USE OF BE^{2}ST IN-HIGHWAYS FOR GREEN HIGHWAY CONSTRUCTION RATING IN WISCONSIN

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ABSTRACT

This paper describes a green highway construction rating system named Building Environmentally and Economically Sustainable Transportation Infrastructure-Highways (BE^{2}ST in-Highways). BE^{2}ST in-Highways employs life cycle analysis techniques to provide a quantitative assessment of the impacts associated with a highway construction project. Energy and water consumption, greenhouse gas emissions, service life, and life cycle cost are evaluated in a quantitative framework that can be used to compare alternative construction strategies from a holistic perspective. The methodology is grounded in quantitative metrics rather than an arbitrary point system so that a transparent linkage exists between the project rating and the sustainable practices employed in design and construction. This transparency reduces the potential for 'gaming' of the rating system. Application of the BE^{2}ST in-Highways system to a project in Wisconsin is described. Results of the application indicate that using recycled materials in a pavement can result in reductions in global warming potential (32%), energy consumption (28%), water consumption (29%), and hazardous waste generation (25%) as compared to the reference design using conventional materials, while also extending the service life of the pavement. In addition, using recycled materials in a pavement can result in a life cycle cost savings of 23%. Because of this environmental and economical outperformance of the alternative design using recycled materials compared to the reference design using conventional materials, the maximum total credit (i.e., 12 points) is granted to the project.

INTRODUCTION

There is considerable research showing that construction projects are directly or indirectly causing adverse environmental impact [Gambatese 2005, Kibert 2002]. For example, the built environment accounts for 30% of all primary energy use in the U.S. [Gambatese 2005]. Approximately 7.0×10^6 MJ of energy are required to construct a 1-km length of a typical two-lane road with asphalt concrete pavement [AASHTO 2008]. Additionally, 6% of the total U.S. industrial greenhouse gas (GHG) emissions was produced by the construction sector in 2002, and 13.4% of that was produced by highway, street, and bridge construction [Kibert 2002]. The U.S. national highway system continuously requires new construction of highways and their periodic improvement to meet growing traffic demand. However, the conventional project value used in the construction industry has primarily emphasized three aspects: cost, schedule, and quality. Using these relatively short-term strategies limits the ability of construction projects to avoid the conflicts between satisfying human demands and abatement of environmental and social responsibility risks. Therefore, availability of procedures to quantify the benefits of sustainable construction practices is a key factor influencing growth in sustainable construction of public infrastructure. For example, the Leadership in Energy and Environmental Design (LEED) evaluation system has resulted in considerable interest and investment in sustainable building construction. Established evaluation systems similar to LEED are not yet available for highway construction projects, but are currently being developed in the U.S. and elsewhere. However, the majority of criteria and their evaluation procedure for such systems are a result of benchmarking the LEED program. Likewise, those rating systems do not consider the logical connection between their purpose and the surrounding factors. In other words, they lack transparency and objectiveness in the criteria selection and weighting process. At the same time, these rating procedures are not based on a standardized method of performance measurement. For this reason, they may lead to improvements, but the quantitative impact on meeting environmental targets is not known. Consequently, such a point system may lead to point mongering regardless of whether the choices add environmental value [Schendler and Udall 2005]. In this study, a rating system that primarily addresses sustainable highway construction, namely Building Environmentally and Economically Sustainable Transportation Infrastructure-Highways (BE^2ST in-Highways), is described. The system encompasses a rating tool to score the performance of an alternative design compared to the reference design (conventional design concept) of the pavement structure using standardized measurement methods. Rehabilitation activities are explicitly included in the life cycle analysis using the international roughness index (IRI) as a metric to define when rehabilitation would be required, as suggested by FHWA [1998].

The proposed rating system was applied to a pilot project to check the system's actual functionality and the degree of difficulty in obtaining the target value in each criterion. In the pilot project evaluation, the proposed rating system was used to quantify the environmental and economic benefits that could be accrued by using recycled materials when constructing a 4.7-km-long section of the Burlington Bypass in southeastern Wisconsin. The rating system, based on quantitatively measured environmental and economic benefits, is expected to encourage wider adoption of recycled materials in roadway construction and rehabilitation.

