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Greenroads: A Sustainability Rating System for Roadways

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Abstract: Greenroads (www.greenroads.us) is a proposed standard for quantifying sustainable practices associated with the design and construction of roadways. It is a performance metric that awards points for approved sustainable choices/practices and can be used to certify roadway projects based on the achievement of a list of project requirements and the total points earned. Such a standard can (1) allow informed sustainability decisions, (2) provide a quantitative means of sustainability assessment, (3) stimulate improvement and innovation in roadway sustainability, and (4) provide baseline sustainability standards. This paper describes Greenroads version 1.0, which consists of 11 Project Requirements, 37 Voluntary Credits (for a total of 108 points) and a Custom Credits section. Specific attention is paid to (1) how the system works, (2) the development cycle in the coming years, and (3) how sustainable concrete pavement solutions fit into the performance metric. Specifically, the direct use of concrete and concrete contractors can earn up to 42 Voluntary Credit points available (39% of the total). Specific concrete-related Greenroads work in the future includes investigation of potential Voluntary Credits covering design-for-deconstruction, ENERGY STAR label cement plants and recognizing recycled content in Portland cement manufacturing processes.

***Key words**: Ecology;Environment;Green;Rating system; Road; Roadway; Sustainability.*

Introduction

The use of sustainable practices in civil infrastructure can often be difficult because (1) decision makers do not have adequate information to make informed decisions on these aspects, and (2) there is no quantitative means of assessment in this area. This paper describes a standard, broadly termed "Greenroads", for quantifying sustainable practices associated with the design and construction of roadways. This project-based system awards points for approved sustainable choices/practices and can be used to certify projects based on total point value.

This standard could:

1. Encourage more sustainable practices in roadway design and construction,
2. Provide a standard quantitative means of roadway sustainability assessment,
3. Allow informed decisions and trade-offs regarding roadway sustainability,
4. Enable owner organizations to confer benefits on certified road projects, and
5. Establish an implementable baseline requirement for roadway sustainability.

Greenroads (www.greenroads.us) could be used in a number of ways by agencies, design consultants, and contractors. Its use could have direct implications for the preservation, repair, and rehabilitation of pavements in general as well as concrete pavements in particular.

This paper presents version 1.0 of the Greenroads performance metric. This system can be freely used and modified by anyone, however the official version resides online (www.greenroads.us) and is maintained by its developers for general use. Options concerning its ultimate use and ownership remain open. This paper includes a discussion of the perceived need for such a metric and the underlying definitions and values that used in its development. Potential avenues to implementation and envisioned uses are discussed followed by a discussion of the role of concrete pavements within Greenroads.

Sustainability Definition

For the purposes of this paper, "sustainability" is defined as a system characteristic which reflects the system's capacity to support natural laws and human values. By "natural laws" we specifically mean three basic principles that must be upheld to maintain the ecosystem [1]:

1. Substances must not be extracted at a faster pace than their slow redeposit and reintegration into the Earth's crust.
2. Substances must not be produced at a faster pace than they can be broken down and integrated into nature near its current equilibrium.
3. Do not harvest or manipulate ecosystems in such a way that productive capacity and diversity systematically diminish because our health and prosperity depend on the capacity of nature to reconcentrate and restructure wastes into new resources.

By "human values" we mean equity and economy. Equity is interpreted as the primarily human concept of seeking quality of life for all involved and includes what is normally thought of as the social component, including items like safety, mobility and access. This is a vague component that changes along with our values as humans. Perhaps "equity" is best summarized as Robèrt's fourth principle [1]: a primarily human concept of meeting nine fundamental human needs: subsistence, protection, affection,

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understanding, participation, leisure, creation, identity, and freedom [2]. "Economy" is broadly interpreted as management of human, manufactured, natural and financial capital [3]. Thus, by this definition economy refers to project finance but it also refers to items such as forest resources management and carbon cap-and-trade schemes.

In total, this definition contains the key elements of ecology, equity, and economy and is essentially consistent but more actionable on a project scale than the often quoted United Nations 1987 Brundtland Commission report excerpt: "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (A/RES/42/187)[14].

