Woodland
- Group 9: Melaleuca Forest and Woodland
- Group 10: Other Forests and Woodlands
- Group 11: Eucalyptus Open Woodland
- Group 12: Tropical Eucalyptus Woodlands/ Grasslands
- Group 13: Acacia Open Woodland
- Group 14: Mallee Woodland and Shrublands
- Group 15: Low Closed Forests and Closed Shrublands
- Group 16: Acacia Shrublands
- Group 17: Other Shrublands
- Group 18: Heath
- Group 19: Tussock Grassland
- Group 20: Hummock Grassland
- Group 21: Other Grasslands, Herbland, Sedgeland and Rushland
- Group 22: Chenopod Shrub, Samphire Shrub and Forbland
- Group 23: Mangrove, Tidal Mudflat, Samphire, Claypan, Salt Lakes, Bare Areas, Sand, Rock, Lagoons and Freshwater Lakes

3.1.2. Decomposition

To establish the amount of greenhouse emissions that are released during the decomposition of the cleared vegetation, the carbon content of the vegetation needs to be estimated. However, for the carbon content of the vegetation to be estimated several factors need to be established. This is where the information in the above section is vital. The carbon content of the vegetation can be calculated by first establishing the specific vegetation type for the project area and then the weight of the specified vegetation. This information will then be used in conjunction with the following two tables that have been identified by the Australian Greenhouse Office (AGO, 2002, 2003). Table 1 below relates to the carbon content of specific sections of the vegetation, while Table 2 refers to the fraction of vegetation that would be represented within that specified vegetation group. The stored carbon within the vegetation can then be quantified by the following equation:

$$TC = WT((Cs \times Ts) + (Cbr \times Tbr) + (Cba \times Tba) + (Clt + Tlt) + (Ccr + Tcr) + (Cfr \times Tfr)) \quad \text{Equation 1}$$

in t CO_{2-e}, where:

WT is weight of vegetation grouping

Ts is vegetation fraction of stems

Tbr is vegetation fraction of branches

Tba is vegetation fraction of bark

Tlt is vegetation fraction of leaves and twigs

Tcr is vegetation fraction of coarse roots

Tfr is vegetation fraction of fine roots

TC is total carbon content of vegetation

Cs is carbon content of stems

Cbr is carbon content of branches

Cba is carbon content of bark

Clt is carbon content of leaves and twigs

Ccr is carbon content of coarse roots

Cfr is carbon content of fine roots

During decomposition of the vegetation this stored carbon will then be converted to CO_{2-e} emissions (NGGIC, 2004). The IPCC use a recommended default conversion factor of 44/12 (NGGIC, 2004), which is simply the molar mass of CO_{2-e}. Thus to establish the total amount CO_{2-e} emission released during the decomposition of the clear vegetation the following equation can be used:

$$\text{Decomposition Emissions (t CO}_{2-e}\text{)} = (44/12) * TC \quad \text{Equation 2}$$

Table 1: Carbon contents of tree components (AGO, 2002; NGGIC, 2004)

Tree Component	Carbon Content (fraction of dry matter)
Stems	0.50
Branches	0.47
Bark	0.49
Leaves and Twigs	0.52
Coarse Roots	0.50
Fine Roots	0.48

Table 2: Allocation of biomass to tree components (AGO, 2003; NGGIC, 2004)

