

# Environmental life cycle inventory of Portland cement and concrete

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## Abstract

Life Cycle Assessment (LCA) is a systematic method for compiling and examining the inputs and outputs of energy and materials and the environmental impacts directly attributable to the manufacture and functioning of a product or service system throughout its life cycle.

Life Cycle Inventory (LCI) is a systematic inventory of the inputs and outputs of energy and materials and emissions directly attributable to the manufacturing and functioning of a product throughout its life cycle.

The Portland Cement Association (PCA) is developing LCI and LCA data for use in evaluating environmental aspects of concrete products, and for comparing concrete with competing building materials. The data is being collected according to recognised guidelines with a clear definition of: the system boundaries, data sources and quality, process steps and product use.

## Introduction

Life cycle cost analysis is an accepted way of comparing products or services. In this procedure, the costs of manufacturing the competing products are estimated. The costs of maintaining them throughout their service life are added, and, if information is available, the cost of recycling or final disposal of the products is included. The sum of these costs, expressed in terms of present value, becomes an input to the product selection process.

Environmental life cycle assessment (LCA) takes a parallel approach. However, instead of looking at costs, it evaluates the energy, material and environmental consequences associated with a product or service. For example, the LCA of a Portland cement concrete road takes into account the raw materials and energy

used in making the cement as well as the emissions from the cement manufacturing process. It includes the energy and resources consumed in mixing, transporting and placing the concrete, and also the materials used in repair and maintenance of the road. Finally, it includes the energy and environmental consequences of recycling or disposal of the concrete at the end of the road's life.

LCA, defined in more formal terms, is a systematic way of evaluating the environmental impacts arising from resource depletion and process emissions associated with a product or service. It considers the environmental impact of a product during its life cycle: starting with raw material acquisition, through production and use, and finally disposal. The general categories of environmental impact to be considered include resource depletion, human health and ecological consequences.

The LCA process consists of three stages (Figure 1).

The methodology for conducting LCIs is relatively well documented. However, the methodology for conducting the impact assessment is still in the development stage, being worked on by organisations such as the Society of Environmental Toxicology and Chemistry (SETAC) and the International Organisation for Standardisation (ISO).

## Uses of LCAs

Traditional methods of comparing competing products are based on cost and performance. Increasing concern over improving the sustainability of industrial operations has started to bring the question of resource depletion and environmental impact into product selection. LCAs offer a structured way of introducing these considerations into decision making processes such as selection of a building material from a number of alternatives, or choice of a manufacturing process.

In general, the potential uses of LCAs internally for an organisation include:

- Environmental strategy development.
- Product and process design, improvement and optimisation.
- Identification of opportunities for environmental improvement.
- Environmental auditing and waste minimisation.

and externally for an organisation:

- Comparison of competing products or services.
- Environmental claims in support of marketing.
- Eco-labelling.
- Advocacy.
- Public education and communication.

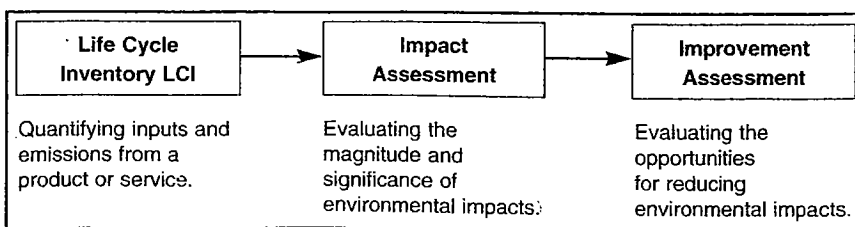


Figure 1. The three stages of the LCA process.

**Standardisation of LCA methodology**

If claims are to be made about how one product compares to another, the comparison must be based on analyses conducted using the same set of rules. At present there are no comprehensive standards for LCAs and the standards for LCIs, though documented, are still at the draft stage.

In addition to using a structured approach, there must be sufficient data available and the quality of the data must be good enough to support a detailed life cycle analysis. Poor quality data limits the external uses of an LCA. For example it may be impossible to compare two competing products if the data for one of the products is not sufficiently representative or accurate.