PRINCIPLES OF BE^{2}ST IN-HIGHWAYS

The first step of designing a sustainable highway construction rating system is constructing a broad view of sustainable highway construction consisting of two general components: the criteria and the target value of each criterion. Gambatese [2005] pointed out that sustainable road construction could be accomplished by several factors including use of recycled material and use of the principles of the 4R's (Reduce, Recover, Reuse, and Recycle). Gambatese [2005] claimed that several other factors such as noise levels, GHG emissions, hazardous waste, and workers' safety should also be incorporated into the planning and design process of a project to generate sustainable road construction. Others [e.g., Kibert 2002, Toleman 2008] also suggested similar criteria. The fifth clause of the Bellagio Principles to gauge sustainable development emphasizes that a limited number of criteria should be used [Bell and Morse 1999]. Bellagio Principles are the result of a conference held by the International Institute for Sustainable Development in November 1996 to discuss action plans for sustainable development. Hence, criteria selection should be based on whether or not standardized measurement is available.

Once the criteria selection is accomplished, the next step is to make decisions about the target value of each criterion. Target values are projected numbers, which the system is ultimately trying to achieve. For example, the target value for global warming potential (GWP) or GHG emissions reduction could be acquired though a series of calculations based on related theories and information. The 2002 Census results show that road construction is roughly 6.8% of the entire construction industry [U.S. Census Bureau 2005]. Thus, if the construction industry is allocated one wedge of the CO_2 stabilization triangle (i.e., 22.7 billion Mg) [Socolow and Pacala 2006], 1.54 billion Mg-CO_2e will be allocated to the road construction industry over a period of 50 years from the overall allocation to the construction industry. According to Carpenter et al. [2007], the U.S. alone is projected to construct 6 million km of roadway over the next 40 years. At the same time, construction of 1 km of a typical four-lane road and related rehabilitation activities for 50 years releases roughly 865 Mg of CO_2. This results in about 6.5 billion Mg-CO_2e. Therefore, 24% CO_2 (i.e., 1.54 billion Mg-CO_2e) should be mitigated during highway construction and rehabilitation to accomplish the reduction goal of the global warming potential.

According to Bell and Morse [1999], as stated earlier, the first task of building a rating system itself is "to identify and bring together the stakeholders in the project and to gain a clear vision of the sustainability system which is expected to emerge from the project process." For this purpose, a series of committee meetings was held at the Wisconsin Department of Transportation with stakeholders to move towards consensus on the criteria and the target values. Figure 1 depicts a summary of the developed criteria and their target values in this rating system being developed with the participation of the Wisconsin Department of Transportation.

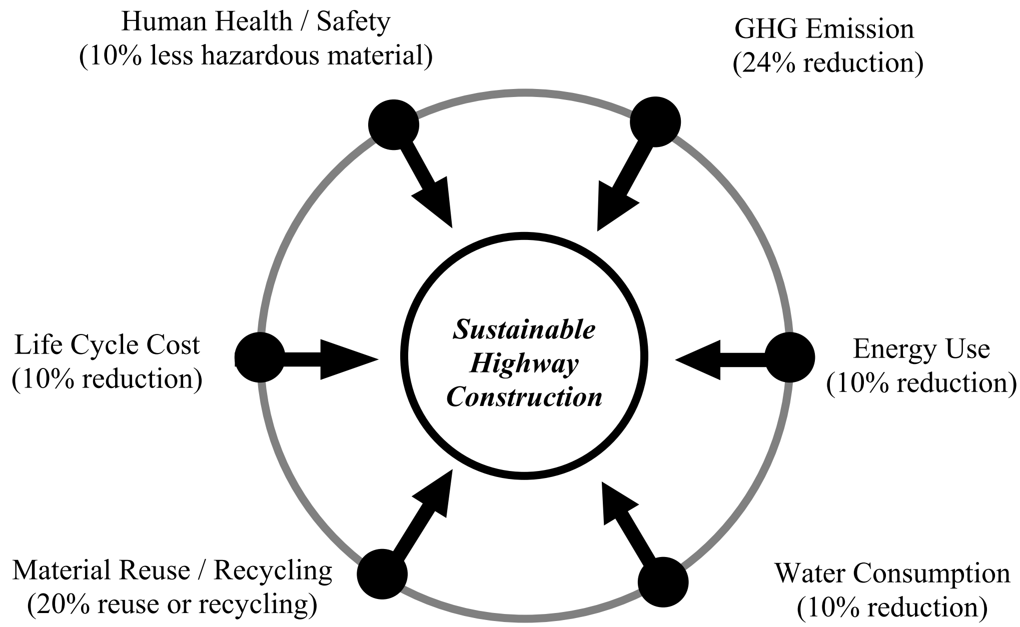

Figure 1. General Components of the BE^{2}ST in-Highways System.