Name	Yield Allocation to Stems (fraction)	Yield Allocation to Branches (fraction)	Yield Allocation to Bark (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Fine Roots (fraction)	Yield Allocation to Coarse Roots (fraction)
Rainforest and vine thickets	0.78	0.06	0.06	0.01	0.06	0.03
Eucalyptus Tall Open Forest	0.67	0.09	0.10	0.02	0.08	0.04
Eucalyptus Open Forest	0.45	0.12	0.10	0.02	0.25	0.06
Eucalyptus Low Open Forest	0.45	0.12	0.10	0.02	0.25	0.06
Eucalyptus Woodland	0.44	0.15	0.10	0.02	0.23	0.06
Acacia Forest and Woodlands	0.42	0.15	0.10	0.02	0.25	0.06
Callitris Forest and Woodlands	0.42	0.15	0.10	0.02	0.16	0.15
Casuarina Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Melaleuca Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Other Forests and Woodlands	0.42	0.15	0.10	0.02	0.25	0.06
Eucalyptus Open Woodland	0.41	0.18	0.10	0.02	0.23	0.06
Tropical Eucalyptus woodlands/grasslands	0.41	0.18	0.10	0.02	0.23	0.06
Acacia Open Woodland	0.22	0.165	0.10	0.025	0.42	0.07
Mallee Woodland and Shrubland	0.22	0.165	0.10	0.025	0.42	0.07
Low Closed Forest and Closed Shrublands	0.22	0.165	0.10	0.025	0.42	0.07
Acacia Shrubland	0.22	0.165	0.10	0.025	0.25	0.24
Other Shrublands	0.22	0.165	0.10	0.025	0.25	0.24
Heath	0.00	0.3	0.18	0.03	0.25	0.24
Chenopod Shrub, Samphire Shrub and Forbland	0.00	0.3	0.18	0.03	0.25	0.24
Mangrove, tidal mudflat, samphire and bare areas, claypan, sand, rock, salt lakes, lagoons, freshwater lakes	0.167	0.167	0.167	0.167	0.167	0.167
Unclassified Native vegetation	0.39	0.14	0.09	0.02	0.25	0.11

3.1.3. Foregone Sequestration

Foregone sequestration refers to the amount of carbon that will not be sequestered by vegetation once it is cleared. As stated by Roxburgh *et al* (2006), foregone sequestration is the difference between the total amount of carbon the vegetation can sequester in its life time minus the total amount of carbon that is already stored within the vegetation. However, estimating the amount of carbon specific vegetation can sequester during its lifetime is a complex task. Many factors need to be considered such as the age of the tree, its expected lifetime and the area's rainfall, as this affects the tree's growth rate. Due to time constraints and the lack of information readily available on foregone sequestration, the adaptation of a method to be incorporated into the modified calculator has been unachievable. However, it should be kept in mind that foregone sequestration does affect the amount of greenhouse emissions produced by the project. It should also be noted that the method used by NetBalance (2008) in the VicRoads Calculator could not be confirmed from their literature source (cf. AGO, 2006a). Therefore it is recommended that, to calculate the effects of vegetation clearing on a project site, the Full Carbon Accounting Model ('FullCAM') developed by AGO is utilised. This model has national certification and is used by Australia to estimate its official total carbon sequestration for the IPCC through land use change (NGGIC, 2006).

3.2 Emission Factors

3.2.1. Scope and Boundaries

In general, emission factors are used to help establish the amount of greenhouse emissions being produced by a specified activity, whether it is mining or the production of electricity or materials. The Australian Government Department of Climate Change have developed the

National Greenhouse Accounts (NGA) Factors report (October 2008) (AGO, 2006b), which details the emission factors for a range of materials, fuels and activities. They have categorised greenhouse emissions into two distinct groups; direct and indirect emissions (DCC, 2008b). These two groups have been further simplified by introducing three scope levels. Scope 1 accounts for direct or point source emissions, while Scope 2 and 3 accounts for indirect emissions (DCC, 2008b). This document also details the calculation methods that companies should use in conjunction with the emission factors to calculate the overall greenhouse emissions from their company's activities (DCC, 2008b). The greenhouse emission totals can then be used to report the company's greenhouse emissions totals to the national Greenhouse and Energy Reporting Scheme (DCC, 2008b).

Within the construction industry, the main source of greenhouse emissions comes from the embodied emissions of materials used on site. The NGA document, however, only provides information on the more widely used and known substances. As a result, other sources of information will need to be used to obtain and calculate the embodied greenhouse emissions of new environmentally friendly product alternatives.

3.2.2. Material Emission Factors

One of the important factors when developing a Greenhouse Calculator will be to ensure that all of the emission factors within it are current. Thus an examination of the emission factors within the VicRoads Greenhouse Gas Calculator and current literature has been undertaken. Data for the emissions factors were sourced from a number of different areas. This included:

- Company information from Australian Vinyls (2008), Blue Scope Steel (2008) and the Cement Industry Federation (CIF 2008);
- Databases within the SimaPro 7.1 Demo (PRe Consultants, 2008);
- Industry investigation i.e Concrete versus Timber Sleepers (Energy Strategies, 2007); and
- NGA Factors report for fuel and electricity emissions factors (AGO, 2006b).

Some of the materials such as concrete, cement treated crushed rock (CTCR) and asphalt relied on the percent content of their make up. For example concrete and CTCR emissions factor depended upon their content of cement and aggregate while asphalt depending upon the content of bitumen and aggregate.