Beyond ecology, equity, and economy we believe there are four other essential components to a sustainability definition. First, sustainability is context sensitive. Hence, for a particular project, the project's extent in space and time (i.e., its scope, physical dimensions, and lifecycle) and performance expectations (i.e., design criteria, metrics of performance, and assessment of risks) must be part of the definition. Second, what transforms "sustainability" from concept to reality are experience (in the form of technical expertise and historical information that drive current decisions) and exposure (in the form of education and training) of the profession and general public to the idea of sustainability and its importance. In total, our sustainability definition has seven components: ecology, equity, economy, extent, expectations, experience, and exposure.

To date, roadways typically approach sustainability in a piecemeal or regulatory manner. Typical means for addressing each of the three major components have been:

- **Ecology**. Regulations describing minimum acceptable standards.
- **Equity**. Political or mandated processes for ensuring environmental justice, cultural and aesthetic considerations.
- **Economy**. Project evaluative procedures (e.g., benefit-cost), budgetary constraints, and political or economic pressures.

Integrative processes associated with roadway projects (e.g., the National Environmental Policy Act, Context Sensitive Solutions/Design) do exist but none yet are purposefully organized around the definition of sustainability presented here.

The Need for a Rating System

Greenroads is a straightforward means of translating sustainability ideas into definable design and construction practices that are likely to result in a more sustainable roadway. The need for such a system arises for four basic reasons. First, roadways can be more sustainable than they currently are. Current standards and decision tools do not fully address sustainability. For instance, while pavements are heavy users of recycled material [5] their design and construction do not consider life cycle emissions or energy use, and ecological considerations can be limited to regulatory compliance. Second, most roadway sustainability efforts to date have not applied a consistent standard by which the relative importance of efforts are judged. Therefore, comparisons between projects or assessments of improvement over time are difficult. Third, the science and engineering underlying roadway sustainability can be complex. Decisions by non-experts that often drive project direction or funding can therefore be problematic. Finally, different aspects of roadway sustainability are difficult to compare because they are not normalized to a common value set. Consequently, it is difficult to get a holistic sense of a roadway's relative sustainability or weigh design and construction trade-offs. A commonly accepted sustainability performance metric could help with all these issues. Such a metric should be straightforward in order for it to appeal to a broad audience. It should also be consistent with existing laws, regulations, and programs such as the Clean Water Act, the Clean Air Act, the National Environmental Policy Act, the Federal Highway Administration's (FHWA) *Environmental Review Toolkit* [6] and the Green Highways Partnership [7]. Finally, it should push the industry to improve on current practices and do more than the required minimum.

Stakeholders

There are a number of stakeholders who may have interest in a sustainability performance metric for roads. Each stakeholder is likely to have opinions on how Greenroads should work. Stakeholders include:

- Road owners: federal, state, county, and city agencies as well as the general public,
- Funding agencies: federal, state, county, city, and other regional authorities,
- Design consultants: those involved with corridor, road, or even parking lot design,
- Contractors: heavy construction, road and paving contractors,
- Trade organizations: representing various industries involved in roadways such as the Portland Cement Association or American Concrete Pavement Association,
- Regulatory agencies: U.S. Environmental Protection Agency,
- Sustainability organizations: U.S. Green Building Council (USGBC), Green Highways Partnership, Sierra Club, etc., and
- Research organizations: universities and other research organizations that participate in investigating related sustainable technologies.

Greenroads Performance Metric

This section first discusses the general underlying philosophy then describes the performance metric in detail including boundaries, categories, and certification. The version described in this paper, version 1.0, is intended to serve as a baseline to be refined, calibrated, and evaluated by potential stakeholders. As such, it is expected that it will change based on stakeholder input and evolve as technology and sustainability savvy evolves.

General Philosophy

The Greenroads performance metric is designed to promote more sustainable solutions within and beyond existing federal, state, and local regulations. Specifically, Greenroads is designed to influence decisions regarding sustainability options where they are not precluded by regulation or where regulation allows a choice between options that could have sustainability impacts. Greenroads is also meant to encourage organizations to include sustainable

practices in their company-wide strategy and daily work practices. Importantly, Greenroads is not meant to dictate design or trade-off decisions. Rather it provides a tool to help with such decisions. Finally, Greenroads is meant to evolve as sustainable thought and technology evolve.