Once the big picture (Figure 1) of criteria and their target values is drawn, a weighting value should be assigned to each criterion followed with the credit levels of criteria. An equally weighted system consisting of 2 points for each criterion, resulting in 12 total points, was adopted in the BE^{2}ST in-Highways system.

The performance of a construction project should be measured based on standardized measurement methods to have wide acceptance. Availability of a standardized measurement is thus necessary in the criteria selection phase. To satisfy this requirement, standard measurement methods was chosen from the currently available methods or developed if no method was available to measure the performance of a criterion.

Figure 2 shows the design procedure of the BE^{2}ST in-Highways system, a comparative quantitative assessment method. This proposed rating system can be used during the process of planning and designing highway construction projects to implement the sustainability goal of the projects (Figure 1).

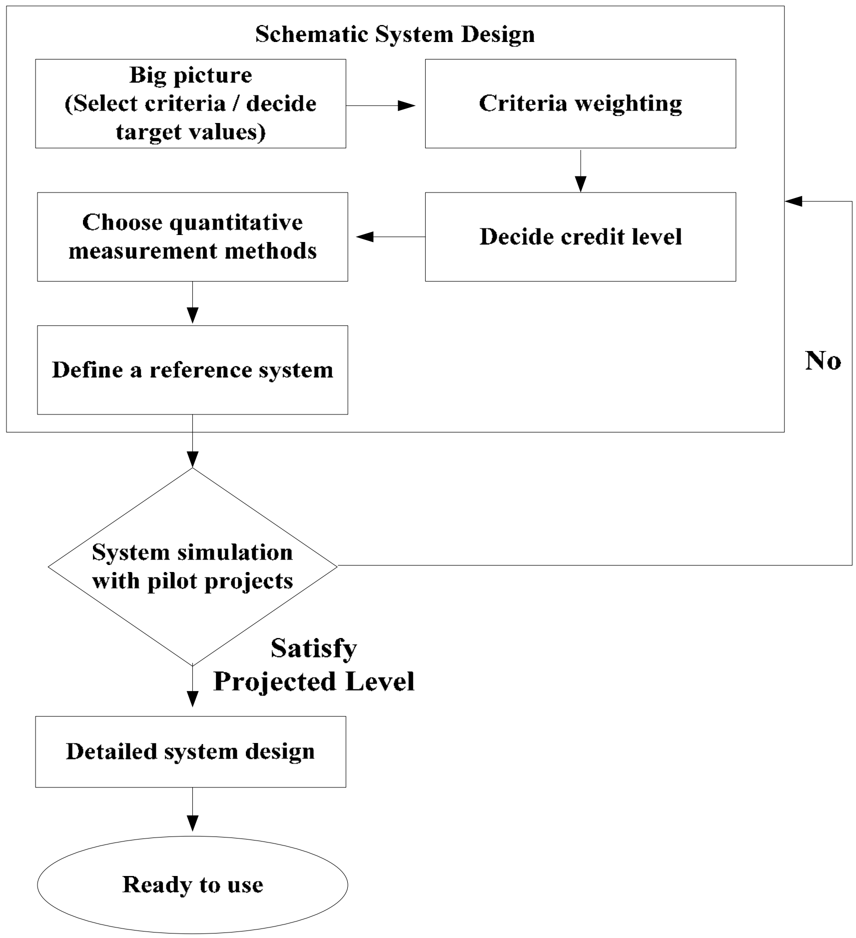

Figure 2. The Design Flow Chart of the BE^{2}ST in-Highways System.

A CASE STUDY: THE BURLINGTON BYPASS PROJECT

A case study was conducted to verify the actual functionality of the BE^{2}ST in-Highways system and to check the degree of difficulty in obtaining a score in each criterion. The case study consists of a comparative assessment and rating based on a life cycle assessment (LCA) and a life cycle cost analysis (LCCA) for construction of a section of Wisconsin State Highway (WIS) 36/83 near Burlington, Wisconsin (the Burlington Bypass) for the pavement structure constructed with conventional or recycled materials. The Burlington Bypass consists of 17.7 km of highway that routes traffic on WIS 11 and WIS 36/83 around the City of Burlington, Wisconsin. The bypass is intended to improve safety, reduce delays, and to provide an efficient travel pattern that reduces truck traffic in the downtown area of the City of Burlington [Wisconsin DOT 2009]. The western portion of the bypass was constructed between Spring 2008 to Fall 2010. A 4.7-km-long section of the western portion of the bypass was analyzed in this study.