4. CALCULATOR DEVELOPMENT

Onsite energy consumption section estimates the amount of greenhouse emissions produced as a result of the energies consumed on site during the construction of the project. These energies include the amount of 'Electricity' consumed onsite and the consumption of 'Fuels' used in both vehicles and the operation of equipment and machinery. The modified calculator also allows the user to choose the state in which the construction is undertaken and contains an option for the use of renewable energy.

The land use change section of the calculator determines the amount of greenhouse gas emitted through the decomposition of different types of cleared vegetation on site. Decomposition of vegetation contains varying factors including; type and weight of the vegetation, percentage makeup of the vegetation particulars (branches, stems, roots, bark and leaves), carbon content of the vegetation particulars and the stored carbon to emissions ratio. All of these factors are used to determine the amount of carbon released during the decomposition of the vegetation. The modified calculator uses the National Vegetation Information System which classifies Australian vegetation into 23 distinct vegetation types.

The modified calculator estimates the total amount of greenhouse gas emissions that are embodied within the materials. To establish an overall emissions generation each material supplied to the project is quantified as a weight (tonnes), except concrete which is m^3 , and then this quantity is multiplied by the materials relative emissions factor. This estimates the greenhouse emissions produced by the use of those specific materials on site.

The CO_{2-e} emissions as a result of transportation of all materials to the construction site also contribute to the project's overall greenhouse gas emissions. These emissions are dependent upon the following factors; type of truck either medium or heavy (where heavy is assumed to be an articulated truck and medium refers to a rigid truck), truck fuel efficiency, fuel type, distance travelled and the number of trips made to the site. The total greenhouse emissions calculated from the transport of materials was calculated using the following formula:

$$\text{GHG (t CO}_{2\text{-e}}) = [\text{distance (km)} * \text{truck fuel efficiency (L/km)} * \text{EF (t CO}_{2\text{-e}}/\text{L})] \quad \text{Equation 3}$$

Where the distance is twice that as the distance from the site to the supplier as it is assumed the trucks make a round trip during their delivery. This distance was then multiplied by the number of trips made to site.

The modified calculator also summarises the amount of greenhouse gas emissions produced from the project for the previous sections. Several other factors are also calculated within the 'Project GHG Totals' section including the addition of an uncertainty factor to the emissions total. The other calculations include the ability to determine the amount of emissions produced per kilometre of rail and the potential cost of offsetting these emissions. All three sections can be manually modified to change the uncertainty factor, the length of rail or the cost of carbon per tonne.

5. RESULTS

Once the modified calculator was finalised, the same set of data for an actual rail project were entered so that the results could be compared between the two calculators and discrepancies noted. The easiest way to compare these calculators is to analyse their 'Totals' pages, and then discuss any discrepancies between their results. Table 3 below summarises the greenhouse emission estimates for both calculators side by side.

Two sections between the calculators gave very similar results, on-site fuel emissions and electricity emissions, while the other three sections vary substantively. These variations are due to a number of varying factors. Overall the discrepancies between the calculators amount to a 52 t CO_{2-e} difference between the total greenhouse emissions produced by the rail construction project.

Table 3: Greenhouse Emissions Calculator Comparison (t CO_{2-e})

Project Area	Modified	VicRoads
Total Electricity GHG Emissions	11.02	11.02
Total On-site Fuel GHG Emissions	43.20	43.16
Total Vegetation GHG Emissions	14.38	21.60
Total Transport GHG Emissions for Materials Supplied	34.35	11.18
Total Material Embodied Energy GHG Emissions	1147.8	1215.8
Overall Total Greenhouse Gas Emissions (t CO_{2-e})	1251	1303

6. DISCUSSION

The similarities between the emission estimates for the onsite fuel usage and electricity consumption are related to the minor or no change in the materials' emissions factors. This is due to the direct correlation between the greenhouse emissions factors used by both.

Vegetation clearing emissions differ by 7.22 t CO_{2-e} due to the calculation methods employed. The VicRoads Calculator uses the wood emissions factor supplied by the NGA Factors (DCC, 2008b) document of 2.7 CO_{2-e}, while the modified version estimates the

decomposition of the vegetation based on the type of vegetation. These emission factors range from 1.78 to 1.82 CO_{2-e}, and the difference between the two factors accounts for the differing greenhouse emissions estimates.