System Boundaries

Greenroads is applicable to the design and construction of new or rehabilitated roadways including expansion or redesign. Specifically, it applies to (1) the design process and (2) construction activities within the workzone as well as material hauling activities, production of portland cement concrete (PCC), and hot mix asphalt (HMA). It is project based and does not consider the planning or operation phases. This means that some typical items associated with roadways are either excluded or only considered marginally:

- Supply chain processes: Items such as cement and asphalt manufacturing/refining are only considered in life cycle inventories or analyses.
- Structures: Bridges, tunnels, walls, and other structures are considered only as a collection of materials. Points can be awarded for materials used; however the structural design, aesthetics, and other non-material qualities are not explicitly featured in the current version of Greenroads.
- Paths and trails: If directly associated with the roadway (e.g., adjoining foot/bicycle path or sidewalk), they are considered. Independent paths and trails (e.g., a conversion of a rail right-of-way to a bicycle path) are excluded.
- Future maintenance and preservation: Since evaluation is complete at substantial completion, Greenroads can only evaluate *plans* for maintenance and preservation and not actual actions. Because of the limitations of the metric, these important elements in roadway projects may receive less emphasis than they should otherwise receive. In general they are often dependent on political will and changing funding levels and as such, a promise at the time of construction may have little value later on.
- Roadway use: Traffic has a profound impact on sustainability. Design decisions that affect how a facility is used by traffic are given credit but judgments on direct use issues such as fleet composition, emissions ratings, and vehicle fuel sources are not considered since they cannot be adequately predicted or verified at substantial project completion.

Project Requirements Voluntary Credits and Certification Levels

Greenroads version 1.0 is fundamentally a list of sustainability best practices (Table 1). They are organized into 11 Project Requirements (items that must be accomplished) and 37 Voluntary Credits (items that may be pursued at the discretion of the project team). While Project Requirements have no point values associated with them, each Voluntary Credit is assigned a point value (1 to 5 points) that corresponds to its impact on sustainability. In this manner, project teams are afforded a basic weighting of voluntary items that is commensurate with sustainability impact. Higher point values indicate larger impacts. The Greenroads Version 1.0 Manual (www.greenroads.us) details how these weighting decisions were made. There is also a Custom Credits section where project teams can propose their own Voluntary Credits and, once they pass a review by the Greenroads team, be used by the proposing project or any other project. Once approved they essentially enter into the system and function like Voluntary Credits.

Certification is based on achieving all 11 Project Requirements and a minimum number of Voluntary Credit points. The following certification levels are provisionally used:

- Certified: 32-42 points (30-40% of the total Voluntary Credit points),
- Silver: 43-53 points (40-50% of the total Voluntary Credit points),
- Gold: 54-63 points (50-60% of the total Voluntary Credit points), and Evergreen: 64+ points (>60% of the total Voluntary Credit points).

These certification levels have yet to undergo extensive calibration, the goal of which would be to make them generally unattainable using current roadway design and specification practices but attainable without drastically changing the scope of work. They may change in future Greenroads Versions.

Flexibility

Greenroads is intended to be a flexible metric rather than a one-size-fits-all solution. This is accomplished through (1) containing

Table 1. Greenroads Listing by Category.

No.	Title	Pts.	Description
Project Requirements (PR)			
PR-1	Environmental Review Process	Req	Complete an Environmental Review Process.
PR-2	Lifecycle Cost Analysis (LCCA)	Req	Perform LCCA for Pavement Section.
PR-3	Lifecycle Inventory (LCI)	Req	Perform LCI of Pavement Section with Software tool.
PR-4	Quality Control Plan	Req	Have a Formal Contractor Quality Control Plan.
PR-5	Noise Mitigation Plan	Req	Have a Construction Noise Mitigation Plan.
PR-6	Waste Management Plan	Req	Have a Plan to Divert C&D* Waste from Landfill.
PR-7	Pollution Prevention Plan	Req	Have a Stormwater Pollution Prevention Plan.
PR-8	Low-Impact Development (LID)	Req	Study Feasibility of LID Techniques for Stormwater.
PR-9	Pavement Management System	Req	Have a Pavement Management System.
PR-10	Site Maintenance Plan	Req	Have a Maintenance Plan for Environment, Utilities.
PR-11	Educational Outreach	Req	Publicize Sustainability inFormation for Project.

