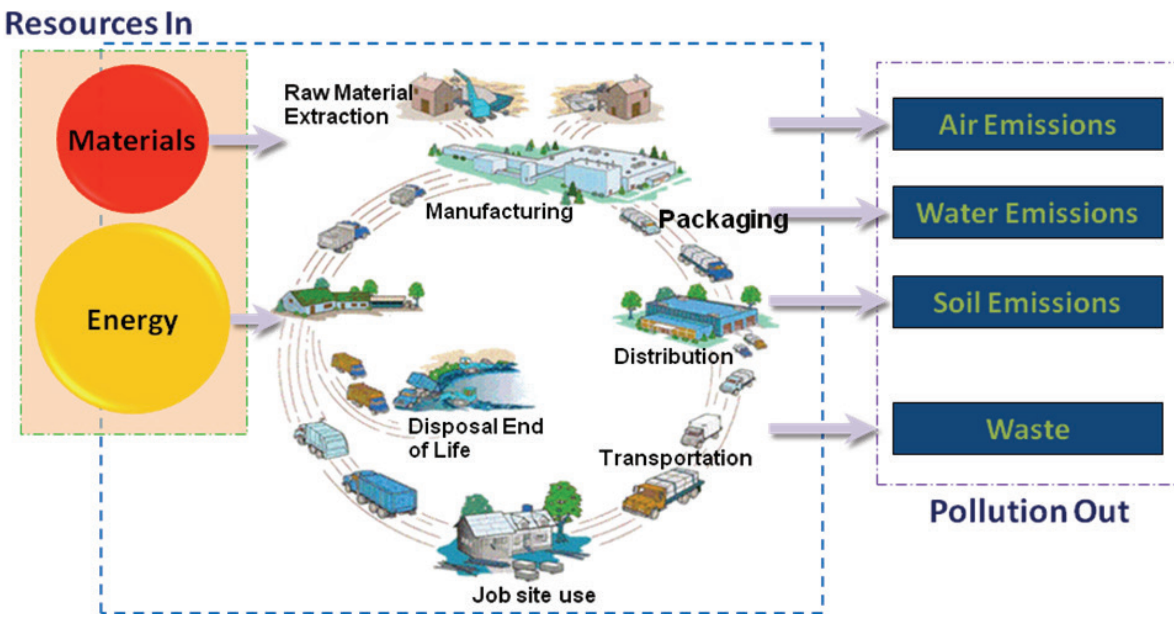
LCA (Life Cycle Assessment)

What are they?

Manufacture of any product will have positive and negative impacts on the environment and future generations. The scientific review of these impacts is referred to as the Life Cycle Assessment (LCA) of that product. LCA is the inventory of all inputs and outputs across all stages of a product. The product can be as simple as a building product, system or whole building. This review must be analyzed throughout all stages of the product's life from first creation or extraction of all raw materials, raw material transportation, manufacturing, packaging, distribution, use, service life and maintenance, end-of-life removal, disposal or recycling or reuse of this product.



A simpler way to say this is that LCA is the scientific method to review everything going into the production, use and disposal of a product, all its impacts on the environment along the way, and what is left over and their impacts.

The impacts that are evaluated are selected from the list of LCA Impacts based on the product type and can change from one product type to another. For example, with most building materials ***Global Warming*** (Carbon Footprint), ***Wastes, Ground Level Ozone*** (Smog), ***Acidification*** (increased acid to air, water or soil), ***Eutrophication*** (increased fertilizers and detergents into our water supplies) and ***Primary Energy*** (Embodied Energy) are usually the key impacts for review. These impacts are required for all construction materials, systems and service of a whole building LCA. Human Health is an impact just beginning to be evaluated from a scientific standpoint and will continue to evolve over the next several years. We need not only to better understand the effect of material exposure, but also understand various absorption rates per types of exposure and safe harbor limits of trace elements.

Other impacts may be selected based on how much effect the product will have on the value or not. For example, a drywall LCA may not select mineral depletion since gypsum, the main raw material used in the production of drywall, is defined as a "***Perpetual Resource***" per ASTM E2114. A ***Perpetual Resource*** is a resource that is virtually inexhaustible on a human time scale or at a minimum will last over 700 years of consumption. Examples include solar energy, tidal energy and wind energy. Mineral examples include gypsum, salt and limestone.