'Transportation of Materials to Site' differs by 23.2 t CO_{2-e}. A comparison between the two determined that the discrepancy lay within the calculation method. The modified calculator used the calculation method established by the AGO Factors and Methods Workbook (AGO, 2006b). NetBalance failed to incorporate the emission factors of the fuels into their calculations. This production of a figure in litres rather than the required t CO_{2-e} accounts for the large difference between the two.

The comparison of the embodied emissions sections of both calculators showed a discrepancy of 52 t CO_{2-e}. Since both calculators contained the same input data and methods to calculate the greenhouse gas emissions produced by the various materials, the source of the discrepancy is clearly the emissions factors used, as shown in table 3. Even though the emission factors only differ slightly, the large amounts of materials used, especially with steel, contribute to the large difference between the two results.

Table 4: Material emissions factors

Materials (t CO_{2-e} per t material)	Modified	VicRoads
Steel	2.20	2.65
Aggregate	0.01	0.01
Asphalt	0.03	0.01
PVC Pipes	2.51	2.32
Envirocrete	0.01	0.01
Cement Treated Crushed Rock	0.0307	0.03
Concrete (t CO _{2-e} /m ³)	0.269	0.26
Concrete Sleeper (kg CO _{2-e} per sleeper)	57.2	57.2
Timber Sleeper (kg CO _{2-e} per sleeper)	140	140

7. DISCUSSION AND CONCLUSIONS

Greenhouse emissions within the construction industry are becoming a major issue due to the looming implementation of a Carbon Emissions Trading Scheme, and the large amount of emissions construction projects produce. As a result, this report has reviewed a number of elements surrounding this issue. In particular, the report has focused on existing methods to determine a simple and comprehensive way for construction companies to report their greenhouse emissions produced from their construction projects. One of the existing methods is a VicRoads' Greenhouse Gas Calculator developed by NetBalance (2008) for road construction projects.

The VicRoads Calculator was applied to an actual rail construction project to establish if there were any information or data gaps between the calculator and project data. From the case study it was found that, aside from the differences between the two project types, the biggest gap was how the greenhouse emissions from vegetation clearing were estimated. This was separated into decomposition emissions and foregone sequestration emissions. To establish how these emissions are determined, this project investigated the information sources used by NetBalance as well as others. From both AGO (2002, 2003), and NGGCI (2004), a method was developed to calculate the amount of emissions released during decompositions. The method involves the determination of the carbon content of the vegetation and hence the amount of carbon emissions that would be released during

decomposition. Finding information on foregone sequestration, on the other hand, has been a rather challenging task. This is due to the complexity of the information required to calculate the emissions. Such information as the rainfall totals, areas, specific tree type, age of trees and soil types are required in most models. It should be noted that the sources used by NetBalance (2008) in the VicRoads Calculator could not be confirmed. A model already developed by AGO called 'FullCAM' can calculate the decomposition and foregone sequestration of vegetation. Hence it is recommended that the FullCAM model be used until a simple method can be established and inserted in to the calculator.

Another major factor in the calculation of the project greenhouse emissions is the usage of emission factors to calculate these values. The emission factors have been based on the Department of Climate Changes' National Greenhouse Accounts (NGA) Factors document. This document outlines the emission scopes and how they relate to different industries, either indirectly or directly. NGA Factors also details the calculation methods used to establish the greenhouse emissions produced by specified activities, materials and fuels. As this document only covers the more general materials such as liquid fuels, solid fuels, electricity and waste products, further investigation was conducted to establish emissions factors for the other construction materials used on site. These emissions factors came from a range of sources and should be updated at the beginning of every project with the emission factors supplied by the companies from whom the materials are obtained. This will ensure that the emissions calculated from the emissions factors are as accurate as possible.

After determining the values for the range of materials used in construction, a modified greenhouse emissions calculator was developed. Both the VicRoads Calculator and the modified calculator were then used on a rail construction project to compare and contrast the differences between the two versions. Overall the modified version was 52.04 t CO_{2-e} lower than the VicRoads Calculator. This was due to a number of reasons; such as, varying emissions factors (which highlights the importance of ensuring these are correct), a calculation error in the VicRoads Calculator and the ability for the modified calculator to calculate the decomposition emissions from specific vegetation types rather than broad geographic areas. Therefore, the modified version allows for a more accurate result of total greenhouse emissions. It is also more simplistic and user friendly than its VicRoads counterpart. Over time, as reporting becomes more widespread across industry sectors and data quality advances, improvements will continue to be made for the emissions factors of a range of materials and energy sources, thereby leading to continual development of the emissions calculator for construction projects.

