LIFE CYCLE ASSESSMENT OF RECLAIMED ASPHALT PAVEMENT TO IMPROVE ASPHALT PAVEMENT SUSTAINABILITY

Authors:
Christopher D. DeDene, Mihai Marasteanu

University of Minnesota
Department of Civil Engineering
500 Pillsbury Drive SE
Minneapolis, MN 55455 USA
Deden008@umn.edu

University of Minnesota
Department of Civil Engineering
500 Pillsbury Drive SE
Minneapolis, MN 55455 USA
maras002@umn.edu

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ABSTRACT

It has become common practice to recycle asphalt pavements in new asphalt roads. The driving force behind this recycling is the economic benefit and cost savings associated with recycling waste materials. For a project to be considered sustainable, it must be socially, economically and environmentally beneficial. Using reclaimed asphalt pavement (RAP) in asphalt pavements satisfies the social aspect of sustainability by recycling and reducing waste. The economic aspect is achieved by costing less than a traditional asphalt road built from virgin materials. However, a pavement constructed with RAP does not address the environmental aspect needed to satisfy the three pillars of sustainability.

To address the environmental impacts of using RAP, a life cycle assessment (LCA) was conducted using SimaPro, a computer program. For the assessment, a functional unit of one lane mile of road with equal thickness was chosen. Two virtual pavements were constructed in SimaPro for comparison, one pavement with no RAP and one with 15% RAP. The model encompasses a cradle to grave approach to analyzing the differences in construction practices and end of life disposal between the two roads. Using the midpoint indicators of cumulative energy demand and equivalent kilograms of CO2 emissions, the environmental impact of the two roads can be compared. With the assumption of equivalent pavement performance and maintenance schedule, the use of RAP generated an increase in total energy and CO2 equivalent emissions.

Keywords: Life Cycle Assessment, Asphalt Pavement, RAP

INTRODUCTION

In the United States, there are an estimated 250 million registered vehicles traveling on four million miles of public road (FHWA 2008). Asphalt roads last less than a decade before they are in need of maintenance or rehabilitation. Even with perpetual pavements, the wearing course must be replaced frequently. This material which is milled off when the wearing course needs to be replaced can be ground up and used as reclaimed asphalt pavement (RAP) (Brock and Richmond Sr. 2007). Even though the use of RAP in new pavements has become common practice, the use of high percentages of RAP in pavements is limited by several factors, such as existing DOT standards, variability in long term performance, and feasibility of the recycling process (Widyatmoko 2008).

Once an existing road has deteriorated and is at the end of its service life, it can be excavated and transported to a disposal site (Hand 2009). For RAP however, the spent road can be ground up and added back into new pavements. For large projects, in order to recycle the current road into the new one, the existing road must be transported back to the asphalt plant. The road undergoes an extensive crushing and is added to new pavements. Heating RAP inside the drum mixer would compromise the integrity of the recycled bitumen. Therefore, to heat RAP the new aggregates are often heated beyond typical temperatures in a process known as superheating. Typically asphalt has an effective binder content of around 5 percent, but the ground RAP has a 4 to 4.5 percent effective content. Since there is less binder in RAP than is required in new pavements, additional binder is often needed when recycling pavements, but less binder than if one was to begin with entirely virgin materials (O’Sullivan 2009). Even though the recycled pavement is made of 15 percent used material, there is additional energy required to mill and transport the RAP and superheat the virgin aggregates.

The primary objective of this research is to determine if the use of RAP reduces the environmental footprint of an asphalt pavement construction. The widespread use of RAP in the pavements industry is proof that it is cheaper to produce, but often the environment takes a backseat to the bottom line of cost savings. For the sake of this study, only emissions and energy demand will be accounted for in order to address the pillar of environmental sustainability.

METHODS

The tool used to assess the environmental sustainability of asphalt pavements containing RAP is a life cycle assessment (LCA). For the LCA presented in this paper, SimaPro was used to determine if it is environmentally beneficial to recycle asphalt pavements. SimaPro is a LCA accounting tool that uses a robust database with the environmental releases and energy consumption for hundreds of different materials and processes, not limited to only Civil Engineering applications (PRéConsultants 2010). By choosing the materials and processes that comprise an equivalent system, in this case an asphalt pavement, SimaPro can tally the components and reports a number amount for the final product.