Scope of LCAs

In most cases, the impacts contributed from each stage of the LCA are uneven, that is, one or two of the stages may dominate the assessment. For example, in the manufacture of aluminum products it is mining of the materials, purification of the ore and chemical reduction of the aluminum into metal that creates the largest environmental impacts. Subsequent usage of aluminum products by consumers contributes very few impacts, although the recycling of aluminum is an important step in reducing the consumption of primary materials and energy. In contrast, for internal combustion-powered automobiles, usage by consumers creates 70-80% of the life cycle impacts. Thus, it is not always necessary that the LCA include all stages of analysis since in many cases it is only a portion of the product/service life that is of interest. Often there is not enough information to include all life cycle stages anyway. For this reason there are certain characteristic terminologies for various "scopes" of LCAs that have emerged:

– Cradle-to-Grave—is the full LCA from resource extraction (cradle) through use and disposal (grave).

– Cradle-to-Gate—is a partial product LCA from cradle to factory gate, before the product is shipped to customers.

– Cradle-to-Cradle—is a variant of Cradle-to-Grave where the final step is recycling rather than disposal.

ISO 14040 Life Cycle Assessment - Principles and Guidelines.

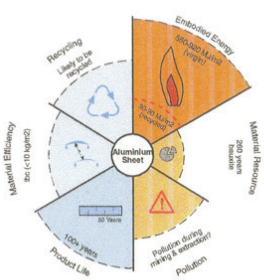
Who uses LCAs and how?

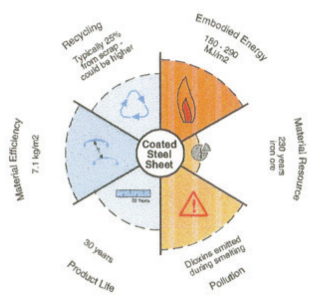
Whether using Cradle-to-Grave or Gate-to-Gate evaluations, LCAs are a great method of understanding the environmental impacts of a product. Historic single attribute metrics used for declaring product environmental benefits can be very misleading. For example, is a product with high Rapidly Renewing content that only last in an application for 10 years better than a material having a growth cycle of 40 years but a service life in the same application of 60 years? Using LCA studies, the longer service life product may yield results that are better across many impacts.

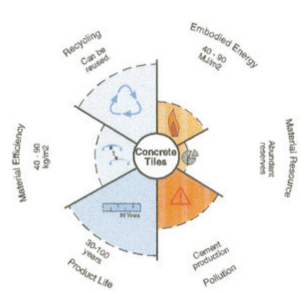
The following are just a few examples of how one company might use an LCA study and how it may assist in better product selection. If you wanted to substitute one of the raw materials of a product, you may want to use Cradle-to-Gate since the final product will have similar or the same transportation, installation methods, service life, deconstruction and waste diversion methods and impacts.

Another example: if you chose a new aggregate material for use in concrete for the construction of a building and this new aggregate was a waste stream material which would be landfilled if not used, you would want to know the comparative environmental impacts of the new and old aggregates.

In order to better understand the impacts of three different types of materials for the same application, you may want to use LCA studies of the different materials. Below are examples of three materials used in the same roof application:







Scope of LCAs

Using the graphs above, the aluminum roof would have the greatest product or service life but also have the highest embodied energy, while the concrete roof would have the best positive and least negative impacts overall. Therefore if the service life is acceptable at 30 to 100 years, concrete would be the best solution using Cradle-to-Gate review.

