Quantifying Greenhouse Gas Emission Reductions When Utilizing Road Recycling Maintenance Processes

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Paper Prepared for Presentation

at the New Realities with Recycling Materials Session

of the 2010 Annual Conference of the Transportation Association of Canada

Halifax, Nova Scotia

Abstract

Economic life cycle analysis techniques assist highway agencies to develop priority lists for maintenance/rehabilitation works. This ensures an optimum spending of the maintenance budget each year, which in turn serves the interest of both the stakeholder and the road user. Although these types of systems are commonly utilized by highway agencies, few, if any, consider the environmental impact of road maintenance activities as part of the decision-making process.

To assess the environmental impact of a road rehabilitation project, consideration must be given to the actual benefits and/or adverse effects to the environment during rehabilitation activities. Any associated benefits and/or adverse effects should ideally be assessed in terms of greenhouse gas reductions/increases when comparing maintenance strategies.

AMEC have recently developed a software programme that can assess greenhouse gas reductions accrued by utilizing road recycling processes when compared to traditional maintenance strategies. The programme quantifies greenhouse gas production in terms of tonnes of CO_2e, for maintenance strategies, either on a project-by-project basis or over the life cycle of the project. Both upstream factors (i.e., environmental effects of producing the fuel to enable production, transportation and placement) and downstream factors (i.e., environmental cost of material production, transportation and placement) are considered.

This paper describes the concept behind the software development, together with numerical examples utilizing real projects in the province of Nova Scotia.

1 Introduction

Highway maintenance is essential for stable economical growth; however, the subsequent demand on non-renewable resources is high. An alternative to using non-renewable resources for highway maintenance is to utilise material from the failed section of road that requires maintenance. Thus the road itself becomes the quarry for the supply of the required aggregates. Recycling of roads has been a widely accepted practice around the world since the petroleum crisis in the early 1970s. Due to an inflated oil price and the development of milling and reclaiming equipment, a favourable and emerging market was created for recycling/reclaiming technologies for highway pavements. These early experiences demonstrated the significance of recycling techniques in reducing the cost of maintenance, as well as minimizing the impact on the environment. Since their inception in the early 1970s, these techniques have gained considerable favour as a sustainable maintenance alternative and are commonly utilised around the world. With the development of better and more powerful equipment, the quality of the end-product has improved drastically and offers a more sustainable alternative to traditional highway maintenance processes.

Recycling processes are ideal where major rehabilitation and/or reconstruction is required. The recycling process not only offers an economical alternative, but also offers a considerably more sustainable approach to highway pavement maintenance as the demand on non-renewable resources is considerably reduced.

When considering appropriate maintenance strategies for a road network, the stakeholder will commonly utilise a decision-making tool to prioritise maintenance strategies for a given network. The utilisation of these tools has become more prevalent in recent times for several reasons. Primarily, agencies are responsible for an ever aging network that is in a relatively poor condition. Funding levels for road network maintenance, set by governments, have not been sufficient to address the maintenance needs. This underfunding has been commonplace for many years. As a result, many road networks require significant investments to maintain and/or upgrade their level of serviceability. Life cycle analysis techniques have assisted highway agencies to develop priority lists for maintenance/rehabilitation works. This ensures an optimum spending of the maintenance budget each year that serves the interest of both the stakeholder and the road user. These tools generally calculate benefits over a certain life cycle and can consider a combination of economical, technical and socio-economical indices in the decision-making process.

Although these types of systems are commonly utilised, very few – if any – consider the environmental impact of road maintenance activities. Where environmental data is considered it is always limited and systems require a socio-economic impact on the user rather than the agency (e.g., increased fuel consumption due to work zones or a road in a poor condition, etc.).

To assess the environmental impact of a road rehabilitation project, consideration must be given to the actual benefits and/or adverse effects to the environment during rehabilitation activities. The benefits and/or adverse effects should ideally be assessed in terms of greenhouse gas reductions/increases: that is, rehabilitation scheme A is better than rehabilitation scheme B because CO_2 emissions during construction are reduced by 25%. This type of analysis is becoming increasingly crucial for government agencies, in particular departments responsible for the maintenance of a country's highway network, as there is pressure to reduce the impact of essential capital works projects on the environment. However, the relevant highway agency has a duty to the tax paying public to minimize capital expenditure. An agency will not approve a rehabilitation technique if it increases the capital expenditure significantly, even if greenhouse gas reductions can be reduced. That aside, the assessment of environmental impacts associated with pavement rehabilitation projects are becoming more pertinent.

