# Industrial Ecology for a Sustainable Future

Royal Institute of Technology
Stockholm

12 - 15 June 2005

# Welcome to Stockholm and the 3rd International Conference

# Industrial Ecology for a Sustainable Future

**The ISIE-2005 conference** highlights the contributions that industrial ecology can make towards attaining a sustainable future for the planet and its population. The conference provides a forum to introduce theoretical advances and to discuss practical experience, to learn about IE modelling and to explore the human dimensions of applying IE in corporate, public policy, and consumer decision making.

The conference in Stockholm 2005 is a major event in the history of Industrial Ecology. There has been an overwhelming response to the ISIE-2005 conference, which will guarantee an event of very high interest. The ISIE Governing Council, Organizing Committee, and Technical Committee, thank you for joining us at the ISIE-2005 conference.

The conference will take place in the Swedish capital, Stockholm - a city built on 14 islands. Well-preserved medieval buildings stand alongside modern architecture. Stockholm is a city of contrasts – land and sea, history and innovation, a small town and a big city, and long, light summer evenings in June. All this leaves the visitor with a wonderful variety of impressions.

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Dr. René van Berkel, Centre of Excellence in Cleaner Production, Curtin University of Technology, Perth, Australia

## ISIE Contact Information

The International Society of Industrial Ecology
c/o Yale School of Forestry and Environmental Studies
205 Prospect Street
New Haven, CT 06511-2189 | U.S.A.

Phone: (203) 436-4835
Fax: (203) 432-5912
Email: is4ie@yale.edu
URL : http://www.is4ie.org/

# An Integrated LCA-LCC Model for Evaluating Concrete Infrastructure Sustainability

*Alissa Kendall[1#], Gregory Keoleian[1], and Richard Chandler[1]*
*[1]Center for Sustainable Systems, University of Michigan, Ann Arbor, MI, USA.*
*[#]Corresponding Author (kendalla@umich.edu)*

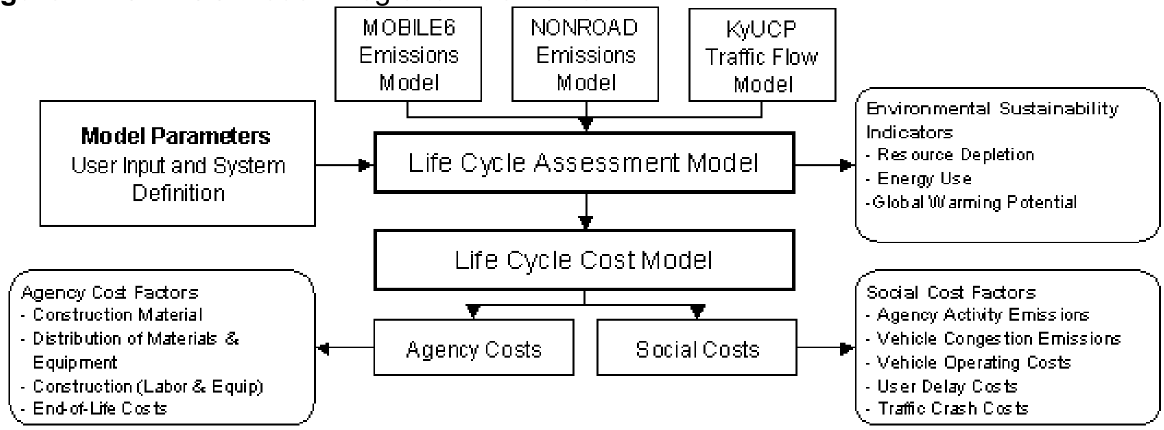
Cement, the key binding material in concrete, is vital to human infrastructure and the economy. We rely on its durability and versatility to build our roads, bridges, buildings and water and sewage systems. Despite its important role in our built environment, its production contributes a significant amount of carbon dioxide ($CO_2$), a greenhouse gas, to the atmosphere; approximately 5% of total anthropogenic emissions[1], and is one of the top two industry producers of $CO_2$.[2] Global flows of concrete amount to approximately 2 tonnes per person on the planet[3], and in the Unites States amounts to flows greater than 1,600 million metric tonnes (Mt) each year. Of total U.S. consumption, approximately 31% is used to build and rehabilitate highways and roads[4]. Despite this investment, an estimated one-third of U.S. roadways are in poor or mediocre condition, burdening the public with construction related impacts such as congestion and vehicle damage.[5, 6]