In addition, LCAs showing specific impacts such as embodied energy and carbon footprint of various assemblies may indicate the best choice of assembly type for your design solution (see a simple comparison below), assuming similar performance of other non-environmental attributes:

Buildings Energy Data Book: 1.6 Embodied Energy of Building Assemblies *March 2011*

1.6.6 Embodied Energy of Commercial Interior Wall Assemblies in the U.S.

Interior Wall Type (2)	Embodied Energy (MMBtu/SF) (1)	CO2 Equivalent Emissions (lbs/SF)
2x4 wood stud (16" OC) + gypsum board (3)	0.03	2.84
2x4 wood stud (24" OC) + gypsum board (3)	0.03	2.78
2x4 wood stud (24" OC) + 2 gypsum boards (4)	0.04	4.45
Steel stud (16" OC) + gypsum board (4)	0.04	3.99
Steel stud (24" OC) + gypsum board (4)	0.04	3.64
Steel stud (24" OC) + 2 gypsum boards	0.05	5.31
6" Concrete block + gypsum board	0.21	34.02
6" Concrete block	0.19	32.34
Clay brick (4") unpainted	0.05	6.97

Note(s): Assumptions: Values are general estimations for the U.S. 60 year building lifetime. Low rise building. 1) Embodied Energy: Energy use includes extraction, processing, transportation, construction, and disposal of each material. 2) All interior walls include two coats of latex paint unless noted otherwise. 3) Rounding obscures difference in embodied energy figures: wood stud with 16" OC is 3.6% higher than wood stud with 24" OC. 4) Rounding obscures difference in embodied energy figure: wood stud wall is 19.9% higher than steel stud wall with 16" OC and 27.6% higher than steel stud wall with 24" OC.

Source(s): Athena Institute. Athena EcoCalculator for Assemblies v.3.5.2. 2010. Available at www.athenasmi.org/tools/ecoCalculator/index.html

These are just a few of the many examples of the benefits of LCA studies. This gives a simplified overview of what they are and how we might use them to improve manufacturing and construction and better educate us on impacts and trade-offs of material selections.

Life Cycle Impact Categories

Typical environmental impacts, assessed throughout the building product's life cycle—including raw material extraction, transportation, manufacturing, packaging use, and disposal at end of life are listed below.

- Global Warming Potential (GWP): refers to long term changes in global weather patterns—including temperature and precipitation that are caused by increased concentrations of greenhouse gases in the atmosphere. GWP will be based on equivalency basis relative to CO_2-in kg or tons CO_2 equivalent.
- Acidification Potential (AP): acidification is a more regional rather than global impact affecting fresh water and forests as well as human health when high concentrations of SO_2 are attained. Acidification is a result of processes that contribute to increased acidity of water and soil systems. Acid rain generally reduces the alkalinity of lakes. The AP of an air emission is calculated on the basis of the number of H+ ions that can be produced and therefore is expressed as potential H+ equivalents on a mass basis.
- Photochemical Ozone/ summer smog Creation Potential (POCP): Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NOX). The POCP indicator is expressed as a mass of equivalent NOX.

  OR

  POCP happens when sunlight reacts with hydrocarbons, nitrogen oxides, and volatile organic compounds, to produce a type of air pollution known as smog.

– Eutrophication Potential (EP): Eutrophication is the effect due to fertilization of surface waters by nutrients (such as Nitrogen, Potassium and Phosphorus) that were previously scarce. When a previously scarce or limiting nutrient is added to a water body it leads to the proliferation of aquatic photosynthetic plant life. This may lead to a chain of further consequences ranging from foul odors to the death of fish. The result is expressed on an equivalent mass of Nitrogen (N) basis.

– Ozone Depletion Potential (ODP): is the destruction of the stratospheric ozone layer, which shields the earth from ultraviolet radiation that's harmful to life, caused by human made air pollution. The ODP indicator is measured as a mass of equivalent CFC-11.

Note: Absent from list above is any impact category dealing with water effluent and solid waste production. And while it accounts for fossil fuel depletion (on a global scale), it does not readily report primary energy use an impact category.

Water consumption, solid waste and primary energy are all key impact indicators over which the building products industry is likely to assert a considerable level of control and thus are good internal targets for resource conservation.

Total Primary Energy is the sum of all energy sources, which are drawn directly from the earth such as natural gas, oil, coal, and biomass or hydropower energy. It consists of both renewable and non renewable energy.