AMEC Earth and Environmental have recently developed a tool (***ECOAGE***) that calculates greenhouse gas reductions associated with various highway maintenance activities. This paper describes the development of this tool, the potential utilisation, and data from case studies in the province of Nova Scotia.

2 Development of *ECOAGE*

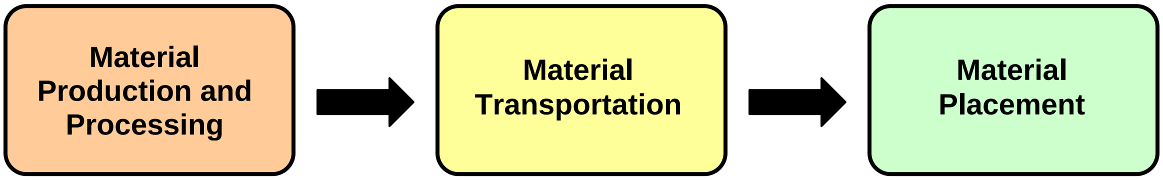
ECOAGE - **E**nvironmental **C**omparison **O**f **A**ggregate/asphalt **G**reenhouse gas **E**missions was developed to estimate environmental benefits: namely, greenhouse gas reduction as a result of alternate highway maintenance activities.

The programme has been developed using a modular approach. Each module considers a specific maintenance strategy. Currently three modules are available:

- Traditional maintenance processes
- Cold in-place processes
- Hot in-place processes

When considering emissions produced during maintenance activities, ***ECOAGE*** calculates emissions generated as a function of three distinct phases. These phases are illustrated in Figure 1.

Figure 1 Construction Phases Considered when Calculating Emissions



For each of the above phases the emissions are calculated based on current state-of-the-art relationships and appropriate emission data.

Material production/processing considers the emissions generated during the production of non-renewable resources utilised within the maintenance activity: namely, the extraction and refinement of bituminous products, quarrying and crushing of aggregates, quarrying and production of cement, etc.

Material transportation considers emissions produced during the transportation of the non-renewable resources either to the designated project site or to a processing plant where paving materials are produced: namely, transportation of liquid asphalt cement to a hot mix asphalt plant for the purpose of producing hot mix asphalt (HMA).

Finally, material placement considers emissions produced as a result of placement of the material at the project site: namely, placement of HMA, in-situ recycling, placement of granular material, etc.

Each one of these phases is considered in each maintenance module and requires pertinent data to calculate emissions. When calculating emissions, both upstream (pre-combustion) energy is considered as well as downstream energy. This is commonly referred to as Life Cycle Inventory (LCI).

Upstream (or pre-combustion) energy considers emissions generated as a result of extraction, processing and any transportation of fossil fuels to the point of their combustion. For example, energy (fuel) is required to drill and extract oil, and then to transport the crude oil to the refinery; these result in upstream energy based emissions. Once the crude arrives at the refinery, energy is required to produce the refined product. This results in emissions as a function of downstream energy requirements.