For the assessment, a typical asphalt pavement was selected as the control. The control pavement was comprised of 3 layers: a 25 cm (10 in) subbase, 20 cm (8 in) granular base, and 15 cm (6 in) hot mix asphalt (HMA). A table summarizing the two pavements can be seen in Table 1. The base and subbase materials are taken from the source quarry and transported to the construction site. The aggregates for the HMA must be moved from the quarry to the asphalt plant, where they are heated and combined with asphalt binder to produce HMA. The fresh HMA is then transported to the construction site.

Table 1: Summary of Roads Considered

	Virgin Material	15% RAP
Functional Unit	1 Lane-Mile	1 Lane-Mile
Subbase	10 inches	10 inches
Base	8 inches	8 inches
HMA	6 inches	6 inches
% RAP in HMA	0%	15%
% Binder	5%	5%
RAP % Binder	N/A	4.5%
% Air Voids	4%	4%
Mixing Temp	260 °F	370 °F
RAP Processing	N/A	YES

This assessment will use the functional unit of one lane mile as a reference, which can then be extrapolated for larger projects simply by multiplication. It will account for the material acquisition, transportation and disposal for two different pavement scenarios: a 100 percent virgin pavement and a pavement containing 15 percent RAP. It is assumed the pavements will perform the same, which means the maintenance schedule and service life of the two pavements is identical. However, the model will take into account the differences from the additional energy needed to transport and reheat the RAP, the material savings from recycling of aggregates and binder, and the conversion of existing pavement into RAP. The environmental impacts, attributed to construction and maintenance of the pavement, are ignored since both pavements are constructed similarly.

The model of the lifecycle of the pavements in this project can best be shown by the diagram in Figure 1. The model represents a cradle to grave assessment of the two pavements. Each arrow represents a transportation process accounted for in the lifecycle, and each box represents a process. The materials must first be quarried and the bitumen refined before they can be turned into HMA at the plant. Next, the new HMA and aggregates are moved to the location of the new road and the road is constructed. Once the new pavement has reached the end of its service life, it is then either recycled, or disposed of in a sanitary landfill (RMRC 2010). For pavements containing RAP, some percent of the new pavement comes from a recycled source. There is also additional transportation needed to transport the RAP at the end of life.

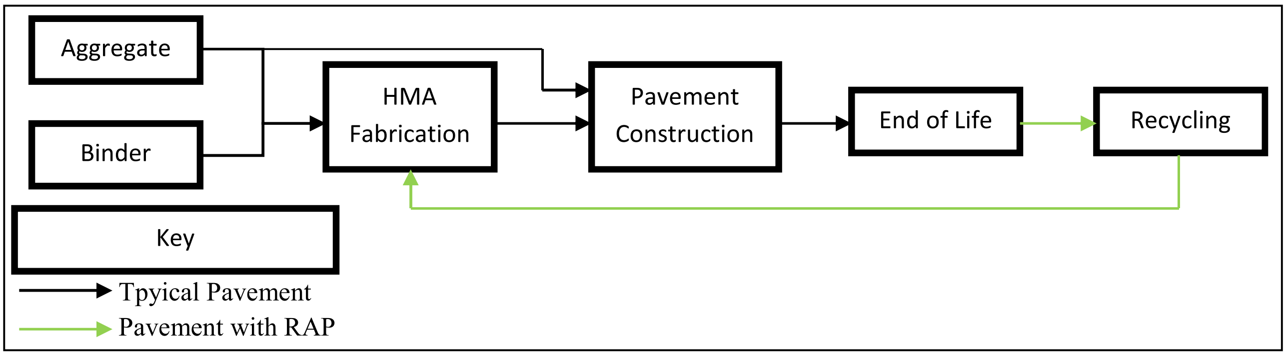

Figure 1: Life Cycle Diagram

The ecoprofiles for the inputs were all obtained from SimaPro's ecoinvent database. From the life cycle diagram, an inventory list for each case was created. The analysis was carried out in two parts, one with a transportation setting in a rural setting, and the other for a more urban environment where infrastructure is closer to the point of use. The two distances are shown in Table 2. The rural transportation distances were based on distances for Houghton, Michigan, USA, while the urban transportation distances were assumed to be closer based, to reduce the large impact longer distances have on LCA's.