(Source-US EPA TRACI 2.0, USG LCA Report Prepared By Athena)

Limitations of Life Cycle Assessment

The great asset of the LCA concept is that it is an ideal way to quantitatively assess the range of environmental impacts attributable to a specific product. However, there are limitations to this approach and the drawing of assessment boundaries are difficult. The specification of the functional unit (product) often is not obvious and it is difficult to recommend a consistent approach. Data collection and analysis are also limitations to accuracy and completeness. *As a result, inventory analysis by different assessment teams can produce different, but defendable results.*

A partial list of the challenges related to the impact assessment stage includes the following:

– LCAs do not incorporate information related to locale (e.g. they assume that emissions of a certain quantity of smog-forming chemicals into the air is just as significant in Oslo as in Los Angeles).

– LCAs do not incorporate temporal information (e.g. they assume that emissions of a certain quantity smog forming chemicals into the air is just as significant at midnight as in midmorning).

– LCA inventory data are often too general (e.g. "VOCs", "metals").

– Linearity of impacts is assumed (e.g. the impact of a 500g emission of a certain chemical is assumed to be 100 times that of a 5g emission). This excludes consideration of non linear responses and thresholds that are known to exist for some materials.

– Durability: product performance in a specific application is NOT captured in an EPD as the service life is stated as a constant in the PCR for that product type. Not all like products perform the same length of time in the same application. For example; bamboo flooring may have a life expectancy of 15 years in a high-traffic lobby area and an oak floor 75 years. While the EPD of bamboo may indicate 25% lower values in several key environmental impacts. If the application would only be designed to maintain for 15 years or less, bamboo might be the best option. However, if the space is to remain 20 or more years then oak might be a much better option.

– Intended Use: EPDs only evaluate environmental attributes. They may elect to state other attributes but are not required to share building science attributes like fire-resistance, acoustical, thermal, structural, etc. So selection of a product purely based on an EPD for a specific application may yield in the selection of a product that does not meet its intended use based on a life-safety issue like fire performance.

– Mature Product Performance: EPDs of mature products may yield better values than a new product. But, as a new product matures, it greatly improves all environmental impacts over a long term. New products need a period of development which is not addressed in EPDs.

– Assumptions: the LCA practitioner makes assumptions and estimates at various points in the LCA of a product based on limitations of data sources, process methodology, company mandates etc. No matter how sophisticated a quantitative analysis may be, if it has a subjective basis or uses subjective data, it gives subjective results.

To demonstrate some of the problems with LCAs at their present state of development, let us elaborate on two examples where difficulties are real and obvious.

The first is depletion of abiotic resources such as metals. There is indeed a general supposition that resources are being depleted at excessive rates in some cases. However there are no satisfactory reference indicators for resource depletion available. Some researchers have multiplied the average concentration of the resource in the earth's crust by the mass of the crust. This is not an accurate assessment because it is not feasible to mine metal as a collective average and enriched ore deposits are instead mined in widely separated locations.

A second example relates to ecotoxicity, where two emissions of equal amount are assumed to have equal impacts. However, the ecosystems and organisms that receive those emissions can be very different. In some cases, organisms can thrive despite small doses of a substance. In others, organisms may ingest a material such as copper that is biologically essential in small amounts but harmful with exposure to greater amounts. Finally, ecosystems differ in their ability to sequester materials so neglecting that difference does not take spatial location into account.

(Source-Graedel, T.E. and Allenby, A.R. : Industrial Ecology and Sustainable Engineering)

Embodied Energy

The embodied energy of a material refers to the energy used to extract, process and refine before using it in manufacturing products. Therefore, a correlation exists between the number and type of processing steps and the embodied energy of materials. For example, the fewer and simpler the extraction, processing and refining steps involved in a material's production, the lower its embodied energy. The embodied energy of a material is often reflected in its price.