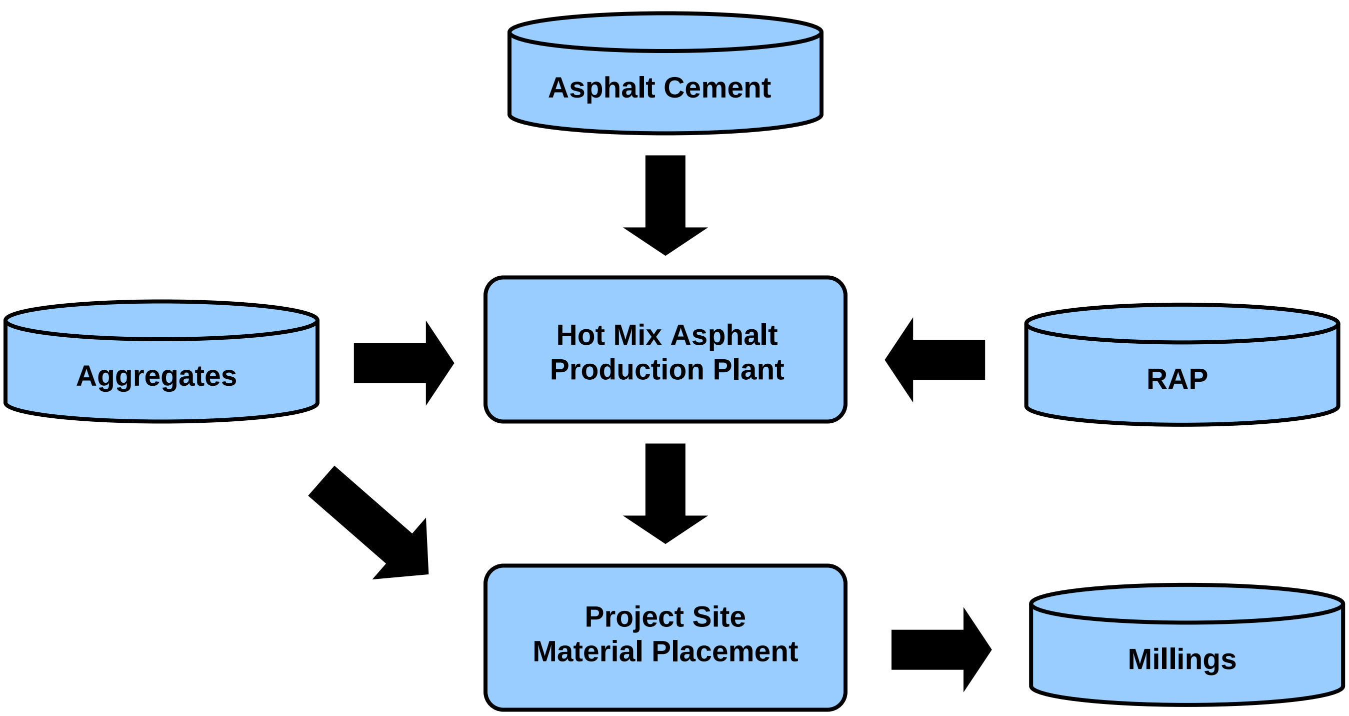
3 Module Development

For each maintenance strategy module both upstream and downstream energy consumptions are considered. These energy requirements result in the generation of emissions. In terms of emission generation ***ECOAGE*** calculates CO, CO_2, NO_x, SO_x and PM_{10} produced at each phase of the maintenance process.

The following section describes the methodology utilised to develop the maintenance modules. Each module utilised the same methodology. As an example, the development of the traditional maintenance module will be discussed in detail. Other modules, although the processes are different, utilise a similar development process.

As a starting point, a process flow diagram was developed. The flow diagram for the traditional maintenance module is illustrated in Figure 2 and is a function of the three phases (i.e., material production, transportation and placement).

Figure 2 Flow Diagram for Traditional Maintenance



3.1 Asphalt Cement Production

Asphalt cement is produced in a refinery from crude oil. When considering emissions from the production of asphalt cement the following phases are considered:

- Crude oil extraction
- Desalting
- Distillation
- Deasphalting
- Storage

Numerous studies have been performed that have quantified the LCI for asphalt products utilised in HMA production. These are summarized in Table 1 below and include both upstream and downstream energy consumption.

Table 1 Emission Data for the Production of Asphalt Cement

Reference	Emissions generated per tonne of asphalt produced				
	CO (kg)	CO_2 (kg)	NO_x (kg)	SO_x (kg)	PM_{10} (kg)
Athena Institute (2001)[1]	0.93	431	1.35	4.25	0.20
Athena Institute (2001)[2]	0.87	359	1.11	4.12	0.14
Athena Institute (2006)[3]	NA	373.7	NA	NA	NA
Eurobitume (1999)	0.14	277	2.09	1.8	0.22
Stripple (2001)[4]	0.11	170	1.02	0.61	0.08

1 Based on US transportation data.
2 Based on Canadian transportation data.
3 An average value for Canada.
4 Based on crude oil extraction from Venezuela.

The table above presents emissions generated for the production of a single tonne (1000 kg) of asphalt cement (bitumen). The data suggests significant differences in emissions when considering both upstream and downstream energy consumption: for example, CO_2 emissions vary from 170 kg/tonne to 431 kg/tonne. These differences are largely explained by the location of the crude oil (e.g., is the oil transported via land or sea to the refinery), and the source of energy required to power the refinery (e.g., oil or gas). Due to these differences ***ECOAGE*** utilizes an average of the above results as a default, but in addition allows the user to specify country or region specific data if available.

