



research

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Environmental Life-Cycle Assessment

Public awareness of everyone from consumers to professionals has elevated the importance of responsibly managing energy and environmental resources. Labels such as “environmentally friendly” or “green” are key phrases in marketing campaigns. Environmental life cycle assessment (LCA) is a detailed, extensive tool used to systematically evaluate the environmental impacts of a product or system. An LCA considers environmental impacts from all possible sources—extraction of raw materials, manufacture, service life, and demolition. This all-encompassing time period of consideration is sometimes called “from cradle-to-grave.” Using LCA, a qualitative assessment can be made of a product’s “environmental friendliness” or “greenness.” Environmental life cycle assessment is gaining popularity because more decision makers are requiring that products be functional, cost-effective, and environmentally friendly.

The following organizations have or are developing environmental life cycle assessment procedures:

- **U.S. Environmental Protection Agency**, “Life-Cycle Assessment: Inventory Guidelines and Principles,” EPA Document No. EPA/600/R-92/245.
- **Canadian Standards Association**, “Life Cycle Assessment,” Publication No. Z760-94 and “User’s Guide to Life Cycle Assessment: Conceptual LCA in Practice,” Publication No. PLUS 1107.
- **International Standards Association (ISO)**: Draft International Standard ISO/DIS 14040 “Environmental Management - Life Cycle Assessment — Principles and Framework.”
- **American Society for Testing and Materials (ASTM)**, Subcommittee E50.06.01 on Life Cycle Assessment of Building Materials: Draft “New Standard Guide for Environmental Life Cycle Assessment of Materials/Products.”

PURPOSE

The purpose of an LCA depends on the viewpoint of the user, but generally falls into one of four categories:

- To aid consumers, owners, and decision makers in comparing products and determining those that have the least negative impact on the environment.
- To aid manufacturers in determining methods, processes, or products that would have the least negative impact on the environment.
- To aid decision makers, such as governmental bodies, in determining which products are the result of processes that have unacceptable environmental impacts. For instance, many governments now agree that depletion of the ozone layer is unacceptable. Many societies have operated under the premise that humans have dominion over other life forms and many aspects of the environment. The current viewpoint calls for more balance between people and the environment.
- To determine requirements for a sustainable environment. This includes limiting resource use to a natural rate of replenishment, limiting air pollution and waste materials to the amount absorbed by the environment without negative impacts, and considering the environmental legacy we leave to future generations.

SETAC-BASED PROCEDURES

Several organizations have or are developing SETAC-based procedures for performing an environmental life cycle assessment. The Society of Environmental Toxicology and Chemistry (SETAC) procedures are divided





into three major phases: inventory, impact assessment, and evaluation.

Inventory Phase

The goal of the inventory phase is to determine quantities of all materials, energy, and pollutants that contribute to the product or system being investigated. These data must be assembled for all life cycle stages. For example, since concrete consists of cement, water, aggregate, and chemical admixtures, a concrete wall has these life cycle stages:

- Extraction of raw materials
- Manufacture of portland cement and admixtures; processing of aggregates
- Transportation of cement, aggregates, and other constituent materials to ready-mix plant
- Preparation of concrete at ready-mix plant and placement of concrete at site
- Use and maintenance of a concrete wall for its life
- Demolition, recycling, and waste at the end of useful life

To complete the inventory, the following information is summarized for all life cycle stages for the product or system being investigated:

- Energy use
- Raw material and fuel use
- Air pollutants
- Solid waste
- Water use and pollutants

The quantities developed for the inventory phase of one system can be compared to those developed for competing systems. In our example, the concrete wall could be compared to a masonry or metal frame wall.

The inventory phase is limited because it compares, for example, the Btu's of energy or tons of pollutants without considering the environmental impacts of the energy or pollutants. Using the inventory, comparisons cannot be made between products or systems that use dissimilar items. For instance, the environmental impact of a product with a high energy use cannot be compared to one with a high material use, since there are no common units of measure or relative weighting factors comparing energy and raw material use.

Since LCA is a complex and newly

evolving topic, at this time only the inventory step is well defined. Computer models are being developed to process inventory data so competing products can be compared. However, models must be populated with accurate data in order to be useful.