The general data quality requirements include a definition of geographic coverage meaning the geographical area from which the data are drawn (regional, national, continental or international). Another general requirement is technology coverage which defines the technology mix, for example whether it is a weighted average of existing processes or best available technology. When the purpose of the study is to make a public product comparison, data quality should be assessed based on the following indicators:

- Accuracy: the conformity of a indicated value to an accepted value. For many LCA data no accepted standard value is available. In such cases the applicability of accuracy as a data quality indicator is limited.
- Currency: the period which the data covers and how current it is, e.g. 1990-1995.
- Precision: measure of the variability of the data expressed as a mean and variance for a unit process.
- Representativeness: qualitative assessment of the degree to which the data set reflects the population of interest.
- Consistency: qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis.
- Reproducibility: qualitative assessment of the extent to which information about the methodology and data values allows an independent individual to reproduce the results reported in the study.

The LCA process makes provision for a critical review of the findings. The

degree to which a critical review is required, and how it should be done, depends on the purpose of the LCA. If the LCA is to be used for comparative claims that are made public, an in depth review is essential in order to ensure:

- The scientific and technical validity of the methods used in the LCA.
- The quality of the data in relation to the goal of the LCA.
- The validity of the LCA conclusions based on the limitations identified in the study.
- The transparency and consistency of the study.

**The PCA's LCA project**

The PCA is in the process of developing an environmental LCA of Portland cement concrete. The ultimate goal of the work is to have a complete and accurate information base to be used to compare Portland cement concrete with competing products.

The Portland Cement Concrete LCA project is following the guidelines proposed by the SETAC. These guidelines parallel the draft standards proposed by ISO in 14040 'Environmental Management - Life Cycle Assessment - Principles and Framework' and other ISO draft documents.

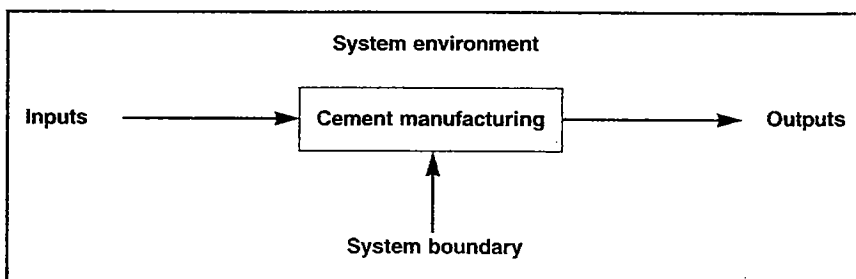
Since the methodology for conducting the impact assessment stage

- Roads made of Portland cement concrete and asphalt concrete.
- Homes made primarily of concrete (basement, walls, roof) with homes made from competing materials.
- Adjustments in concrete mix design for including recycled materials.

**LCI of cement manufacturing**

The product or service being inventoried is described as a system which performs a defined function. The system is separated from its surroundings by a system boundary. The region outside the boundary is referred to as the system environment. Materials and energy flow from the environment into the system; and outputs, products and emissions, flow from the system into the environment.

The system boundary in the cement manufacturing LCI is drawn to include all operations from the quarry to the plant gate. This gives a clearly defined unit for which good quality data is available from PCA surveys, PCA emission data bases and from member companies. In cases where a quarry is not contiguous with the plant, the quarry is still regarded as being included within the boundary but having an extended transportation link (Figure 2).



**Figure 2. The LCI for cement manufacturing.**

of an LCA is not well established, the PCA project started by preparation of an LCI of the cement manufacturing process. The next step is development of LCIs for concrete products, such as ready mix of selected compressive strengths and concrete block, and from there to LCIs of concrete structures, such as walls, roads or bridges.

The database developed by the project should allow, for example, a comparison of:

- Structural components, such as concrete walls, with walls of alternative materials.

In compiling the inputs, the system is divided into unit operations each taking as inputs the outputs from an upstream operation. The cement manufacturing process, for example, has been divided into four steps (Figure 3).

Representative data covering inputs of energy and materials and outputs including products and releases to air, water and land, are collected for each process step. The cement LCI used, for the most part, primary data, meaning that from operating companies. If primary data are not available, secondary data can be used. This would include information