Table 1. Greenroads Listing by Category. (Continued)

No.	Title	Pts.	Description
Voluntary Credits			
Environment & Water (EW)			
EW-1	Environmental Management System	2	Have ISO 14001 Certification for General Contractor.
EW-2	Runoff Flow Control	3	Reduce Runoff Quantity.
EW-3	Runoff Quality	3	Treat Stormwater on-site.
EW-4	Stormwater Cost Analysis	1	Conduct a LCCA for Stormwater BMP*/LID Selection.
EW-5	Site Vegetation	3	Use Native Low/no Water Vegetation.
EW-6	Habitat Restoration	3	Create New Habitat Beyond what is Required.
EW-7	Ecological Connectivity	3	Connect Habitat Across Roadways.
EW-8	Light Pollution	3	Discourage Light Pollution.
	EW Subtotal:	21	
Access & Equity (AE)			
AE-1	Safety Audit	2	Perform Roadway Safety Audit.
AE-2	Intelligent Transportation Systems (ITS)	5	Implement ITS Solutions.
AE-3	Context Sensitive Solutions	5	Plan for Context Sensitive Solutions.
AE-4	Traffic Emissions Reduction	5	Reduce air Emissions Systematically.
AE-5	Pedestrian Access	2	Provide/improve Pedestrian Accessibility.
AE-6	Bicycle Access	2	Provide/improve Bicycle Accessibility.
AE-7	Transit & HOV* Access	5	Provide/improve Transit/HOV Accessibility.
AE-8	Scenic Views	2	Provide Views of Scenery or Vistas.
AE-9	Cultural Outreach	2	Promote Art/Culture/Community Values on Roadway
	AE Subtotal:	30	
Construction Activities (CA)			
CA-1	Quality Process Management	2	Have ISO 9001 Certification for General Contractor.
CA-2	Environmental Training	1	Provide Environmental Training.
CA-3	Site Recycling Plan	1	Provide Plan for on-site Recycling and Trash.
CA-4	Fossil Fuel Reduction	2	Use Alternative Fuels in Construction Equipment.
CA-5	Equipment Emission Reduction	2	Meet EPA* Tier 4 Standards for Non-road Equip.
CA-6	Paving Emission Reduction	1	Use Pavers that Meet NIOSH* Requirements.
CA-7	Water Use Monitoring	2	Develop Data on Water use in Construction.
CA-8	Contractor Warranty	3	Offer an Extended Warranty on Pavement.
	CA Subtotal:	14	
Materials & Resources (MR)			
MR-1	Lifecycle Assessment (LCA)	2	Conduct a Detailed LCA of the Entire Project.
MR-2	Pavement Reuse	5	Reuse Existing Pavement Sections.
MR-3	Earthwork Balance	1	Balance Cut/Fill Quantities.
MR-4	Recycled Materials	5	Use recycled materials for New Pavement.
MR-5	Regional Materials	5	Use Regional Materials to Reduce Emissions.
MR-6	Energy Efficiency	5	Improve Energy Efficiency of Operational Systems.
	MR Subtotal:	23	
Pavement Technologies (PT)			
PT-1	Long-Life Pavement	5	Design Pavements for Long-life.
PT-2	Permeable Pavement	3	Use Permeable Pavement as a LID Technique.
PT-3	Warm Mix Asphalt (WMA)	3	Use WMA in Place of HMA*.
PT-4	Cool Pavement	5	Use a Surface that Retains Less Heat.
PT-5	Quiet Pavement	3	Use a Quiet Pavement to Reduce Noise.
PT-6	Pavement Performance Monitoring	1	Relate Construction to Performance Data.
	PT Subtotal:	20	
	Voluntary Credit Total:	108	
Custom Credits (CC)			
CC-1	Custom Credits	10	Design your own Credit.
	CC Subtotal:	10	
	Greenroads Total:	118	

*C&D = construction and demolition; BMP = best management practice; HOV = high occupancy vehicle; EPA = U.S. Environmental Protection Agency; NIOSH = National Institute for Occupational Health and Safety; HMA = hot mix asphalt.

a wide array of Voluntary Credits, (2) use of Custom Credits, and (3) a system by which a project can translate its values into desired Voluntary Credits.