3.2 Aggregate Production

Aggregates are crushed rocks produced at appropriate rock sources. When considering emissions from aggregate production, the following upstream and downstream energy consumption should be considered in the production of aggregate ready for utilization in an HMA:

- Rock blasting
- Transportation of rock to crusher
- Crushing, screening and stockpiling

Table 2 Emission Data for the Production of Aggregates

Reference	Emissions generated per tonne of aggregate produced				
	CO (kg)	CO_2 (kg)	NO_x (kg)	SO_x (kg)	PM_{10} (kg)
Sjunnesson (2005)[1]	0.00081	1.6	0.014	0.00078	NA
PCA (2007)[2]	0.0022	0.99	0.0061	0.00045	0.182
Athena Institute (2006)[3]	NA	7.96	NA	NA	NA
Stripple (2001)	0.00149	1.42	0.000123	0.000788	0.0459
Dorchies (2008)	NA	10	NA	NA	NA
Weiland (2008)	0.0086	1.21	0.0159	0.000425	0.000925
WRAP (2006)[4]	NA	2.44	NA	NA	NA
Miansong, et al (2006)	NA	2.8	NA	NA	NA

1 Values presented are for aggregates produced for the production of concrete.
2 Values presented are back calculated from values presented for the production of $1m^3$ of concrete.
3 An average value for Canada.
4 Value calculated based on energy consumption multiplied by CO_2 per unit of energy consumption.

3.3 Hot Mix Asphalt Production Plant

An HMA is produced at a processing facility that combines the aggregates with the asphalt cement. When considering emissions generated from an HMA facility, the downstream energy consumed to produce the HMA must be considered. Energy consumption associated with asphalt cement and aggregate production is not considered as this has already been calculated. Upstream energy consumption should also be considered (i.e., energy consumed to produce the fuel that powers the facility). The following table summarizes emissions resulting from HMA production.

Table 3 Emission Data for the Production of HMA

Reference	Emissions generated per tonne of HMA produced				
	CO (kg)	CO_2 (kg)	NO_x (kg)	SO_x (kg)	PM_{10} (kg)
EPA, AP-142 Section 11.1 (2004)[1,5]	0.063	17	0.013	0.0017	0.34
EPA, AP-142 Section 11.1 (2004)[2,5]	0.063	17	0.028	0.0054	0.34
EPA, AP-142 Section 11.1 (2004)[3,5]	0.2	18	0.02	0.0023	NA
EPA, AP-142 Section 11.1 (2004)[4,5]	0.2	18	0.058	0.044	NA
Athena Institute (2006)[6]	NA	28.84	NA	NA	NA
Stripple (2001)	0.0038	23.87	0.0459	0.0145	0.00285

1 Values for drum mixers using gas and/or propane as primary energy source.
2 Values for drum mixers using fuel oil and/or waste oil as primary energy source.
3 Values for batch mixers using gas and/or propane as primary energy source.
4 Values for batch mixers using fuel oil and/or waste oil as primary energy source.
5 Values presented only consider downstream energy consumption. No consideration is given to upstream energy consumption.
6 Calculated value based on data presented in emissions/m^3.

3.4 Millings

When a new HMA layer is placed it is common practice to remove a portion of the old wearing course prior to the placement of the new (i.e., mill and fill). This minimizes an increase in elevation as a result of the placement of the new HMA layer. The milling portion of the maintenance process consumes energy via two processes. Firstly, energy is consumed by specialized equipment utilised to remove a portion of the old wearing course. Secondly, energy is consumed during the transportation of the millings to an appropriate storage or disposal area. Both upstream and downstream energy consumption are considered in ***ECOAGE*** and are discussed in 3.6 and 3.7.

3.5 RAP

It is becoming more common to include a proportion of RAP in the production of HMA. When RAP is included the following two scenarios are considered

1) RAP directly utilized from millings from the project site considers emissions resulting from milling activities and transportation of the RAP to the HMA facility.
2) RAP utilized from an existing stockpile (not from the project site in question) considers emissions resulting from transportation activities only.