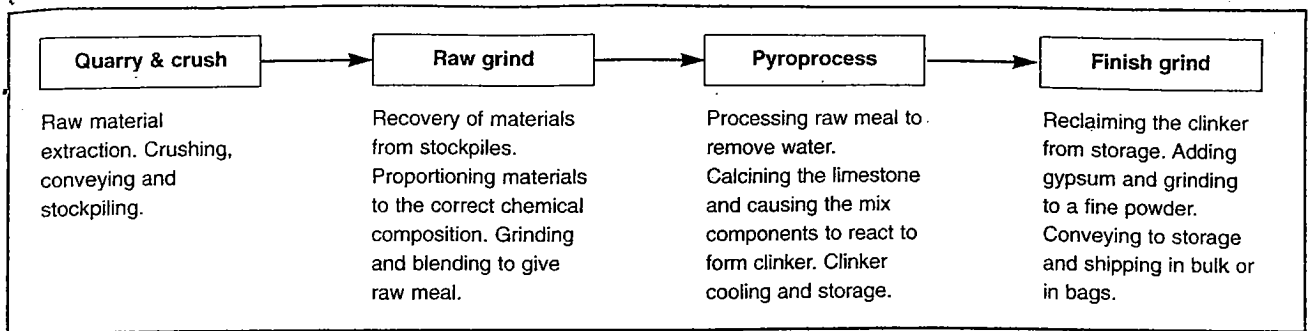


Figure 3. The process steps of the cement manufacturing LCI.

from equipment vendors, public sources and commercial data bases, and estimates from similar operations.

The PCA's 'Labour and Energy Survey' provided data on energy inputs. Data on inputs of raw materials were obtained by a questionnaire sent to PCA member companies. The questionnaire also gathered information on the transportation distances for purchased materials such as coal and coke. This information is necessary in order to estimate the amount of transportation energy used in manufacturing a ton of cement. A PCA data base supplied emission data for the kiln stack. Estimates of other emissions from plant sources, including, for example, conveyor transfer points, milling operations, and crushers, were made from the U.S. Environmental Protection Agency AP-42 emission factors.

The LCI includes, as an input, the energy used in delivering purchased materials to the plant but does not include the energy to extract or manufacture them. For example, the resources consumed in mining, cleaning and loading coal and the emissions from the mine site are outside the cement LCI system boundary. The same applies to resources and emissions involved in the generation of electricity. The upstream profiles of these inputs are available and can be added to the cement manufacturing LCI by means of programmes like the Batelle Life Cycle Computer Aided Data Project (LCAD).

Inputs and emissions were estimated as lbs/t of cement for wet, dry, preheater and precalciner kilns and as a weighted average. The weighted average represents inputs and emissions from the average ton of cement manufactured in the U.S..

### Concrete products LCI

The initial LCI covers a number of concrete mixes over a range of compressive strengths and concrete block.

It will be extended to include selected concrete products, and subsequently selected structures.

The boundaries of the system include quarrying and transportation of aggregates to the plant site, and all the activities within the ready-mix plant, up to the time when the product is ready for shipment. The boundaries also include transportation of cement, admixtures and cementitious materials from their source to the ready-mix plant. Setting the boundary at the plant gate means that transportation of concrete to the customer is not included in the LCI.

The process is viewed as consisting of four steps:

- Quarry and crushing.
- Materials receiving and storage.
- Batching.
- Mixing and loadout.
- Truck wash off.

Emptying and washing out trucks returning to the ready-mix plant is not strictly part of the production process, but is a related step. Inputs and emissions from this activity will be estimated separately and allocated to concrete production.

Data from the cement manufacturing LCI is a primary input to the concrete products LCI. Data on the inputs of other materials and energy consumption are from operating companies and published sources. Estimates of emissions and water effluents are from tests, published reports or AP-42 emission factors.

### The Batelle Life Cycle Computer Aided Data (LCAD) project

In order to help standardise the LCA process, Batelle is developing a computer model that supports the management, control and manipulation of life cycle data. The LCAD is designed to address two difficulties hindering wider scale application of LCA. These are lack of standardised LCA tools and

lack of standardised data sets.

The specific goals of the Batelle project are:

- To develop a computer modelling system that supports the management, control and manipulation of life cycle data.
- To collect, store and disseminate energy and environmental data for industrial commodities such as primary metals, bulk chemicals, forest products, cement, coal etc.

The PCA has co-operated with the development of the Batelle LCAD, and has the option to use the model if it is suitable for the project's needs. The PCA beta tested the production version in June 1996 using preliminary cement process input and emission data. Comments and recommendations were returned to Batelle for inclusion in the final revised version of the software. A fully functional version of the model is expected during 1997.

### Conclusion

The PCA life cycle analysis project will result in a comprehensive information base which initially will consist of life cycle inventories of Portland cement manufacture, concrete products and concrete structures. It is being pursued in phases so that information on impact assessment can be added when the methodology and data are available. The work is being conducted according to accepted standards and will be subject to critical review. This is to ensure that comparisons between Portland cement concrete and other construction materials will be fair and unbiased. The results are expected to demonstrate that concrete products are not only cost-effective construction materials, but also make good use of resources in the context of an acceptable and sustainable environmental impact during their life cycles.