First, there are currently 37 Voluntary Credits and we speculate that no individual project would be able to achieve all 37. In fact, for some projects certain Voluntary Credits may be in direct opposition to one another, which reflects the tradeoffs that are inherent in pursuing sustainability. Second, Custom Credits were added to give projects a stake in defining sustainability best practices. In other words, the Custom Credits section allows the performance metric to grow by using individual project innovation. Finally, Greenroads embeds a system whereby an individual project can trace its own defined goals back to specific Greenroads Project Requirements and Voluntary Credits. This is done in two ways. First, all Project Requirements and Voluntary Credit are directly traced to at least one, if not several, of the seven components of sustainability. Second, all Project Requirements and Voluntary Credits are associated with at least one, if not several, of 16 defined project benefits:

1. Ecological benefits
   a. Reduce emissions
      i. Reduce air emissions
      ii. Reduce wastewater emissions
      iii. Reduce soil/solid waste emissions
   b. Reduce consumption
      i. Reduce water use
      ii. Reduce fossil energy use
      iii. Reduce raw materials use
      iv. Create renewable energy
      v. Optimize habitat and land use
2. Human-centric benefits
   a. User improvement
      i. Improve human health and safety
      ii. Improve access and mobility
   b. Performance improvement
      i. Improve business practice
      ii. Increase lifecycle savings
      iii. Increase lifecycle service
   c. Interaction improvement
      i. Increase awareness
      ii. Improve aesthetics
      iii. Create new information

We feel that the ability to (1) choose Voluntary Credits to pursue, (2) develop Custom Credits, and (3) relate project goals and objectives to specific Project Requirements and Voluntary Credits makes the performance metric context sensitive in that it can conform to project values while still maintaining an objective assessment of sustainability.

Benefits

The ultimate benefit of Greenroads is more sustainable roadways. This means impact in any or all of the seven sustainability components. Whether overtly stated or not, the implicit mission of most public road agencies is a sustainable transportation network. A survey of all 50 state department of transportation (DOT) and the USDOT mission statements [8], a crude proxy for DOT missions, shows 10 DOT mission statements contain ideas directly relating at least three components of "sustainability" as defined in this paper (ecology, equity, economy) while 34 address at least one component. If ideas of safety and mobility are included this number increases to 47. Given this implicit goal of sustainable transportation, Greenroads can be of benefit to because it can:

1. Provide a credibly accounting system for sustainable roadway projects,
2. Define basic roadway sustainability attributes,
3. Provide means for sustainability assessment,
4. Allow a greater audience to participate in roadway sustainability in a meaningful way,
5. Allow sustainability tradeoffs and decisions to be made in a systematic manner,
6. Confer marketable recognition on sustainable roadway projects, and
7. Allow for innovation because it is end-result oriented.

In essence, Greenroads can provide a relatively straightforward means by which owner agencies can assess their performance against their stated mission.

Implementation

Implementation of and participation in Greenroads will likely happen through various forms of voluntary or mandated use. This section discusses the most likely paths. Presently, it is unclear which, if any, will predominate.

Voluntary Use by Consultants/Contractors

Consultants and contractors could use Greenroads as a list of vetted and researched sustainable practices that could be incorporated into a roadway project. Certification levels could be used as standard sustainability goal levels. Early anecdotal evidence suggests that this may be the initial way Greenroads is used as owner agencies are beginning to ask consultants to incorporate sustainability into their roadway projects.

Voluntary Use by Agencies

Owner agencies could set goals (required or not) of a particular Greenroads certification level. In addition to improving sustainability similar certification systems have shown that certification can be successfully marketed as a value added service by designers and contractors and as positive community relations by owners [9]. While the voluntary approach is noble, it is often difficult for public agencies to justify higher initial costs despite potential long-term benefits.

Agency Requirements

Owner agencies could adopt a formal policy of greater sustainability and use Greenroads to specify its minimum standards. This is being done in the building industry: the USGBC lists 353 government and school agencies with such policies concerning their LEED™ system [10]. While this may be viewed as imposing more requirements on already burdened public agencies, mandating sustainability may be

the best way to ensure higher initial costs do not deter sustainability efforts that may result in longer-term benefits and difficult-to-quantify benefits.

General Sustainability Monitor

Owner agencies could use Greenroads to assess roadway sustainability and monitor its improvement over time. Most large agencies already have pavement management systems; a Greenroads rating for each roadway or portion of roadway could be added as another data category and this could be tracked over time just as pavement management systems track roadway condition over time. In this sense, Greenroads becomes an internal sustainability benchmark.

