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Defining Green

Embodied Energy Considerations In Existing LEED Credits

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Integrating Life Cycle Assessment Into LEED

The US Green Building Council (USGBC) is undergoing an effort to include more accurate quantification of life cycle environmental impacts into existing Leadership in Energy and Environmental Design (LEED) credits. The USGBC Working Group A (WG-A) was assigned Task 1 – defining the Goal and Scope of a life-cycle assessment (LCA) of a building project – to begin integration of LCA into LEED.

Embodied energy, also referred to as a "cradle-to-gate" LCA analysis, has been defined as "…the energy consumed by all of the processes associated with the production of a building, from the acquisition of natural resources to product delivery"[1]. For example, the embodied energy and emissions of cement manufacturing would include all processes from the mobile direct emissions (off-road quarry trucks, excavators and even company cars), the direct emissions from stationary combustion (cement kiln and non-kiln units using a company specific energy mix), and the indirect emissions associated with grid electricity use and other fugitive emissions. Delivery to the project site as concrete would then include the mining and transport of aggregate, the energy required for the ready-mix operations and, finally, the forms and machinery needed for placement.

The goal of USGBC's LCA in LEED groups is to develop a concise framework to evaluate the total carbon footprint of a building project by quantifying the embodied energy of building materials, under the Materials and Resources (MR) credits, as well as the operational energy under the Energy and Atmosphere (EA) credits. The USGBC is aware that integrating LCA into existing LEED credits needs to be streamlined to enable minimal time input for all parties involved. As a result, this paper looks at the existing MR credits to identify the synergies and potential conflicts that may affect reducing the total embodied energy of building materials and the relationship between embodied energy of building materials and the service life and location of the project.

Influence of Assumed Building Service Life on Relative Embodied Energy Impacts

WG-A recommended that the relevant EA and MR credits could be combined into a single LCA environmental impact measure to provide summation for the total greenhouse gas (GHG) of the building project (for purposes of this paper, GHG is the only impact considered). A single value assumes that the credits will properly account for the relationships between embodied and operating effects, and that prescriptive credits will no longer be necessary. However, this methodology of combining the LCA impact of EA and MR credits into a single cumulative GHG emission hides the impact that climate zone (project location), service life, and the building's operating efficiency have with regard to the relative importance of the buildings embodied energy.

The World Council on Sustainable Business Practices recently issued a report on energy efficient buildings[2] that claimed the embodied energy of a building accounted 16% of the total carbon footprint over its service life, without mentioning the length of the service life. This statement is based on a 1997 report on the total

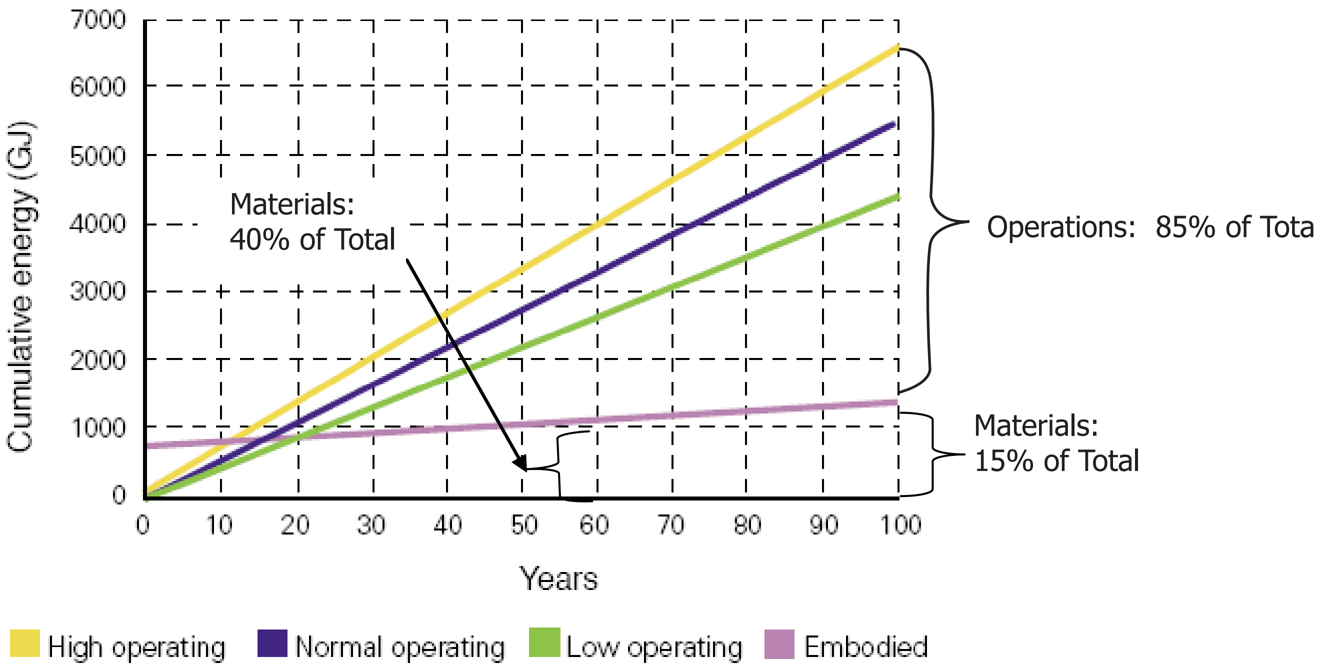
1 http://www.greenhouse.gov.au/yourhome/technical/fs31.htm