8. REFERENCES

- AGO, 2002, *National Carbon Accounting System, Greenhouse Emissions from Land Use Change in Australia: An Integrated Application of the National Carbon Accounting System*. Department of the Environment and Heritage, Australian Greenhouse Office (AGO), Australian Government, 123p.
- AGO, 2003, *Land Use Change Emission Estimates Supplementary Methods*. Department of the Environment and Heritage, Australian Greenhouse Office (AGO), Australian Government, 17p.
- AGO, 2006a, *Investing in Trees as Greenhouse Sinks: An Overview for Industry, Australian Government*. Department of the Environmental and Heritage Australian Greenhouse Office, Australian Greenhouse Office (AGO), Australian Government, 14p.
- AGO, 2006b, *AGO Factors and Methods Workbook*. Department of the Environment and Heritage, Australian Greenhouse Office (AGO), Australian Government, 49p.
- Australian Vinyls, 2008, *Sustainability Report 2007*. www.av.com.au/Assets/7/1/2007SustainabilityReportcorrected.pdf, Accessed 6 January 2009.
- Blue Scope Steel, 2008, *Our Greenhouse Performance*. csereport2007.bluescopesteel.com/energy_greenhouse/our_greenhouse_performance.html, Accessed 6 January 2009.

- CIF, 2008, *Australian Cement Industry: 2007 Statistics (Fastfacts)*. Cement Industry Federation (CIF) Australia, cement.org.au/publications/cif-technical-reports, Accessed 6 January 2009.
- DCC, 2008a, *Carbon Pollution Reduction Scheme*. Department of Climate Change (DCC), Australian Government, www.climatechange.gov.au/emissionstrading/index.html, Accessed 20 August 2008.
- DCC, 2008b, *National Greenhouse Accounts (NGA) Factors*. Department of Climate Change (DCC), Australian Government, November 2008, 65p.
- Energy Strategies, 2007, *Review of CO_{2-e} Emissions From Concrete versus Timber Sleepers*. www.enerstrat.com.au/lib/documents/Review-of-CO2-Emissions-from-Concrete-versus-Timber-Sleepers.pdf, Accessed 24 November 2008.
- NetBalance, 2008, *VicRoads Greenhouse Gas Calculator v2*. Developed by NetBalance Management Pty Ltd for VicRoads, Melbourne, VIC, www.vicroads.vic.gov.au, Accessed 24 November 2008.
- NGGIC, 2004, *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2004: Land Use, Land Use Change and Forestry*. Department of Climate Change, National Greenhouse Gas Inventory Committee (NGGIC), Australian Government, 192p.
- NGGIC, 2006, *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Industrial Processes*. Department of Climate Change, National Greenhouse Gas Inventory Committee (NGGIC), Australian Government, 39p.
- PRe Consultants, 2008, *SimaPro 7.1 Demo*. PRe Consultants, The Netherlands, www.pre.nl/simapro/download_simapro.htm, Accessed 8 January 2009.
- Roxburgh, S H, Wood, S W, Mackey, B G, Woldendorp, G and Gibbons, P, 2006, *Assessing the Carbon Sequestration Potential of Managed Forests: A Case Study from Temperate Australia*. *Journal of Applied Ecology* 2006, 43, pp 1149–1159.

9. BIOGRAPHIES

Vicky Grima recently completed a Bachelors degree in Environmental Engineering at Monash University in Melbourne, Australia. Her experience in the construction industry involved practical assessment of the greenhouse emissions for a range of civil construction projects. Recently Vicky has travelled across the world, seeing the broad array of social, economic and environmental challenges the world faces – the true heart of sustainability !!

Dr Gavin M. Mudd joined Monash University in May 2003 and is presently Lecturer and Course Director for Environmental Engineering. His broad ranging experience has included research, teaching and advocacy, with a particular focus on environmental management and impacts associated in mining, as well as important contributions to groundwater resources and management. He continues to be very active in research and teaching, adopting a strong multi-disciplinary approach to all of his work, including industry, community and government groups.