A flowchart for the system simulation is shown in Figure 3. The steps include creating pavement designs using conventional and recycled materials, predicting the service life of both designs, identifying rehabilitation strategies, and conducting LCA and LCCA. The environmental analysis of the conventional and alternative pavements was conducted using LCA. Four environmental criteria were considered in the assessment: energy consumption, GHG emissions, water consumption, and generation of hazardous wastes, as defined by the U.S. Resource Conservation and Recovery Act (RCRA).

LCCA is a financially based decision-making tool for long-term assessment of construction projects that can be used to systematically determine costs attributable to each alternative course of action over a life cycle period and to make economic comparisons between competing designs [Bull 1993, Kirk and Dell'isola 1995].

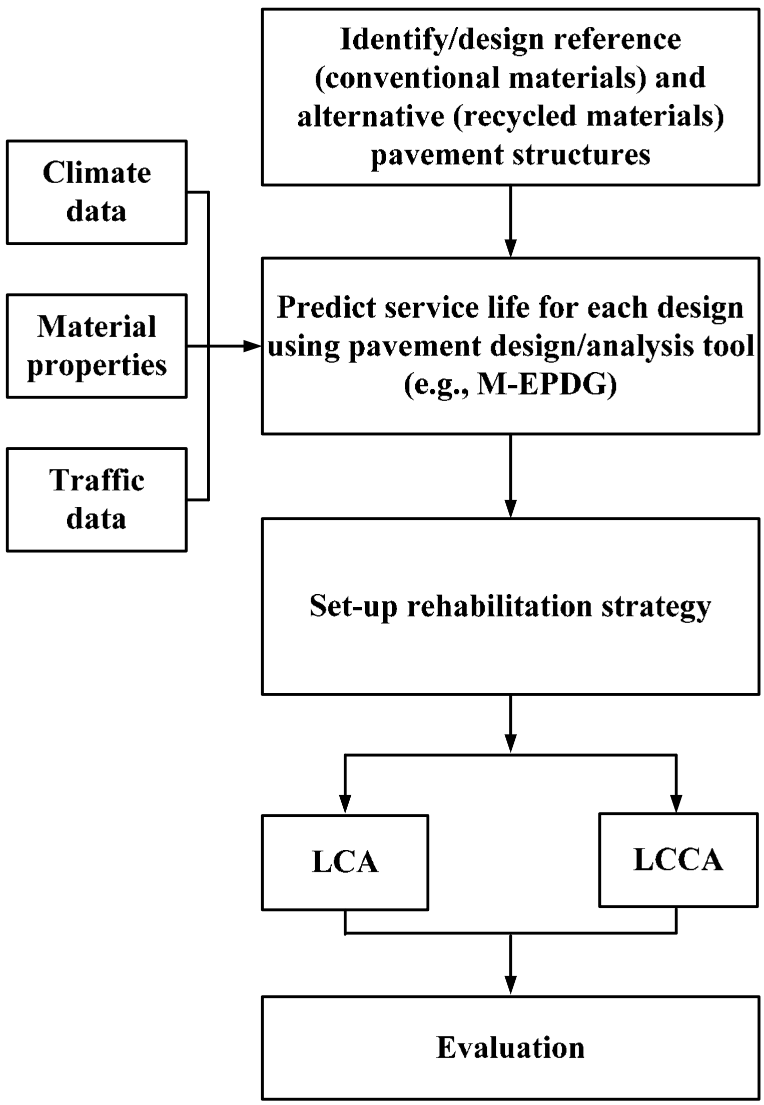

Figure 3. Flow Chart for the System Simulation Phase of Figure 2 (After Lee et al. 2010).

Two potential pavement designs considered in the assessment are shown in Figure 4, a conventional pavement design proposed by the Wisconsin Department of Transportation (WisDOT) and an alternative pavement design employing hot mix asphalt (HMA) using 15% recycled asphalt pavement (RAP) and 5% reclaimed asphalt shingles (RAS) for surface course, recycled pavement material (RPM) stabilized with fly ash as the base course, and foundry sand as the subbase. Recycled materials can also be used in other elements in the right-of-way (e.g., pipes, guide rails, barriers, etc.); however, in this study, recycled materials were considered only in the surface, base, and subbase layers of the pavement structure.