A common error for computer modelers and users is to assume concrete and cement are the same. Cement is the most energy intensive, and therefore has the greatest environmental impact, of the constituent materials of concrete. However, cement only represents 10% to 15% of the total mass of concrete. Assuming a ton of concrete has the same inventory as a ton of cement erroneously penalizes concrete by as much as 1000%. The concrete industry is working on ways to minimize these potentially devastating modeling errors.

Inventory Data for Cement and Concrete. The Portland Cement Association (PCA) is currently reviewing data it has compiled for the environmental life cycle inventory (LCI) of portland cement. This includes data from the time materials are quarried until cement is loaded at the plant for bulk shipment. LCI's have been completed for four common types of kilns used to manufacture portland cement, and generally follow guidelines of SETAC. PCA intends to make these data available for LCI computer models. Plans for the remainder of 1997 include developing inventory data for the other constituent materials in concrete. With coordination through PCA and the Environmental Council of Concrete Organizations (ECCO), other material interests are participating in developing these data.

Battelle Inventory Model. Battelle Pacific Northwest Laboratories, under a subcontract with the U.S. Department of Energy, is developing an inventory model, "Life-Cycle Assessment Modeling System." The program has a format allowing the input of LCI data for each step of any process or product. The model allows the user to piece together process steps so results of the inventory can be summarized for prescribed scenarios.

Battelle is working with major industries to populate the model with their inventory data. PCA, representing the cement industry, is a member of the Core Industrial Guidance Group that has worked with Battelle in developing the model. Members of the Guidance Group, including PCA, beta-tested the Battelle

model during 1996, but it is not yet fully functional or available for distribution.

Impact Assessment Phase

The intent of the impact assessment phase is to characterize and assess the environmental impacts of the energy use, depleted resources, and pollutants identified in the inventory phase. These include the effects on human health and the earth's ecological system. For example, this phase would identify diseases caused by pollutants, extinctions caused by warming or cooling rivers and lakes, or contributions to ozone depletion. The methodology for impact assessment is under development and no generally accepted method has evolved.

Evaluation Phase

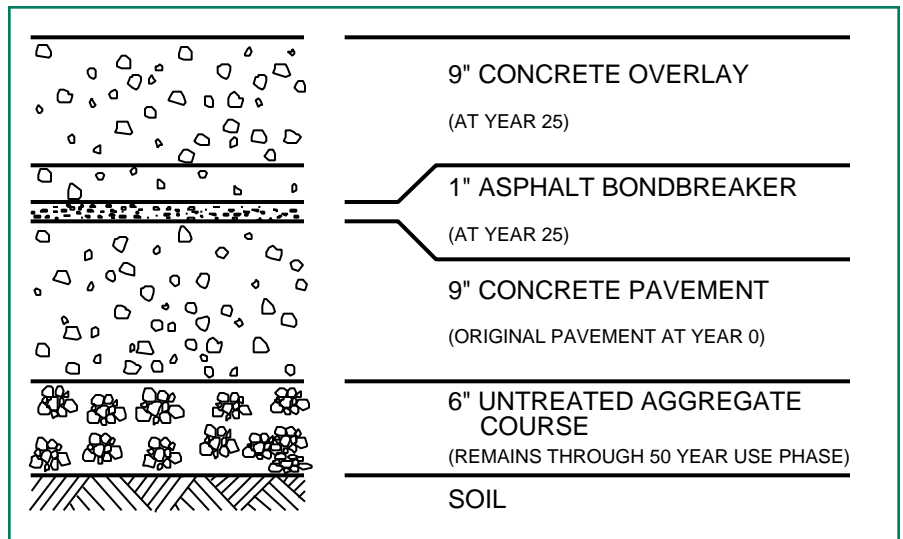
The evaluation phase assigns weights to the impacts so competing systems can be compared. For instance, this phase assigns values for contracting cancer, species extinction, and resource depletion that can be measured on the same relative scale. This phase is needed because competing products cannot be compared without a weighting system to compare different environmental impacts.

The evaluation phase is the least defined and is much more subjective than the other phases. The choice and use of a weighting system to compare different environmental impacts may have large subjective components. The weights assigned to impacts will be influenced by the values and opinions of the modelers and stakeholders.

ENVIRONMENTAL VALUE ENGINEERING (EVE) LIFE CYCLE ASSESSMENT

The environmental value engineering (EVE) life cycle assessment, first applied to the construction industry by Dr. Wilfred Roudebush, provides a method of comparing life cycle assessments of competing materials. Although SETAC-based life cycle inventory methods have emerged as the most popular first step in a life cycle assessment for the American and European markets, these models include only an inventory and cannot be used to compare competing products.