Table 2: Transportation Distances

Material to Destination	Rural Transportation Distances (Km)		Urban Transportation Distances (Km)	
	Virgin Material	15% RAP	Virgin Material	15% RAP
Refinery to HMA Plant	96.56	96.56	1.61	1.61
Aggregate to HMA Plant	197.95	197.95	8.05	8.05
HMA Plant to Road Location	197.95	197.95	8.05	8.05
Base Aggregate to Road Location	16.09	16.09	16.09	16.09
RAP to HMA Plant	N/A	197.95	N/A	8.05

The amounts of material in the model were based on calculations for the assumed pavement design. Table 3 contains a comprehensive summary of the material inputs used. The volume of each component was calculated, then specific gravities were used to approximate the mass of each input required. For the pavement containing RAP, a 15% reduction in HMA material was applied compared to the virgin pavement case. The transportation distances were multiplied by the mass of materials in order to get units of kilogram kilometers for the transportation inputs. Since RAP pavements require superheating of virgin aggregates to melt the recycled binder, the temperature of the drum mixer was increased from 126°C (260°F) to 187°C (370°F). Using the specific heat of typical rocks (0.2 kJ/Kg K) the required increase in energy was calculated. To account for the energy to process the existing pavement to RAP, a milling process was included in the RAP pavement model. The milling process was based on the energy consumption and production rate from a typical milling machine.

Table 3: LCA Inventory

SimaPro Input	Purpose	Virgin Material Amount	15% RAP Amount
Bitumen	HMA	172.04 kg	154.84 kg
Coarse Agg.	HMA	2,138.00 kg	1,817.30 kg
Fine Agg.	HMA	5,644.32 kg	4,797.67 kg
Gravel	Base	6,770.33 kg	6,770.33 kg
Sand	Subbase	14,253.33 kg	14,253.33 kg
Heat, nat. gas	Superheating	N/A	2,886,615.60 KJ
200 KW diesel	RAP Processing	N/A	200.00 KWh

RESULTS

Two different methods were used to compare the pavement systems, Cumulative Energy Demand (CED) and Intergovernmental Panel on Climate Change 2007 100a (IPCC) for global warming potential (GWP). The CED model compares the total amount of energy used by each model, in megajoules of equivalent power (MJ-eq), which is a midpoint indicator of environmental impacts. The IPCC 2007 100a values correspond to a report released by the IPCC in 2007 for GWP impacts at the 100 year time frame. The IPCC model measures global warming potential based on calculated kilograms of CO_2 equivalence (kg of CO_2-eq). Also a midpoint indicator, this method is used to determine which pavement contributes the least to global warming by measuring the greenhouse gas emissions and translating the total gas emissions into an equivalent amount of CO_2 emissions. If the assumption that each pavement has equivalent performance holds, then the pavement which uses the least amount of energy is the most energy-efficient option and the pavement which produces the least amount of CO_2 is the more environmentally sustainable option.

Using the first results from the rural construction scenario, the effect of the lengthy transportation distances can be seen in the results breakdown in Figure 2a. Since the transportation effects accounted for almost 30% of the total emissions in the assessment, the need for shorter transportation distances was established. With the urban transportation distances, Figure 2b was created. The shorter distances minimized the contributions from transportation, and emphasized the effect superheating the aggregates have on the emissions.