The same layer thicknesses (i.e., volume of materials) were used in the conventional and the alternative designs and the structural capacity of both pavements was determined using the same procedure. However, the recycled materials have different engineering properties than the conventional materials, which resulted in differences in the calculated service life. Design parameters for the recycled materials were obtained from the recommendations made by Geo Engineering Consulting [2009], which are based on research findings reported by Li et al. [2008] and Tanyu et al. [2005].

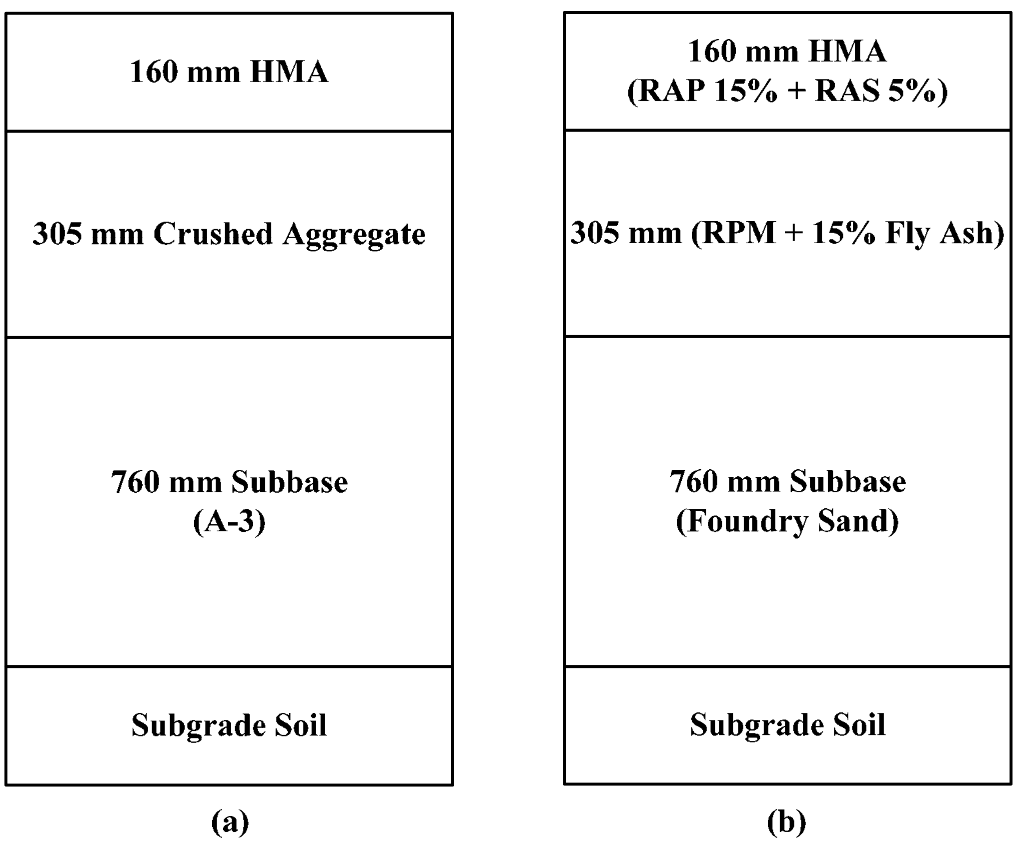

Figure 4. Schematic of Two Pavement Designs: (a) Reference-Conventional Materials vs. (b) Alternative-Recycled Materials.

Pavement systems are assumed to be serviceable until the international roughness index (IRI) reaches 2.7 m/km, as recommended in FHWA [1998]. Once this IRI is reached, the pavement is assumed to require rehabilitation. The IRI was predicted using the *Mechanistic-Empirical Pavement Design Guide (M-EPDG) Version 1.0* [NCHRP 2009]. *M-EPDG* primarily uses three key variables in the analysis: (1) traffic data, (2) climate conditions, and (3) material properties.

Predictions of the IRI for the conventional and recycled designs are shown in Figure 5. The conventional and recycled material designs reach their terminal serviceability at 29 and 32 yr, respectively. The service life for the pavement using recycled materials is 3 yr longer because of the superior properties of the recycled materials relative to the conventional materials.