2 WBCSD: "Energy Efficiency in Buildings: Business Realities and Opportunities – Summary Report", 2007

energy of a standard wood frame house built in Sweden in 1991[3] with a 50-year life. Keoleian et al, looked at the percentage of embodied energy to the total by comparing a standard efficiency house (SH) to a 60 percent more energy efficient house (EEH) in Ann Arbor, Michigan[4]. The embodied energy of the SH accounted for only 9% of the total while the embodied energy of the EEH accounted for more than 26%. Clearly, the energy efficiency of the building is a major contributor to the relationship of embodied and operational energy.

The impact of service life and operating efficiency of a building are best illustrated in Figure 1[5]. As this project is located in Sydney, Australia, the figure also illustrates the impact of project location when compared to the percentages reported by WBCSD and Keolian's house in Ann Arbor. For a standard efficiency building, over a 100-year service life, the approximate percentage of the total carbon footprint of a building attributable to the embodied energy of materials is 15%[6]. The WG-A has recommended a 60-year service life for whole building LCA assessment. This shorter service life, in addition to increasingly more efficient buildings (as represented by the green line), has an inversely proportional impact of increasing the importance of embodied energy while decreasing the importance of operational energy to the total carbon footprint. In fact, as the USGBC has embraced the 2030 Challenge and buildings move to zero net carbon (rather than zero net energy as the buildings will always use energy), the embodied energy of the building materials may well surpass the operational energy footprint.

Figure 1: Temporal Relationship of Embodied Energy to Operating Energy [7]



3 Building & Environment, Vol. 32, No. 4, pp. 321–329 (1997)

4 Keoleian, Gregory A., Blanchard, Steven, and Reppe, Peter, "Life-Cycle Energy, Costs, and Strategies for Improving a Single-Family House" Journal of Industrial Ecology, 2000

5 http://www.dbce. csiro.au/ind-serv/brochures/embodied/embodied.htm

6 http://www.dbce. csiro.au/ind-serv/brochures/embodied/embodied.htm

7 ibid

Therefore, analyzing and reporting the LCA impacts of EA and MR credits separately enables builders/designers to use this information to improve existing designs and to spark future innovation – particularly in the material reuse and recycled material credits.

Synergies and Conflicts in Existing MR credits

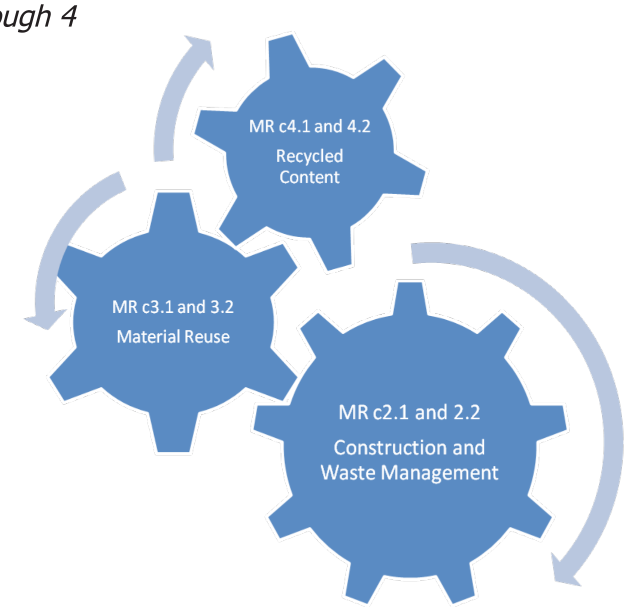
Within the existing MR credits, three categories work symbiotically to reduce embodied energy and emissions, as represented on Figure 2. By emphasizing construction waste management, the industry can create economically viable resources of material reuse and recycling. These credits emphasize the "cradle" in the "cradle-to-gate" or "cradle-to-cradle" LCA concept.