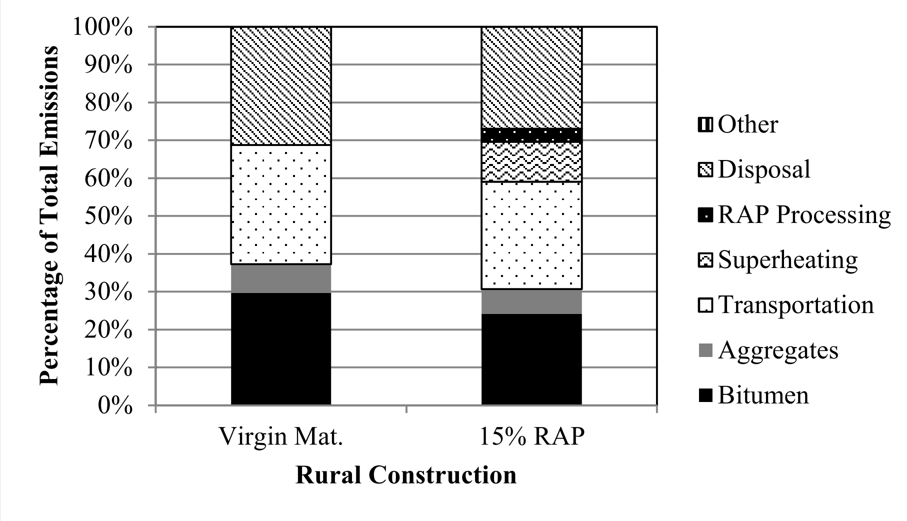

Figure 2a: Emissions Sources for Rural Construction Scenario

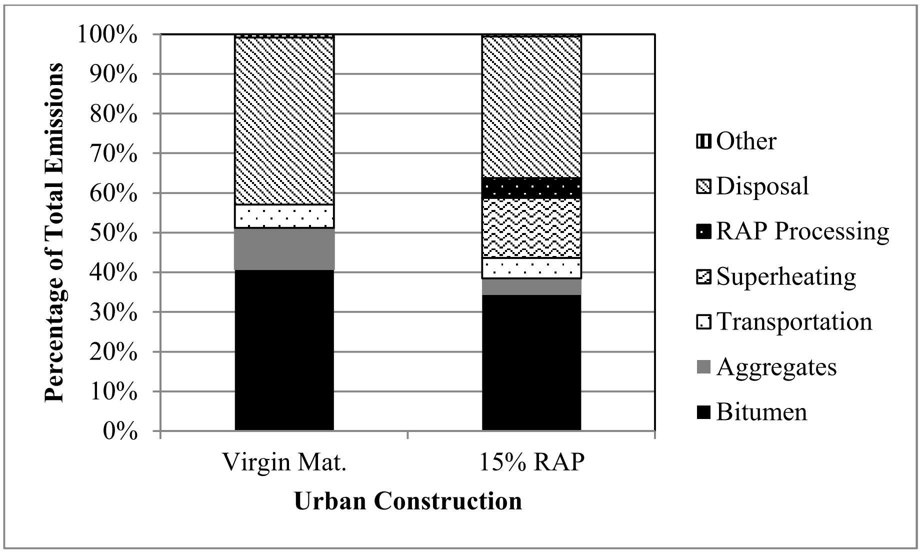

Figure 2b: Emissions Sources for Urban Construction Scenario

Comparing the results of the CED analysis across the four cases, as shown in Figure 3a, the effect of reducing transportation distances for the two scenarios is clear: shorter distances result in a significant decrease in the amount of energy needed to produce the pavement. It can also be observed that regardless of the transportation distances used, the pavement constructed with 15% RAP required more energy to construct. Similarly, by comparing the GWP between the four cases, as shown if Figure 3b, it can be seen that the pavement containing 15% RAP produced more CO_2 than the one made entirely from virgin materials.