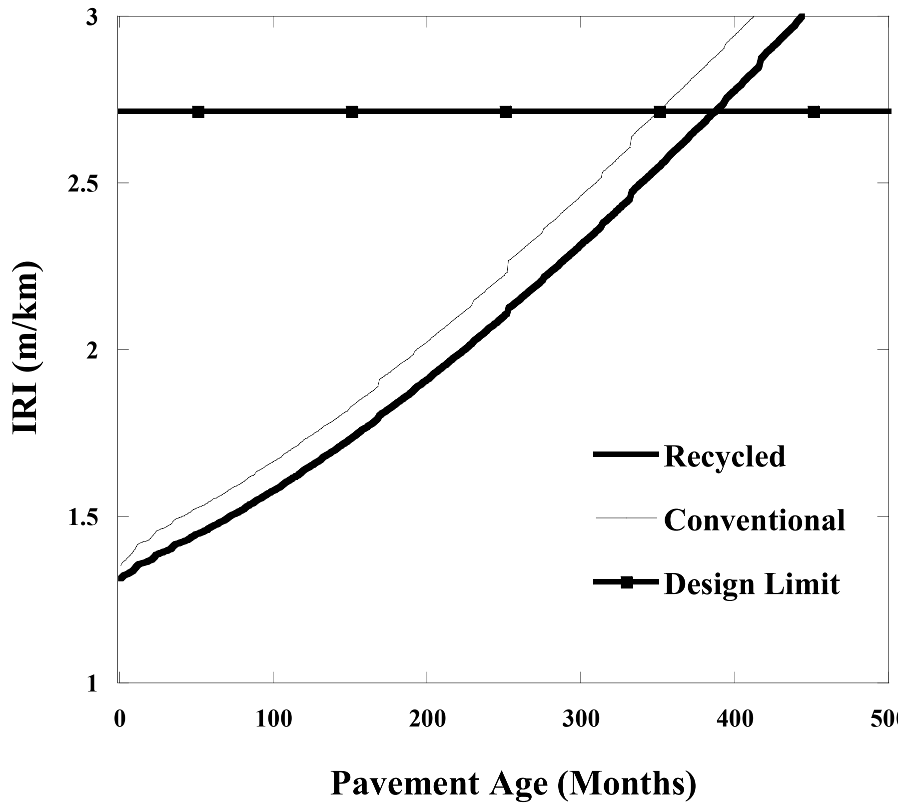

Figure 5. IRI as a Function of Pavement Age for Pavements Constructed with Conventional and Recycled Materials as Predicted Using M-EPDG.

PERFORMANCE MEASUREMENT

The LCA was conducted using the spreadsheet program, *PaLATE Version 2.0* [RMRC 2009]. *PaLATE* was used because it includes information on a variety of recycled materials, including the fly ash and foundry sand used in the base and subbase in this study. *PaLATE* employs reference factors to calculate environmental impacts for a project. For example, *PaLATE* uses CO_2 emission factors for construction equipment from the US Environmental Protection Agency inventory data [U.S. EPA 1996] to compute emissions from construction for a project. Total effects are computed as the product of unit reference factors and the quantity of an activity or material in the project.

PaLATE employs economic input-output (EIO) LCA, which permits an assessment of environmental impacts of the entire supply chain associated with conventional and recycled construction materials. EIO-LCA uses economic input-output data (e.g., data from the US Department of Commerce) as well as resource input data and environmental output data to analyze both the direct impact and supply chain effects [Horvath 2003]. Additional detail on the LCA approach used in *PaLATE* can be found in [Horvath 2003].

The LCA was conducted for a 50-yr period, which is the standard practice employed by the WisDOT. This analysis included one-time rehabilitation of the pavement at 29 or 32 yr, as noted previously. Energy use and global warming potential (reported in carbon dioxide equivalents, CO_2e) reported by *PaLATE* were used for comparing the environmental attributes of the pavements constructed with the conventional and the recycled materials. Generation of RCRA hazardous waste and water consumption during construction was also considered in the environmental assessment.

The LCCA was conducted using the spreadsheet program *RealCost version 2.5* [FHWA 2009]. As with the LCA, the LCCA was conducted for a 50-yr period. Agency costs and work zone user costs were included in the LCCA. The user costs include delay costs (cost of delay time spent in work zones) and crash costs associated with construction and rehabilitation.