3.6 Transportation

Transportation of material to site and/or production facilities consumes energy; therefore, it generates emissions. The distances traveled are a function of raw material location. The production of aggregate and asphalt cement already consider transportation costs and the associated downstream and upstream energy consumption. When considering the placement of a new HMA layer the following transportation distances need to be considered:

- Aggregate stockpile to HMA production facility.
- Asphalt cement from refinery storage to HMA facility.
- HMA from production facility to project site.
- Millings from project site to storage/disposal area.
- Aggregates to project site (if required).

Many different estimates have been used and published for truck pollutant emissions. These can be based on distance traveled and weight of goods moved, quantity of energy consumed, and a variety of other methodologies. The following table summarizes emissions resulting from truck movements and emissions produced as a function of emission produced per tonne, km travelled. Unless noted otherwise, all factors presented consider both upstream and downstream energy consumption (i.e., pre-combustion and combustion).

Table 4 Emission Data Resulting from Truck Haulage

Reference	Emissions generated g/tonne,km				
	CO	CO_2	NO_x	SO_x	PM_{10}
Sjunnesson (2005)[1]					
• 14 tonne truck	0.13	140	1.2	0.034	0.019
• 40 tonne truck	0.045	480	0.42	0.01	0.0067
OECD (1997)[1]					
• Truck	0.25-2.4	127-451	1.85-5.65	0.10-0.43	0.04-0.90
EcoTransIT (2008)[2]					
• Truck 34-40 tonnes	NA	72	0.553	0.09	0.016
Stripple (2001)					
• 14 tonne truck	NA	943	6.0	NA	0.10
• 32 tonne truck	NA	1050	8.03	NA	0.13

1 These values are only associated with emissions resulting from combustion only.
2 All data presented are based on data sets from 16 EU countries.

3.7 Project Site

Once all materials are produced and transported to the project site, placement of the material occurs. Energy consumed during placement is a function of fuel consumed by construction equipment. ***ECOAGE*** considers emissions resulting from upstream and downstream energy consumption.

The quantity of fuel utilised during construction is based on the following:

- Daily production rates.
- Horsepower of each piece of equipment.
- Efficiency of equipment.
- Utilisation of the equipment during construction activities.
- Construction duration.

Once fuel consumptions are calculated for each piece of equipment, the following factors are utilised to determine associated emissions as a result of fuel combustion during construction.

Table 5 Emission Data for Fuel Consumption (Combustion)

Reference	Emissions generated g/litre burned				
	CO	CO_2	NO_x	SO_x	PM_{10}
EPA-*FIRE* Database	14.74[1]	2708	41.94[2]	4.76	0.94
Athena Institute (2006)	45.36	2196	6.69	0.52	5.17

1 Average of 2 values presented.
2 Average of 4 values presented.
3 All values have been converted from lbs/1000 gallons burned.

When considering upstream energy consumption (i.e. pre-combustion), the following data is utilised to determine an appropriate average:

Table 6 Emission Data Resulting from Fuel Consumption (Pre-Combustion)

Reference	Emissions generated g/litre diesel produced				
	CO	CO_2	NO_x	SO_x	PM_{10}
Athena Institute (2006)	0.65	267	0.86	2.63	0.17
Lewis (1997)[1]	0.19	275	1.57	2.19	0.05
EcoTransit (2008)	NA	393	1.57	3.85	0.21
T J McCann & Associates (2008)[2]	NA	334	NA	NA	NA

1 Average of production data from 15 European countries.
2 Average of production data from 6 different crude oils.

ECOAGE presents standard default values for all of the above, but allows the user to change any given parameter and the inclusion of addition equipment.

4 Case Study using Recently Recycled Roads in Nova Scotia

4.1 Overview

The province of Nova Scotia has been utilizing road recycling processes since 2002. Processes utilised to date include partial depth treatment with emulsion or foamed asphalt, and full depth treatment with foamed asphalt and more recently with cement. In 2009 approximately 70 km of highway were maintained utilizing one of the above recycling processes.

In order to demonstrate potential greenhouse gas savings resulting from recycling activities, two project sections that were recycled in Nova Scotia during 2009 were analyzed using ***ECOAGE***. Details of these projects are described in the following sections.