The Role of Concrete Pavements in Greenroads

Concrete pavements make up an important part of U.S. and worldwide roadway infrastructure. In the U.S. concrete pavements constitute 52,078 centerline miles (83,811 centerline kilometers) of roadway owned by state highway agencies, federal agencies, and other non-local jurisdictions (local jurisdictions are not categorized by pavement type) or about 5% of the total [11]. For the most heavily trafficked roads, urban Interstates, these numbers are 4,902 centerline miles (7,889 centerline kilometers) or about 32% of the total [11]. Such a ubiquitous material should be adequately represented in a roadway design and construction performance metric. This section describes the specific Project Requirements and Voluntary Credits where the direct use of concrete or concrete contractors can meet requirements or earn points. Following this is a brief list of other Project Requirements and Voluntary Credits that would be applicable to concrete projects but may not be directly related to concrete use.

Direct Use of Concrete or Concrete Contractors

There are 11 Voluntary Credits worth up to 42 points (out of 108 total points) that involve the direct use of concrete of concrete contractors.

EW-1 Environmental Management System (2 points)

Requires the prime contractor, design builder, or construction management firm to have an environmental management system (EMS) in place for the project that meets the requirements of ISO 14001:2004. Currently, EMS adoption in the U.S. construction industry is in its infancy with relatively few certified firms [12]. December 2006 ISO 14001 certification statistics show that across all U.S. industry there were 5,585 certifications, which, along with Canada and Mexico certifications, represented only 6% of the world total. Christini et al. [12] point to evidence that such certification can be beneficial by reducing landfilled waste and producing financial savings, however most evidence of certification benefits come from surveys or case studies of contractors that are already certified [12-14].

CA-1 Quality Management System (2 points).

Requires the prime contractor, design builder, or construction management firm to have a quality management system (QMS) in place for the project that meets the requirements of ISO 9001:2008 or ISO 9001:2000. As with EMS, QMS adoption in the U.S. construction industry is in its infancy with relatively low participation [15, 16]. December 2006 ISO 14001 certification statistics show that across all U.S. industry there were 44,833 certifications, which, along with Canada and Mexico certifications, represented only 7% of the world total. As with EMSs, most evidence of certification benefits comes from surveys or case studies of contractors that are already certified [17, 18].

CA-7 Water Use Tracking (2 points)

Requires the project to track and document total water use during construction. The amount of water used in roadway construction is poorly understood and not a necessary reported number in most cases. Concrete mixing, washout, and curing are significant sources of water use in construction. For these activities, water use is often already tracked by the contractor; meeting this credit would only require reporting the information.

CA-8 Contractor Warranty (3 points)

Requires a minimum 3 year warranty for pavement construction to include: the definition of what is warranted, length of warranty, responsibilities, conflict resolution process, performance indicators, threshold levels that require corrective action, requirements for correct action, and the basis of payment [19]. 2002 data from the FHWA's SEP-14 [20] experimental program reported 40 concrete pavement warranty projects from various states; the number of warranty projects has grown significantly since then. Some states have concrete pavement warranty special provisions in place (e.g., Wisconsin, Florida, Michigan) while other warranty programs for smaller items such as driveways are "…available in many parts of the country" [21].

MR-2 Pavement Reuse (4-5 points)

Requires a minimum amount of existing pavement to be reused in a new pavement. U.S. raw materials use has increased by a factor of 17 between 1900 and 1995 while worldwide raw materials usage has increased even more [22]. In this same time, the fraction of renewable materials has slipped from just under 50% to about 8% [22]. Along with this significant rise in consumption comes a significant amount of waste. Worldwide, general estimates of waste generation range between about 12*lbs/day* (5.4*kg/day*) per capita (for Organization for Economic Co-operation and Development (OECD) countries) down to about 2*lbs/day* (0.9*kg/day*) per capita for developing countries (Global Development Research Center, GDRC, [23]). Estimates of construction and demolition waste range from 20-40% of the total waste stream [23, 24]. Thus, reusing existing material can have substantial benefit. For the purposes of this credit, "reuse" means no transport outside of the project limits has occurred at any time since original placement. Reuse applies to

preservation, reclamation, rehabilitation, resurfacing, and other types of improvement or maintenance projects. Therefore, overlay (whitetopping) projects as well as in-place reuse projects (e.g., crack-and-seat, rubblization) qualify for this credit. Importantly, MR-2 rewards pavement preservation programs that seek to renew existing pavement structure before it reaches a condition requiring total replacement.