RESULTS AND ANALYSIS

Results of the LCA are shown in Table 1 in terms of material production, transportation, and construction (placement of the materials in the roadway). The column labeled "difference" corresponds to the total percent change in the environmental metric by using the recycled materials in lieu of the conventional materials. Using recycled materials in other elements of the right of way (e.g., pipes, guide rails, barriers, signage) in the alternative design would further enhance the environmental benefits. However, using recycled materials just in the surface, base, and subbase layers results in significant environmental and economic benefits as illustrated subsequently.

Table 2 provides a comparison of the benefits accrued from the surface asphalt layer versus the unbound layers below due to the use of recycled materials. Considering that relatively small amount of recycled materials were incorporated in the surface layer, environmental benefits of using recycled materials in the surface layer are significant. In the case of water savings and RMRC hazardous waste reduction

TABLE 1: LCA Predictions for Pavements using Conventional and Recycled Materials

Environmental Metric	Conventional Materials			Recycled Materials			Difference
	Material Production	Transportation	Construction	Material Production	Transportation	Construction	
CO_2e (Mg)	3,630	323	111	2,551	163	54	-32%
Energy (GJ)	66,680	4,318	1,476	49,630	2,178	723	-28%
RCRA Hazardous Waste (Mg)	629	31	9	480	16	4	-25%
Water (L)	17,185	735	144	12,398	371	70	-29%

Note: GJ = gigajoules = 0.001 terajoules (TJ), Mg = megagrams.

replacing virgin asphalt concrete with concrete that includes RAP and RAS result in even higher percent changes than the base and subbase together. This is a result of higher rates of hazardous wastes production and water use during the asphalt production process than the aggregate production process. Therefore, use of recycled materials in the HMA (or an alternative asphalt construction processes) would enhance the environmental and economic benefits significantly and efficiently.

TABLE 2: Comparison of LCA Results of HMA and Other Layers

	Surface (HMA)	Base and Subbase	Total
CO_2e (Mg)	477 (-12%)	819 (-20%)	1,296 (-32%)
Energy (GJ)	8,401 (-12%)	11,542 (-16%)	19,943 (-28%)
RCRA Hazardous Waste (Mg)	131 (-19%)	38 (-6%)	169 (-25%)
Water (L)	3,241 (-18%)	1,984 (-11%)	5,225 (-29%)

Greenhouse Gas Emissions

The quantities in Table 1 indicate that a 32% reduction in GWP (CO_2e) can be achieved in this case study using recycled materials. Most of the reduction in CO_2e (83%) is from reduced emissions during material production. Heavy equipment operation is the main source of CO_2e emissions during material production. Most recycled materials are available as a byproduct from another operation (e.g., fly ash is a byproduct of electric power production) and therefore do not require mining, crushing, etc. Consequently, production of recycled materials requires less usage of heavy equipment relative to conventional materials, which results in a reduction in CO_2e emissions. Similarly, the asphalt content of RAP and RAS in the HMA does not require production of new asphalt.

To stabilize greenhouse gas emissions at current levels, the highway construction industry must reduce emissions by 1.54 billion Mg-CO_2e over 50 yr as indicated above. The LCA for this case study indicates that a reduction of 1,296 Mg-CO_2e could be achieved using recycled materials in the 4.7-km portion of the Burlington Bypass considered in this study, or 276 Mg-CO_2e/km. The U.S. alone is projected to construct 6 million km of roadway over the next 40 yr [Carpenter et al. 2007]. Based on this construction rate and the emissions reductions computed in this study, using recycled materials in roadway construction could achieve an emissions reduction of 2.07 billion Mg-CO_2e over 50 yr using the relatively modest changes in pavement design illustrated in this example. Thus, with other modest changes to pavement design, reducing emissions by 1.54 billion Mg-CO_2e over 50 yr in roadway construction appears achievable.

Energy Savings

The quantities in Table 1 indicate that approximately 85% of the total energy savings obtained using recycled materials is associated with material production. These energy savings are analogous to the reductions in emissions associated with material production and are associated with the heavy equipment used to mine and process conventional construction materials. Use of recycled pavement materials *in situ* such as RPM also reduces the energy associated with transportation (e.g., transport to a landfill for disposal and transport of new materials to the construction site).

The total energy savings (28%) using recycled materials for the 4.7-km section is 17 terajoules (TJ), or 3.6 TJ/km, which corresponds to the annual energy consumed by 170 average households in the U.S. (based on the 2005 energy use statistics, EIA 2009). Similar application of recycled materials on a nationwide basis (assuming 150,000 km of construction annually based on Carpenter et al. 2007) corresponds to an energy savings of 540,000 TJ in the U.S. annually, which is equal to the annual energy consumed by 5.4 million average homes (e.g., a state the size of Illinois or Pennsylvania). Thus, substantial energy savings can be accrued on a nationwide basis using recycled materials in roadway construction assuming that recycled materials are readily available.