In some cases, the most technically appropriate material will lower energy costs over the life cycle of a product. For example, composite materials involving carbon fibers or ceramic compounds may have a relatively high embodied energy, but when they are used appropriately, they can save energy in a product's use-phase due to their advanced physical properties, e.g., strength, stiffness, heat or wear resistance.
http://www.sda-uk.org/materials/principles/embodied_energy.htm

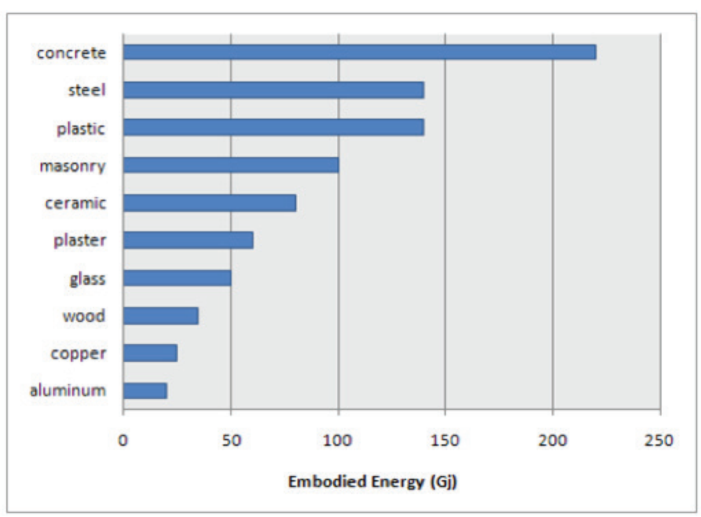


Fig: Materials Embodied Energy

Operational Energy

Operational energy refers to all of the energy used in the operation of a finished building, over its useful lifespan, excluding embodied energy and energy required to demolish, disassemble and dispose of the building when its lifespan is over.

How Much Does Embodied Energy Matter?

Embodied energy has become a debating point for some material producers who seek a market advantage based upon their product's typically lower embodied energy. For instance, the wood, steel and cement industries have debated this issue for a number of years, as each industry seeks to position itself as the preferred "green" option.

In terms of the overall environmental impacts from energy use in buildings, the central question is: how much does embodied energy really matter? Here, the evidence is quite clear. Some research suggests that the amount of embodied energy in a building is as much as 20 to 50 times less than the operational energy used by occupants during a building's lifespan. This puts the relative importance of embodied energy into perspective.

Carbon Footprint

Global Warming Potential is the metric used to report the carbon footprint of a product for life cycle analysis purposes. Scientifically, it refers to long-term changes in global weather patterns—including temperature and precipitation that are caused by increased concentrations of greenhouse gases in the atmosphere. GWP will be based on equivalency basis relative to CO_2-in kg or tons of CO_2 equivalent.

The GWP does not express the contribution made by a trace gas to the greenhouse effect in absolute terms, but describes it in *relation to* CO_2, which is the most important of substances contributing to the vital and natural greenhouse effect, and at the same time, considering the increased quantities released by the combustion of fossil fuel brought about by industrial activities, is the most important substance that make a significant contribution to the anthropogenic greenhouse effect. In short, this means that quantities of any substance likely to be released are converted into equivalent quantities of CO_2 (kg), the factor of multiplication to determine the equivalent potential of the emitted pollutant being the normalized GWP of CO_2.

The GWPi of a selected choice of substances related to a span of 100 years is given in the following table.

Substance	Global Warming Potential GWPi (GWPi in kg CO_2-equiv./kg)
CO2	1
CH4	11
N2O	270
CF4	>4.500
C2F6	>6.200
CCl4	1.300

(Source-Heijungs, R. et al; Environmental Life Cycle Assessment of Products: Guide, Ed. CML (Center of Environmental Science), Leiden 1992)

It should be noted that though carbon footprint of a product might be a useful metric for environmental impact of most building materials, a multi attribute analysis of LCA impacts will minimize ambiguity. The following example will help illustrate this. The energy utilized throughout the life cycle stages of a product from extraction of raw material to end of life stage is measured in megajoules (MJ) of Total Primary Energy. This includes renewable and non renewable energy. The primary energy number is influenced by a number of factors such as location of manufacturing facility, fuel type and the mix of renewable and non renewable energy sources. For example, 1 MJ of electricity from natural gas has a GWP number of 0.1447. The number goes up to 0.2595 when hard coal is burned to produce electricity. The GWP number decreases considerably when the primary energy requirement during a material's life cycle is decreased.