4.2 Data Input for ECOAGE Analysis

To demonstrate potential greenhouse gas reductions as a result of road recycling, two projects – utilizing road recycling processes – were analyzed. In order for potential environmental benefits to be assessed, an analysis was run for each highway project whereby the adopted recycling strategy was compared to a hypothetical, comparative traditional maintenance process. When considering the hypothetical traditional maintenance strategy, consideration was only given to standard maintenance strategies utilised by Nova Scotia Transportation and Infrastructure Renewal (NSTIR), which offered similar structural performance. Specific details of the projects are presented in the following tables. Both the recycling strategy along with the hypothetic maintenance strategy is presented.

Table 7 Adopted (Recycling) and Hypothetical (Traditional) Maintenance Strategies for Trunk 8 and Route 236

Project	Adopted Strategy (Recycling)	Alternative Traditional Strategy (Hypothetical)
Trunk 8	• 50mm milling to amend grade/cross fall • 100mm Partial Depth Reclamation (PDR) - stabilized with foamed asphalt) • 50mm HMA surfacing	• 50mm milling to amend grade/cross/fall • 50mm HMA base • 50mm HMA surfacing
Route 236	• 250mm Full Depth Reclamation (FDR) - stabilized with foamed asphalt • 50mm HMA surfacing	• 50mm milling • 150mm gravel sandwich layer • 50mm HMA surfacing

Figure 3 Trunk 8 PDR operations (left) and Route 236 FDR operations (right)

Table 8 Project Quantities for the Adopted and Hypothetical Maintenance Strategies for Trunk 8 and Route 236

Project Section	Material Quantities
Trunk 8 (12.5km)	
Recycling Strategy (adopted)	
Milling	88,000 m^2
100mm PDR with foamed asphalt	88,000 m^2
50mm HMA surfacing	12,000 tonnes
Traditional Strategy (hypothetical)	
Milling	88,000 m^2
50mm HMA base course	12,000 tonnes
50mm HMA surface course	12,000 tonnes
Route 236 (6.4km)	
Recycling Strategy (adopted)	
250mm FDR with foamed asphalt	42,500 m^2
50mm HMA base course	5,100 tonnes
50mm HMA surface course	5,100 tonnes
Traditional Strategy (hypothetical)	
Milling	42,500 m^2
150mm gravel sandwich	14,025 tonnes
50mm HMA base course	5,100 tonnes
50mm HMA surface course	5,100 tonnes

Table 9 Haulage Distances for Materials

Material	Haulage Distance
Liquid asphalt from refinery to HMA plant	200 km
Liquid asphalt from refinery to project site	200 km
Aggregates to HMA plant	1 km[1]
HMA from plant to project site	35 km
Millings from project site to storage area	50 km
Aggregates to project site	50 km

1 HMA plant located in quarry 1km assumes nominal haul distance.
2 Above haul distances are the same for both recycled and traditional maintenance strategy.

4.3 Results from *ECOAGE* Analysis

The data presented in 4.2 were utilised to analyze emissions as a result of construction activities utilizing ***ECOAGE***. Emissions for both the adopted strategy and the hypothetical strategy are presented in Tables 10 and 11. ***ECOAGE*** calculates emissions generated during the material transportation, material production and material placement phase in terms of CO, CO_2, PM_{10}, NO_x and SO_x. CO_2 emission results are also graphically presented in Figures 4 and 5.

Table 10 Emissions for Trunk 8 – Adopted (recycling) and hypothetical (traditional) strategies

	Emissions (kg)				
	CO_2	**CO**	**PM_{10}**	**NO_x**	**SO_x**
Recycling Strategy					
Material Transportation	175376.2	152.0	18.7	584.6	233.8
Material Production	672382.6	1208.7	4307.1	1484.1	4531.5
Material Placement	71532.2	389.3	24.8	1107.8	125.7
Total	**919291.0**	**1750.0**	**4350.6**	**3176.5**	**4891.1**
Traditional Strategy					
Material Transportation	248742.8	215.6	26.5	829.1	331.7
Material Production	1000000.0	1946.0	8462.1	2124.2	5778.4
Material Placement	57583.2	313.4	20.0	891.8	101.2
Total	**1306326.0**	**2475.0**	**8508.6**	**3845.1**	**6211.3**
% Reduction[1]	**-29.6**	**-29.3**	**-48.9**	**-17.4**	**-21.3**

1 "-" indicates a reduction, "+" indicates an increase when comparing recycling with traditional

Table 11 Emissions for Route 236 – Adopted (recycling) and hypothetical (traditional) strategies