- MR Credits 2.1 and 2.2: Construction Waste Management – This credit represents the "C" in a construction and demolition (C&D) waste management plan and helps to provide a source of material for reuse and recycling. The avoided waste from a landfill can be quantified in the LCA as negative emissions and energy use using such tools as the EPA's WaRM model[8] or economic input-output LCA (EIOLCA)[9]. Although this credit occurs during construction and, therefore, the diverted materials are unlikely to be recycled back into the project, it provides the closest model of an end-of-life credit for converting a demolished building into new products, i.e. "cradle-to-cradle".

- MR Credits 3.1 and 3.2: Material Reuse – Material reuse represents the lowest embodied energy of a material that can be used in a project, and thus should be weighted as such for its contribution to green building practices. Additionally, this credit provides the momentum for developing "green collar" jobs around reusing material in new projects.

- MR Credits 4.1 and 4.2: Recycled Content – Recycled materials also represent the "cradle" LCA concept by substituting for virgin materials and, generally, reducing the embodied energy of a project. Since recycled materials may otherwise be landfilled, (e.g. fly ash) the avoided environmental impacts from disposal can be considered as reductions to the project's overall footprint.

Figure 2: Symbiotic Relationship of MR Credits 2 through 4



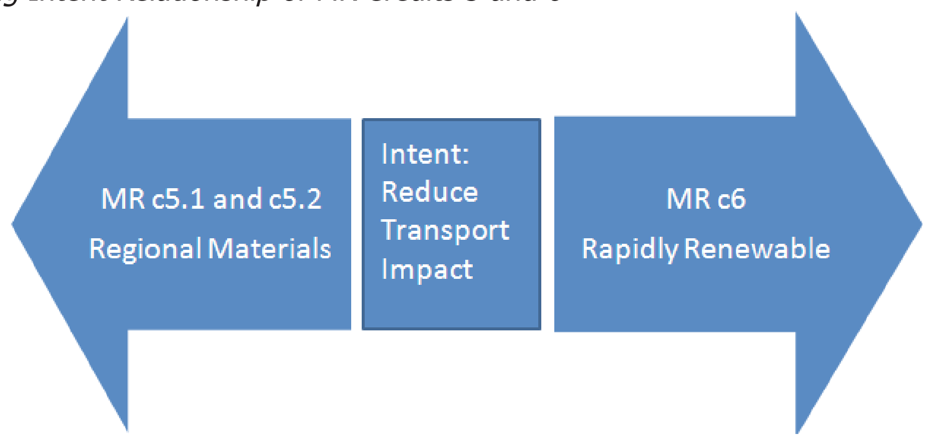
8 http://epa.gov/climatechange/wycd/waste/calculators/Warm_home.html

9 http://www.eiolca.net/

This symbiotic relationship between LEED credits does not always apply, as is the case for the Regional Materials and Rapidly Renewable credits (MRc5 and MRc6, respectively).

- MR Credits 5.1 and 5.2: Regional Materials – The requirement for this credit is to "use building materials or products that have been extracted, harvested or recovered, as well as manufactured, within 500 miles of the project site"[10] and is intended to increase demand for "indigenous resources" thereby reducing the transportation-related environmental impacts. However, this credit overlooks the fact that transportation energy may total less than 5% of the total energy of a project. Or, when evaluating a specific product, the transportation energy may greatly exceed the embodied energy of the product itself, e.g. bamboo flooring, as discussed below.
- MR Credit 6: Rapidly Renewable Materials – The requirement to use materials "made from plants that are typically harvested within a ten-year cycle or shorter"[11] may provide environmental benefits, e.g., when using straw bale, but unless the renewable is regionally grown, this credit can potentially 'cancel out' the intent of MR c5, as illustrated on Figure 3. For example, the choice of using bamboo flooring obtained from the "bamboo sea" of the Hunan Province of China, not only reverses the intent of MR Credit 5, but also may preclude the choice of material reuse (MR Credits 3.1 and 3.2, e.g. reused hardwood flooring) and therefore increase the embodied energy of the project, as discussed in the next section.

Figure 3: Opposing Intent Relationship of MR Credits 5 and 6



Impact of Transportation on Material Embodied Energy: Bamboo Flooring Example

The carbon footprint of transportation energy is largely influenced by the mode of transport, as shown in Table 1. When calculating transportation energy and emissions impacts, the units are expressed as megajoules (MJ) and the mass of carbon dioxide equivalents (lb CO2e), respectively, required to transport one-ton of freight over one mile (per ton-mi). To illustrate the impact of transportation, the energy and emissions associated with transporting one-ton of a low-embodied energy material with a high-embodied energy material is presented on the following page. The two materials being compared are enumerated below, while the energy and emissions impacts of different modes of transportation are shown in Table 1.