MR-4 Recycled Materials (1-5 points)

Requires an amount of recycled material to be substituted for virgin materials. The number of points increases with the percentage of recycled materials used. Given that construction and demolition waste is significant (see MR-2 discussion); diversion of waste from landfill by recycling has sustainability benefits. In fact, concrete recycling is substantial and contributes perhaps the largest single component (by weight) to diverted waste. Data from the Washington State Department of Ecology [25] indicates that 2,089,972 tons of "asphalt and concrete" (they are co-listed) were diverted in 2007, which constitutes 29% of all diverted waste and 13% of all waste generated. This is the largest constituent of diverted waste by a factor of two.

MR-5 Regional Materials (1-5 points)

Requires a percentage of materials used to be from the local area; generally defined as within a 50 mile (80*km*) radius of the project. The number of points increases with the percentage of regional materials use. Based on a recent meta-analysis of 14 roadway LCA journal articles [26], transportation of materials tends to contribute 10-30% of the energy use and CO_2 emissions associated with road construction. While indicates the importance of transportation, the solution is, to some extent, already addressed by existing economic realities. In general, concrete is a relatively inexpensive and heavy material (when compared to most consumer goods on a weight basis). Therefore, transportation costs must be minimized in order to win competitive contracts, which means materials such as concrete and aggregate are usually sourced near to the project. Thus, motivation is already in place to limit material travel distance.

PT-1 Long-Life Pavement (5 points)

Requires a long-lasting pavement structure as defined by this credit. It is generally accepted that a pavement designed for long life will result in higher initial costs and materials use but lower lifecycle costs and materials use; although empirical evidence is limited. While older design standards often use design lives of 20-30*yrs* (based on an NCHRP Report 1-32 survey in 1997)[27], newer design standards (especially at the state level) use much longer design lives (e.g., 50-60*yrs*) based on expectations and, importantly, past performance [28-30]. Therefore, most concrete pavement designed using existing standards meet the definition of long-life pavement by this credit; however excessive design is not needed. For example, AASHTO 1993 [31] design generally meets PT-1 requirements, however additional thickness beyond 325*mm* (13*ins*) (corresponding to 28 million equivalent single axle loads - ESALs) for higher loading is not necessary. PT-1 also contains a minimum concrete pavement thickness of 175*mm* (7*ins*) for loading less than 870,000 ESALs.

PT-2 Permeable Pavement (3 points)

Requires use of a permeable pavement surface to treat at least 50% of the 90th percentile average post-construction rainfall event. Porous (pervious) concrete has been successfully used in a multitude of applications including residential roads, sidewalks, pathways, parking areas, and slope stabilizations and foundations. Industry organizations provide ample guidance for use and evidence of success. For instance, the Ready Mix Concrete (RMC) Research & Education Foundation offers a compilation of pervious concrete research [32] that details numerous reports and papers documenting empirical evidence of success as well as a report detailing construction and maintenance issues [33], while the National Ready Mix Concrete Association (NRMCA) offers contractor certifications programs in "pervious concrete technician", "pervious concrete installer", and "pervious concrete craftsman." *Benefits: reduces wastewater emissions, reduces soil/solid waste emissions, optimizes habitat and land use, and increases aesthetics.*

PT-4 Cool Pavement (5 points)

Requires a reflective or porous pavement surface. It is generally thought that such pavements are beneficial in urban areas since they contribute less to the urban heat island (UHI) effect [34]. Concrete pavements can be pervious (see PT-2) and generally meet the minimum surface reflectivity requirement regardless of age or aggregate source [35, 36].

PT-5 Quiet Pavement (2-3 points)

Requires a pavement that reduces tire-pavement noise to a predetermined level measured by on-board sound intensity (OBSI). While conventional concrete surface texturing generally cannot meet the requirements of this credit [37], more advanced diamond grinding techniques (often referred to as "next generation concrete surface" or NGCS) have shown the ability to do so.