	Emissions (kg)				
	CO_2	**CO**	**PM_{10}**	**NO_x**	**SO_x**
Recycling Strategy					
Material Transportation	96453.5	83.6	10.3	321.5	128.6
Material Production	669099.4	1179.8	3699.3	1548.8	4915.9
Material Placement	67695.8	368.5	23.5	1048.4	119.0
Total	**833248.7**	**1631.9**	**3733.1**	**2918.7**	**5163.4**
Traditional Strategy					
Material Transportation	216752.3	187.9	23.1	722.5	289.0
Material Production	656683.8	1021.0	3648.5	1427.2	3691.8
Material Placement	73414.7	399.6	25.5	1137.0	129.0
Total	**946850.8**	**1608.5**	**3697.2**	**3286.7**	**4109.9**
% Reduction	**-40.9**	**-30.2**	**-47.7**	**-34.8**	**-5.8**

1 "-" indicates a reduction, "+" indicates an increase when comparing recycling with traditional

Figure 4 CO_2 Emissions for Trunk 8 – Recycled vs Traditional Strategy

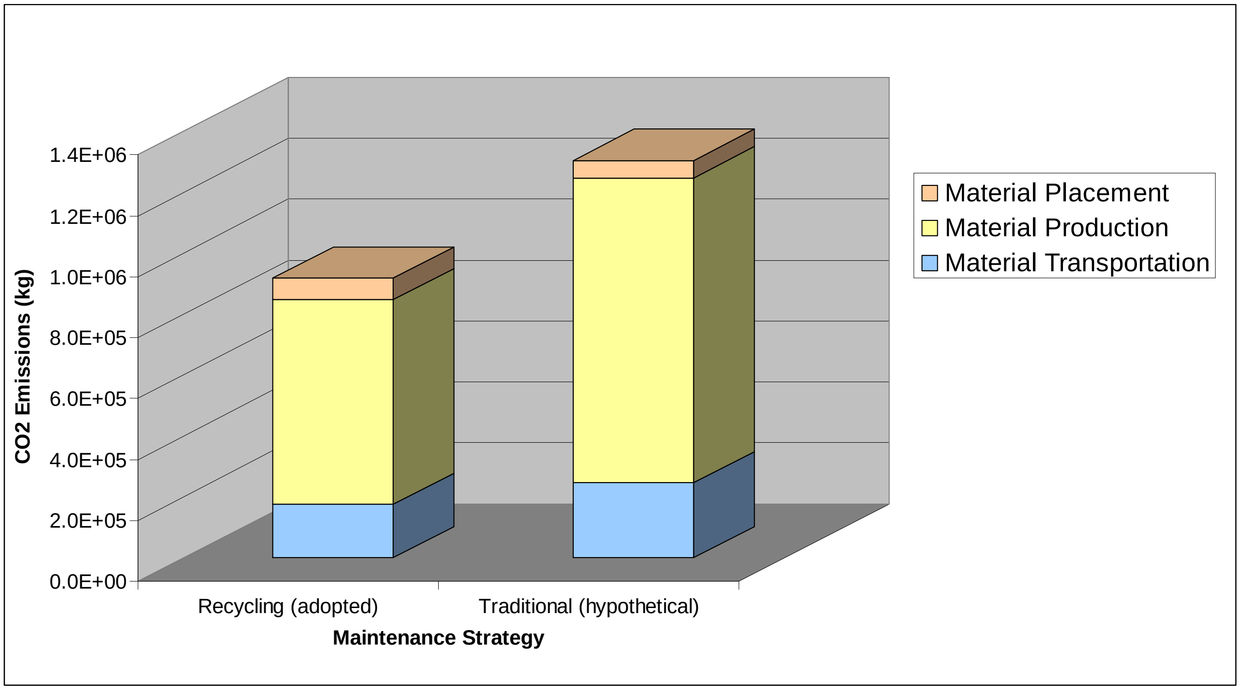
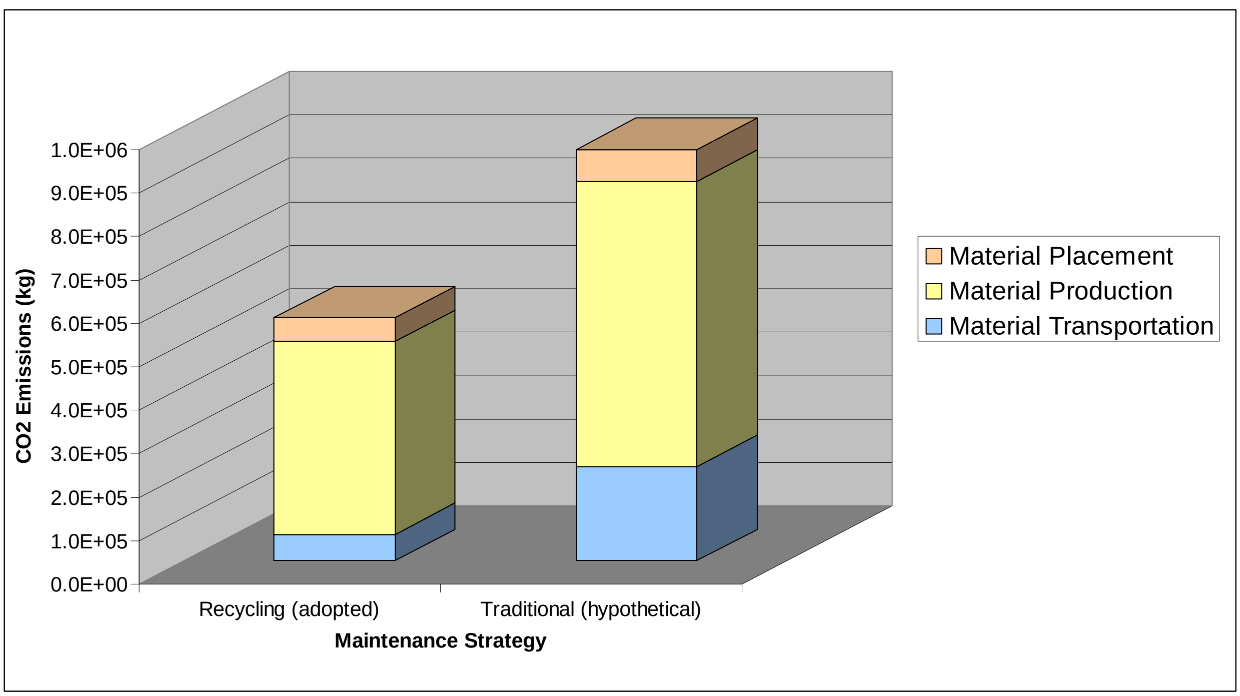