Other Environmental Impacts

Using recycled materials in the pavement design also reduced the amount of hazardous waste produced and the amount of water consumed. The reduction in hazardous wastes results in lower management costs [U.S. EPA 2009]. Using recycled materials results in a savings of 5,225 L of water (29% or 1,112 L/km) for the 4.7-km section considered in the analysis. Similar application of recycled materials on a nationwide basis (assuming 150,000 km of construction annually based on Carpenter et al. 2007) could potentially result in a savings of 166.8 million L of water nationwide (approximately 10,410 persons' annual water use for shower) and an annual reduction of 5.4 million Mg of hazardous waste.

Life Cycle Cost

The life cycle costs and the cost savings using recycled materials are summarized in Table 3. These costs savings also include avoidance of landfill disposal of the recycled materials based on an average landfill tipping fee of $40/Mg [Wisconsin Department of Natural Resources 2009]. As shown in Table 3, total life cycle costs can be reduced 23% by using recycled materials in lieu of conventional materials.

TABLE 3: Life Cycle Costs for Pavement Designs Using Conventional and Recycled Materials

Categories	Reference	Alternative	Saving
Agency Cost ($)	9,044,570	7,006,830	2,037,740 (-23%)
User Cost ($)	10,570	8,380	2,190 (-21%)
Total ($)	9,055,140	7,115,610	2,039,930 (-23%)

Based on the performance of a project in each criterion compared to the reference design (i.e., 50% or 100% satisfaction of the target value of a criterion), 1 point or 2 points will be awarded to the project respectively. Because of the superior performance of the alternative design of the Burlington Bypass project (see Table 4) compared to its reference design, the maximum total credit (i.e., 12 points) can be granted to the project. The project outperformed the target values by a wide margin in some criteria. For example, 32% reduction of global warming potential passed its target value (24%) and the recycling ratio (92%) largely exceeded its goal (20%). Therefore, the target values of the criteria can be adjusted so the rating system is more challenging. If a rating system is too easy, the power of discrimination cannot be achieved.

TABLE 4: Rating Results

Criteria	Target Value	Performance	Score
Global Warming Potential	-24%	-32%	2
Energy Consumption	-10%	-28%	2
RCRA Hazardous Material	-10%	-25%	2
Water Consumption	-10%	-29%	2
Life Cycle Cost	-10%	-23%	2
Reuse / Recycling	20%	92%	2
Total			12/12

SUMMARY and CONCLUSIONS

The potential benefits of using recycled materials and industrial by-products instead of conventional materials in a highway construction project in Wisconsin have been described using a rating system named Building Environmentally and Economically Sustainable Transportation Infrastructure-Highways (BE^{2}ST in-Highways). Life cycle analysis and life cycle cost analysis were used in the rating system to evaluate the environmental and economic benefits. The analyses indicate that using recycled materials in the surface, base and subbase layers of a highway pavement can result in reductions in global warming potential (32%), energy consumption (28%), water consumption (29%), and hazardous waste generation (25%). Overall, 92% use of recycled materials in the surface, base and subbase layers has a potential life cycle cost savings of 23% while providing a longer service life. For the environmental and economic benefits of using recycled materials, the case study obtained the maximum total score (12 points), thus the best label of sustainable highway construction can be awarded to the project.

When extrapolated to a nationwide scale, using recycled materials in roadway construction has the potential to provide the reductions in greenhouse gas emissions needed to maintain the emissions by the highway construction industry at the current levels using the suggested strategies. In addition, energy savings commensurate with the annual energy consumption of households in a state comparable in size to Illinois or Pennsylvania can be achieved by using recycled materials in roadway construction on a nationwide basis.

As illustrated in the case study, BE^2ST in-Highways employs life cycle analysis techniques to provide an overall assessment of the environmental impacts associated with a highway construction project. Energy and water consumption, greenhouse gas emissions, service life, and life cycle cost are evaluated in a quantitative framework that can be used to compare alternative construction strategies from a holistic perspective. The methodology is grounded in quantitative metrics rather than an arbitrary point system so that a transparent linkage exists between the project rating and the sustainable practices employed in design and construction. This transparency reduces the potential for 'gaming' of the rating system.

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