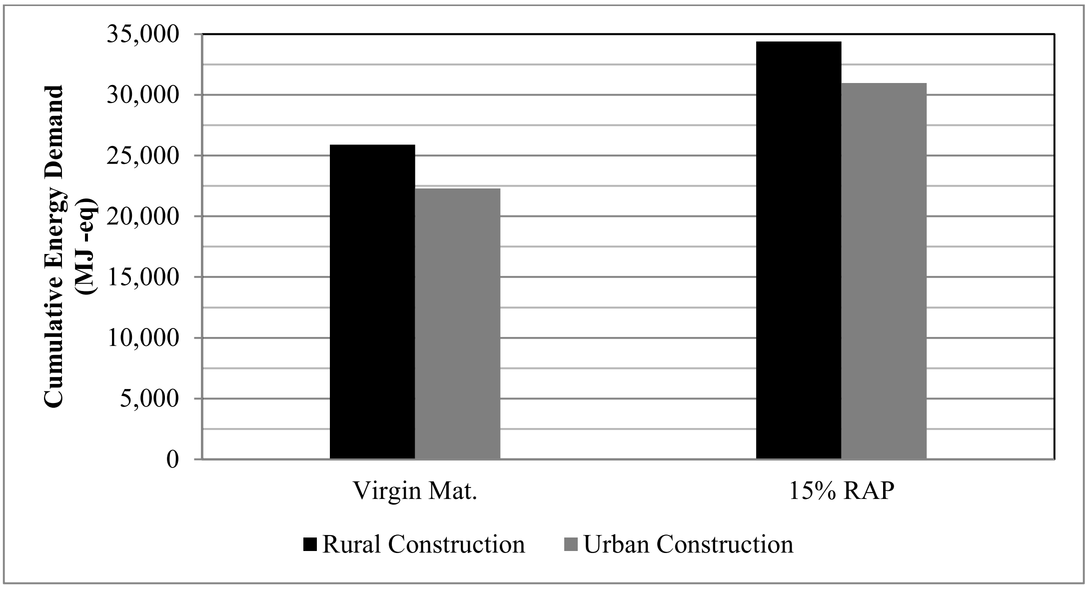

Figure 3a: Cumulative Energy Demand Results

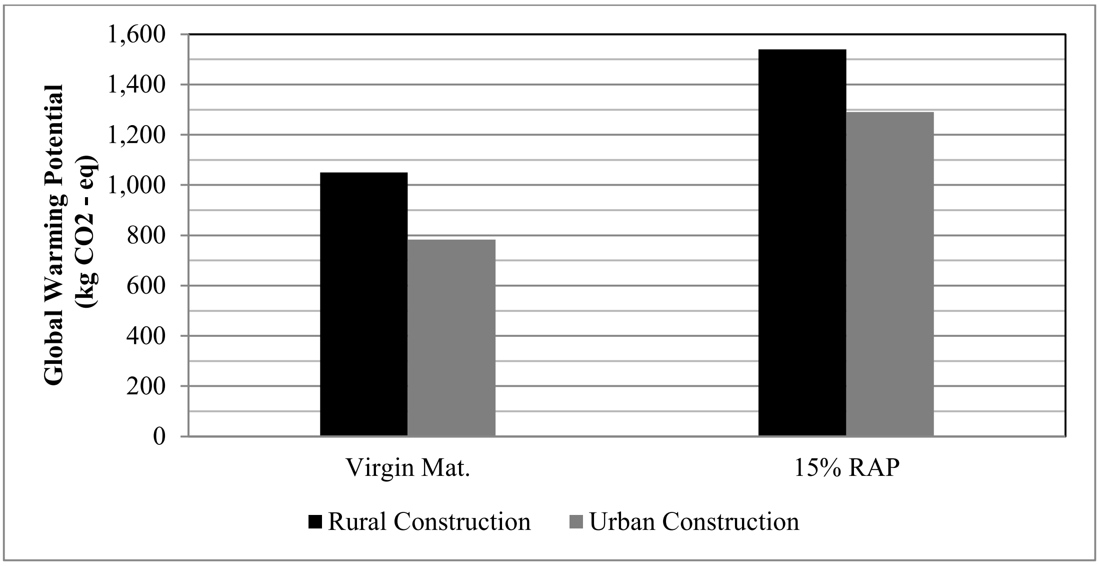

Figure 3b: Global Warming Potential Results

CONCLUSIONS

The concept of recycling is inherently sustainable because it reduces virgin material consumption; however, for the simple case discussed in this paper, a net increase in emissions and energy was attained when 15 percent RAP was used in new pavement. The cause for the increase in emissions and energy demand can be directly attributed to the need to superheat and process the RAP, since modifying the transportation distances had little effect on the net difference between scenarios. Though recycled materials are economically viable and save on virgin consumption, the virtual road constructed with recycled materials was more environmentally taxing, for both energy consumption and CO_2 emissions criteria, when substituting new materials with 15 percent RAP.

This result agrees with previous research, presented by Bahia in 2010, that showed 90% of life cycle energy in asphalt pavements is from production (Bahia 2010). Since RAP is essentially heated twice in its' lifetime, there is a significant contribution of energy attributed to the recycled material in a LCA. Bahia also noted the need to reduce the heat in asphalt mixing operations, especially when incorporating RAP. One shared recommendation that could be made to improve the sustainability of recycling asphalt pavements is to build more pavements with warm mix asphalt (WMA) to reduce the need to heat asphalt pavements to such extreme temperatures. Using cold in place recycling practices to mitigate the environmental impact from transporting and reheating RAP would be another obvious alternative.

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REFERENCES

Bahia, H. (2010). Energy, Emissions, and Recycling: Opportunities for Making Asphalt Greener. Upper Midwest Transportation Materials Summit. Houghton, MI.
Brock, J. D. and J. L. Richmond Sr. (2007). Milling and Recycling. I. ASTEC. Chattanooga, TN, ASTEC, INC. **T-127**.
FHWA (2008). Highway Statistics 2008, U.S. Department of Transportation.
Hand, A. J. T. (2009). Green Pavement Construction. Reno, NV, Nevada T2 Center.
O'Sullivan, K. (2009) "100 Percent Recycling – Sustainability in Pavement Construction."
PRéConsultants (2010). SimaPro 7, PRé Consultants.
RMRC (2010) "Reclaimed Asphalt Pavement Material Description." Recycled Materials Resource Center.
Widyatmoko, I. (2008). "Mechanistic-empirical mixture design for hot mix asphalt pavement recycling." Construction and Building Materials **22**(2): 77-87.