Figure 5 CO_2 Emissions for Route 236 – Recycled vs Traditional Strategy



5 Discussion and Conclusions

Results for Trunk 8 demonstrate significant reductions in emissions when a recycling strategy was utilized. The most significant is the marked reduction in CO_2 emissions. When compared to a hypothetical, equivalent traditional maintenance strategy, CO_2 emissions are reduced by 29%; this equates to 387,035kg. Reducing CO_2 emissions (greenhouse gas) assists in reducing the effect of global warming.

Detailed analysis of the results for Trunk 8 indicates that the majority of the CO_2 reductions are accrued during the material production and material transportation phases of the project (see Tables 10 and Figure 4). The reason for this is twofold. Firstly, fewer non-renewable resources are being extracted and processed when the pavement is recycled. Secondly, due to the recycling process and the utilization of the in-situ material, fewer haulage trucks are used. CO_2 emissions as a result of material placement were very similar for both strategies.

Results for Route 236 were similar to those for Trunk 8. Once again the full depth recycling strategy adopted reduced the CO_2 emissions when compared to the hypothetical, equivalent traditional strategy; however, the reduction was slightly higher at 40.8%. Similar to Trunk 8, CO_2 emissions associated with material transportation and production were significantly reduced. CO_2 emissions as a result of material placement were very similar for both strategies.

For both projects, reductions in CO, NO_x, SO_x and PM_{10} were also significant when a recycling strategy was adopted. When compared to traditional process, reductions varied from 5.8% to 48.9%.

CO_2 emissions are clearly reduced as a result of road recycling strategies. ***ECOAGE*** is able to quantify these as a function of material production, transportation and placement. The next challenge is to try to investigate mechanisms by which these emission reductions can be traded as off-sets, if in deed they can. Regardless of the ability to off-set CO_2 reductions accrued from road recycling, ***ECOAGE*** offers another life cycle tool, based on environmental considerations, by which decision makers can select appropriate maintenance strategies.

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