There are also 10 Project Requirements and 6 other Voluntary Credits that involve concrete design and construction in an indirect way as listed below:

- PR-1 Environmental Review Process,
- PR-2 Lifecycle Cost Analysis,
- PR-3 Lifecycle Inventory,
- PR-4 Quality Control Plan,
- PR-5 Noise Mitigation Plan,
- PR-6 Waste Management Plan,
- PR-7 Pollution Prevention Plan,
- PR-8 Low-Impact Development,
- PR-9 Pavement Management System,
- PR-11 Educational Outreach,
- CA-2 Environmental Training (1 point),
- CA-3 Site Recycling Plan (1 point),
- CA-4 Fossil Fuel Reduction (1-2 points),
- CA-5 Equipment Emission Reduction (1-2 points),
- MR-1 Lifecycle Assessment (2 points), and

- PT-6 Pavement Performance Tracking (1 point).

Future Work Related to Concrete in Greenroads

Greenroads is a constantly evolving system. As such, new work is already planned for future versions beyond 1.0. Future work related to concrete includes potential Voluntary Credits addressing:

- Design for deconstruction: Concrete pavements built today will eventually require replacement at some point in the future. While that point is debatable, a plan for deconstruction may be useful in (1) focusing attention on the eventual deconstruction and reuse/recycling of concrete, and (2) providing explicit directions for successful reuse/recycling and even building such plans into the pavement lifecycle (including lifecycle costing and LCA).
- ENERGY STAR cement plants: The U.S. Environmental Protection Agency (EPA) has a program to award their ENERGY STAR label to industrial plants (including cement plants) that achieve a high level of energy performance within their industry [38]. This involves scoring a cement plant on a scale of 1 to 100 using a performance-based indicator [39]. A score of 75 or better earns the ENERGY STAR label. As of early 2010, 19 cement plants have received the rating at least once.
- Hidden recycled content in cement production: While it is fairly straightforward to measure the amount of industrial byproducts added as supplementary cementitious material (SCM) to a concrete mixture, it is more difficult to recognize other recycled materials in concrete such as reprocessed water, recycled supply chain fuel, contaminated soils, and scrap tires that can be used in cement production. For instance, based on first quarter 2008 data the Seattle Lafarge cement plant produced Type I/II cement the contained 32.9% including both fuel (e.g. scrap tires and contaminated soil) and raw materials (e.g., contaminated soil) [40].

Conclusions and Recommendations

This is paper describes a proposed standard for quantifying sustainable practices associated with roadway design and construction. Importantly, sustainability is defined as having seven key components: ecology, equity, economy, extent, expectations, experience, and exposure. A sustainable roadway is one that balances these components and seeks the best outcomes for each.

Greenroads is a straightforward rating system that can help produce more sustainable roadways. Version 1.0 consists of 11 Project Requirements, 37 Voluntary Credits (108 points total), and Custom Credits (up to 10 points total). Roadways can be certified by achieving all 11 Project Requirements and a minimum number of points associated with Voluntary Credits. More points earn higher certification levels. Greenroads can be implemented in a number of ways including (1) voluntary consultant use, (2) voluntary agency use, (3) agency requirements, and (4) as a general monitoring system for roadway sustainability. The expected benefits of Greenroads include:

1. A means to assess roadway sustainability and make sensible sustainability tradeoffs through the use of a common metric,
2. Greater participation in roadway sustainability through the use of a straightforward and understandable system,
3. Improved awareness of roadway sustainability through marketing. and
4. Encouragement for sustainability innovation.

As a key component material of roadways, concrete plays a large role in Greenroads. There are 11 Voluntary Credits worth 42 points (39% of the total Voluntary Credit points) that involve the direct use of concrete or concrete contractors. Additionally, there are 10 Project Requirements and 6 Voluntary Credits (worth 9 points) that involve concrete in an indirect manner. In all, the use of concrete for roadway construction can play a role in 10 of 11 Project Requirements (91%) and 51 of 108 Voluntary Credit points (47%). Even given this substantial treatment of concrete, Greenroads is an evolving metric and work involving new concrete-related Voluntary Credits is planned for design-for-deconstruction, ENERGY STAR labeled cement plants and recognition of hidden recycled content in cement production.

Sustainability has become an important topic in engineering and construction, of which roadway work is a substantial part. Greenroads can potentially provide a common metric for considering sustainability in roadway design and construction. Fundamentally, such a metric can help people make better roadway sustainability decisions.

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