1. Bamboo flooring from the Hunan Province, China delivered to Denver, Colorado
2. Concrete, where all materials are produced within 500 miles of Denver, Colorado

10 USGBC Green Building Rating System for New Construction & Major Renovations Version 2.2, Revised June 26, 2007

11 ibid

Table 1: Emissions and Embodied Energy of Transport per Ton-Mile Freight

	Energy Use MJ/ton-mile	GWP lb CO_2e/ton-mi	Reference
Ocean Freighter	0.28	0.05	NREL US LCI Database, 2007
Locomotive	0.37	0.06	NREL US LCI Database, 2007
Barge	0.54	0.09	NREL US LCI Database, 2007
Cargo Plane*	1.15	0.17	NREL US LCI Database, 2007
Combination Truck	1.54	0.26	NREL US LCI Database, 2007
Single Unit Truck	3.29	0.56	NREL US LCI Database, 2007

** = Cargo Plane database only includes CO2-related GHG emissions. Additional GHG releases, such as N20 and CH4, would likely increase GWP (lb CO2e/ton-mi) by an additional 1%.*

Even though energy is required to produce bamboo flooring – hollowing and slicing the shoots prior to boiling, kiln drying and laminating into solid boards, which are then milled and treated with preservatives – there is no research data available on the embodied energy coefficient. Therefore, it was assumed that the energy and emissions of bamboo flooring was essentially zero (one-hundredth that of concrete) for purposes of illustrating the impact of transport of a product 500-miles by truck from Hunan Province to the port in Hong Kong and the 7,362 nautical mile trip to San Diego, and final transport by rail to Denver, Colorado, as included on Table 2.

Table 2: Energy and Emissions Associated with the Manufacture and Transport of One-ton of Bamboo Flooring and One-ton of Concrete

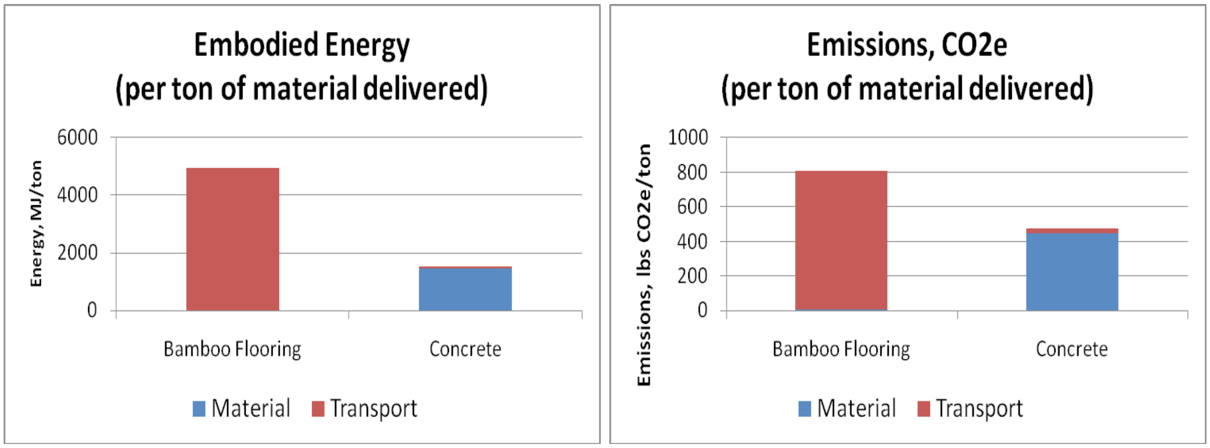
Material			Transportation				Cumulative Impact	
Item	Energy, MJ/ton	Emissions, lb CO2e	Mode	Distance, mi.	Energy, MJ	Emissions, lbs CO2e	Energy, MJ	Emissions lbs CO2e
Bamboo Flooring	15	4.5	Truck	500	1645.0	280.0	4943.1	809.4
			Ship	7,362	2061.4	368.1		
			Rail	1,221	451.8	73.3		
Concrete**	1452.3	446.7	Truck	177	32	12.0	1537.3	475.4
			Ship	58	53	16.3		

*** Reiner, PhD Dissertation "Technology, Environment, Resource, and Policy Assessment of Sustainable Concrete in Urban Infrastructure" – University of Colorado at Denver, May 2007.*

The materials considered in concrete included: cement from the Holcim cement plant in Florence, Colorado transported by rail and virgin aggregates from quarries along the South Platte River corridor transported by truck to a local ready-mix (distributor?). The total emissions and energy for one ton of concrete presented in Table 2 are similar to that reported in other research[12].