Dr. Roudebush uses EVE assessment developed by Dr. Odum at the University of



Florida. EVE evaluates the environmental contribution and impact of built environment alternatives over their life cycle in units of solar EMERGY. Solar EMERGY is the solar energy required to directly or indirectly make a product or service. The units for solar EMERGY are solar emjoules (SEJ). The EVE analysis includes the contributions of the environment, fuel energy, goods, and services (labor). The effects of these contributions are converted to a common unit of energy, the solar emjoule, which EVE uses as the unit of measure to weight environmental impacts.

A concrete pavement system is evaluated over a fifty year period.

EVE of Concrete Pavement

Dr. Roudebush has performed an EVE assessment of portland cement concrete pavement for a 50-year time period. For his analysis, 9-in. thick portland cement concrete is placed on 6-in. aggregate base. After 25 years, the pavement is resurfaced with a 1-in. asphalt concrete bond breaker and a 9-in. portland cement concrete overlay. The pavement is 24-feet wide.

The emergy analysis includes ten life cycle phases for a system: natural resource formation (A), natural resource exploration and extraction (B), material production (C), design (D), component production (E), construction (F), use (G), demolition (H), natural resource recycling (I), and disposal (J). For this project, the environmental contribution of design was not considered. The component production phase (E) has a zero value because the manufacture of portland cement was included in the material production phase (C) and the mixing and placing of concrete is included in the construction phase (F).





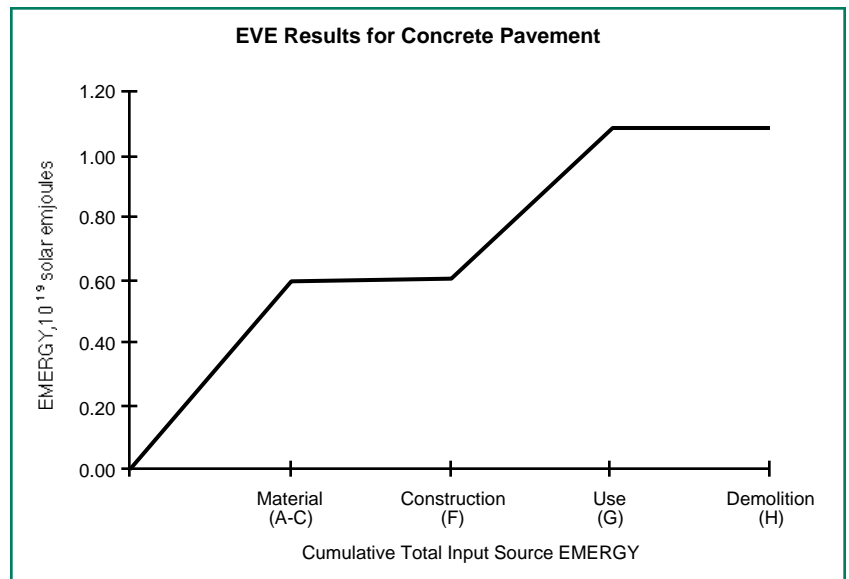
Demolition material is assumed to be recycled and therefore disposal also has a zero value for this analysis.

EVE Results

The EVE results indicate portland cement concrete uses the most EMERGY in the material (A-C) and use (G) phases. (see figures)

The large components of EMERGY in the material phase are the EMERGY of the aggregate used to make portland cement, the manufacturing of portland cement, and the aggregate in the concrete and base. These same components for the bond breaker and overlay contribute to the relatively large EMERGY of the use phase.

While the EVE method allows comparison of competing products, it is relatively new and has not received wide dissemination or use. Using EMERGY as the unit for weighting environmental impacts may not



coincide with weighting factors perceived by consumers or industries.

EVOLUTION OF LCA

Environmental life cycle assessment methods are relatively new and evolving. Methods are needed to compare the environmental impacts of competing products, but need to be peer reviewed and generally accepted by major industries. No comparative method meets these requirements at this time.

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the Environmental Council of Concrete Organizations

The Environmental Council of Concrete Organizations is a coalition dedicated to promoting the environmental benefits of concrete and its role in safe and sustainable construction.

ECCO members are companies, organizations, and individuals affiliated with the concrete industry.

Together, they are committed to developing and disseminating information on the environmental benefits of concrete and concrete products.