Long-term environmental and economic impacts of infrastructure design and material selection are modeled as part of a five-year NSF MUSES[7] project whose goal is to enhance the life cycle management of concrete infrastructure by developing a holistic approach for modeling. In the first phase of this research, an integrated life cycle assessment (LCA) and life cycle cost (LCC) model was developed to simulate construction and rehabilitation processes and traffic flow over the full service life of a bridge deck. This model is applied to two alternative concrete bridge deck designs: one a conventional steel reinforced concrete (SRC) deck with mechanical steel expansion joints, and the other an SRC deck with engineered cementitious composite (ECC) link slabs. Figure 1 shows the LCA-LCC model integration framework. This dynamic LCA-LCC model includes over 100 user-defined parameters and incorporates a traffic congestion model, the Kentucky Transportation Center's KyUCP model; and two

[1] WBCSD. (2002). "Toward a Sustainable Cement Industry. Draft report for World Business Council on Sustainable Development." Battelle Memorial Institute.
[2] van Oss, H. G., and Padovani, A. C. (2003). "Cement Manufacture and the Environment, Part II: Environmental Challenges and Opportunities." *Journal of Industrial Ecology*, 7(1), 93-126.
[3] van Oss, H. G., and Padovani, A. C. (2002). "Cement Manufacture and the Environment. Part I: Chemistry and Technology." *Journal of Industrial Ecology*, 6(1), 89-105.
[4] Portland Cement Association, P., "2000 Apparent Use of Cement by Market", October 11, 2004. http://www.cement.org/market/.
[5] TRIP, "Key Facts About America's Road and Bridge Conditions and Federal Funding." March 2002, The Road Information Program (TRIP). http://www.tripnet.org/nationalfactsheet.htm
[6] ASCE. (2001). "Renewing America's Infrastructure: A Citizen's Guide." American Society of Civil Engineers, Washington, D.C.
[7] Materials Use: Science, Engineering, and the Society (MUSES) is part of the National Science Foundation's Biocomplexity in the Environment Program.

emissions models, the U.S. Environmental Protection Agency's (USEPA) MOBILE6.2 emissions model for assessing vehicle emissions, and USEPA's NONROAD emissions and fuel use model to evaluate construction equipment impacts. The integrated model accounts for changes in vehicle and equipment emissions, and changes in traffic flow rate patterns over the bridge deck lifetime.

**Figure 1**. LCA-LCC Model Integration Framework




Results from the LCA model provide a set of environmental sustainability indicators that also serve as key inputs to the LCC model. The LCC model accounts for both agency and social costs. Agency costs consist of material, construction, and end-of-life costs. Social costs are comprised of emissions damage costs from agency activities, vehicle congestion, user delay, vehicle crash, and vehicle operating costs.

The two design alternatives are evaluated over a 60-year time horizon: the ECC link slab system is modeled with a 60-year service life, while the conventional joint system requires two bridge decks each lasting 30-years. Over this time period the ECC link slab system shows significant benefits in environmental performance relative to the conventional joint system, despite that ECC material is more energy intensive than conventional concrete on a per-volume basis. Results show that the ECC link slab system consumes 40% less total primary energy, produces 39% less carbon dioxide, and consumes an average of 38% less of key natural resources such as coal, limestone, and water. Construction related traffic dominates model results. For a 0% traffic growth scenario, construction related traffic energy (shown as Δ Traffic in Figure 2) comprises 80% of total primary energy consumed by the conventional system and 85% of total primary energy consumed by the ECC system. Construction related traffic also dominates results for the majority of air emissions including; hydrocarbons, carbon monoxide, methane, and greenhouse gas emissions.

As with the LCA model, the LCC model shows that user-related costs such as time lost to motorists and commercial trucks due to construction related congestion dominate the total life cycle costs calculated in the model. In fact user costs, led primarily by the costs of delays from construction-related traffic congestion, account for 99% of costs in the ECC design system and 98% of costs in the conventional design system. Overall, however, the ECC system has an approximate cost advantage of 15% over the conventional system.

**Figure 2.** Lifecycle Energy Use and Cost for the ECC Link Slab and Conventional Bridge Deck Designs