12 Hammond, Geoff and Jones, Craig, University of Bath, Department of Mechanical Engineering, "Inventory of Carbon and Energy (ICE) Version 1.5 Beta" - 2006

Figure 4: Total Embodied Energy and Emissions for One Ton of Bamboo Flooring and Concrete



As shown in Figure 4, the assumed embodied energy of bamboo flooring materials is insignificant when compared to the transportation energy. In fact, the transportation energy for the bamboo flooring is more than 3 times the total embodied energy of concrete and generates 70% more greenhouse gas emissions than concrete on a per unit mass basis. The example serves to illustrate that the intent of reducing transport energy in one credit should not be opposed by the intent of another credit, whenever possible.

Key Conclusions

- The embodied energy of materials will soon equal or exceed the operational energy of green buildings as the USGBC embraces the zero net carbon goal of the 2030 Challenge. Analyzing the embodied and operational energies separately allows for a better understanding of a building's life cycle impacts. ***Recommendation:*** The USGBC should separate embodied energy and operational energy into separate LCA indicators.

- Construction Waste Management, Material Reuse, and Recycled Content credits interact symbiotically, but Regional Materials and Rapidly Renewable can be counter-productive. ***Recommendation:*** Keep MRc2 through c4 and replace MRc5 and c6 with a highly weighted embodied energy and emissions evaluation of the complete "cradle-to-gate" of the project. This would highlight the tremendous impact of transportation on low-embodied energy materials. Or, require that all rapidly renewables in MRc6 be obtained within 500 miles of the project to maintain the intent of MRc5.

- The required data collection for materials and transportation energy can be readily obtained from the bill of materials and existing shipping protocol (e.g., packing slips, etc.). ***Recommendation:*** Data collection for accurate quantification of material and transportation impacts associated with the embodied energy of materials should include the mass transported and ideally the location of major contributing manufacturers.

- Although only GHG emissions were considered/evaluated in this analysis to make a point, future development of USGBC LEED credits should consider/take into account other environmental factors/impacts beyond just GHG emissions.

About the Authors

Mark Reiner, PhD, PE, PG, LEED AP™ – Principal

Mark has been a Project Engineer and Design Engineer on a variety of governmental and private sector projects including the design, construction-related engineering, and review of superfund projects, water storage reservoirs, dams, and various geotechnical projects. He currently serves as an Adjunct Faculty at the University of Colorado at Denver and Health Sciences Center where he teaches a course on Urbanization in Developing Countries and conducts research related to a technology, environment, resource, and policy assessment of sustainable concrete in urban infrastructure. Mark has extensive international experience as the former Projects Director for Engineers Without Borders – USA and as Co-Lead on developing sustainable scenarios for the master infrastructure plan for Kigali/Rwamagana, Rwanda.

Mark Pitterle, PhD, MS, BS – Principal

Stressing applications of zero waste, waste-to-energy, and systems thinking, Mark has years of hands-on field and consulting experience in designing, construction, and installation of sustainable energy and water treatment systems. His efforts have focused on quantification of life cycle performance impacts as a means to establish what technologies are most sustainable for a given region and population. Mark has been involved internationally, designing and installing renewable energy systems for villages in Sri Lanka and India.

As part of his doctoral dissertation work, Mark worked with wastewater professionals in a participatory manner to develop sustainability metrics and an accepted life cycle quantification methodology of US wastewater treatment plants. Life cycle assessments (LCAs) were performed for wastewater treatment plants of different sizes and scales throughout the country to highlight advantages/disadvantages of centralized vs. decentralized systems and these conclusions will be used in future city planning activities. His dissertation is titled: *Evaluating and Enhancing Urban Wastewater System Sustainability*.

Mike Whitaker, PhD, MS, BS – Principal

Mike has extensive experience in the quantitative analysis of environmental projects and policies including developing detailed calculations with clear, concise explanations for the City and County of Denver's action plan for greenhouse gas reduction in the transportation sector. Mike has also used his life cycle assessment expertise to analyze the impacts of distributed electricity generation in California as part of a joint National Renewable Energy Laboratory/California Energy Commission study and to compare the life cycle greenhouse gas and energy use impacts of transit bus and electrified urban rail transit systems in the U.S. and India. In addition to living in Chennai, India while conducting the mass transit LCA, Mike has also traveled to Indian villages to develop sustainable energy systems and researched urban environmental sustainability in the developing world while at the National Academy of Sciences.

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