LIFE CYCLE ANALYSIS

A KEY TO BETTER ENVIRONMENTAL DECISIONS

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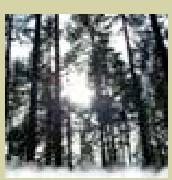
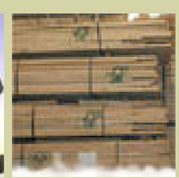
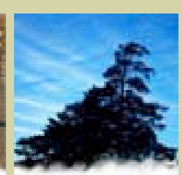


Life Cycle Analysis
A Key to Better Environmental Decisions

Introduction

An environmental manager is faced with the task of identifying areas in which her company's environmental performance can be improved, but she does not have trustworthy data with which to make an evaluation. A homebuilder committed to environmentally responsible building construction needs a way to identify construction materials and building designs that minimize environmental impacts, but finds available information to be limited, conflicting, confusing, and often based on a single attribute. A government organization wishes to mount a preferred purchasing program for all of its paper products with the intent of minimizing environmental impacts and providing environmental leadership for society at large, but is faced with pressure to focus only on recycled content.

As society becomes more and more interested in environmental attributes of products, those involved in all aspects of product manufacture, selection, use, maintenance and end-of-life disposal need definitive, scientifically based tools for evaluating environmental impacts and potential mitigation strategies. Environmental life cycle analysis, or LCA, has become the tool of choice for leading organizations in both the public and private sectors. Sometimes referred to as "cradle to grave" analysis, LCA provides a mechanism for systematically evaluating the environmental impacts linked to a product or process and in guiding process or product improvement efforts. LCA-based information also provides insights into the environmental impacts of raw material and product choices, and maintenance and end-of-product-life strategies. Because of the systematic nature of LCA and its power as an evaluative tool, the use of LCA is increasing as environmental performance becomes more and more important in society. It is likely that LCA will soon become widely used within American industry and by those involved in crafting national and regional environmental policy.

Life Cycle Assessment History

1969: Coca Cola evaluates bottles

1970's: LCA Methodology discussed

1972: UK's Ian Boustead calculates total energy of beverage containers

1974: Early LCI study on materials in U.S. residential construction - USNRC

1979: SETAC North America formed to unify environmental findings

1984: Publication by EMPA of the "Ecological report of packaging materials"

1989: SETAC Europe formed

1990's: US-EPA & SETAC hold LCA workshops

March 1992: First European scheme on Eco-labels

1996: Creation of a data exchange standard

1996: NF X30-300, first standard in France for Life Cycle Assessment

1997-2000: ISO 14040-43, defines the different stages of the LCA methodology

1999-2001: ISO 14020, 25, 48, 49, address communication, environmental declaration directions, and working methods

List obtained in part from http://www.ecobalance.com/uk_lca02.php

Life Cycle Analysis

The Basics

An LCA typically begins with a careful accounting of all the measurable raw material inputs (including energy), product and co-product outputs, and emissions to air, water, and land; this part of an LCA is called a Life Cycle Inventory (LCI). Examination of energy use is particularly revealing, since a number of serious environmental problems are related to consumption of energy including acid deposition, oil spills, air pollution (SO_2, NO_x), and increasing concentrations of atmospheric carbon dioxide. An LCI may deal with product manufacture only, or the study boundaries may be defined more broadly to include product use, maintenance, and disposal. In a subsequent stage of the LCA, factors are considered that are currently not precisely measurable, such as impacts of an industrial activity on the landscape, flora, fauna, air, or water.

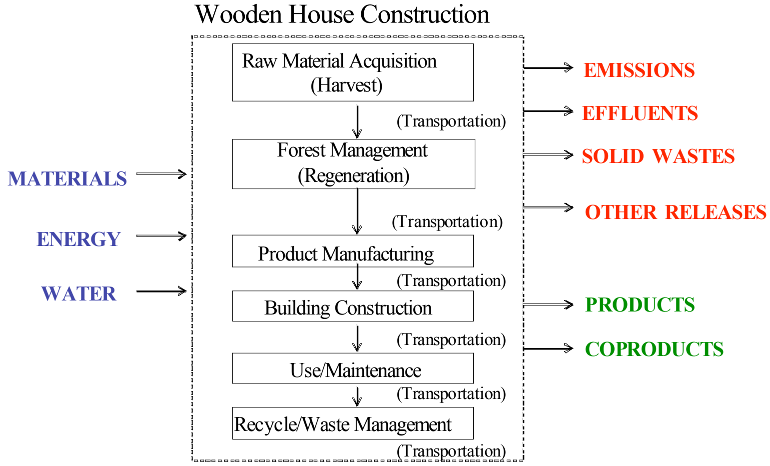
4 Steps in Life Cycle Analysis

1. *Define goal and scope of study*
2. *Make a model of product life cycle (LCI)*
3. *Evaluate environmental impacts of inflows and outflows (LCIA)*
4. *Interpret results, select product or process*

The Life Cycle Inventory

As depicted in Figure 1, a life cycle inventory may involve all stages in production, use, and disposal including raw material extraction, transportation, primary processing, conversion to finished products, incorporation into finished products, maintenance and repair, and disposal. The system boundary (indicated by the dashed line) defines those operations to be included in the inventory of environmental impacts.

Figure 1
Schematic of a Life Cycle Inventory of Wooden House Construction



Verified by performing a materials balance.

Source: Based on Fava et al. 1994

In the life cycle inventory of wooden house construction illustrated in Figure 1, the inventory would begin with the harvesting of trees and would include an accounting of the use of gasoline, oil, lubricants, saw blades, tires, and so on consumed in that process. All of the impacts associated with producing and transporting items consumed would also be considered. Included as well would be regeneration of the forest harvest site.

Since the construction of wooden houses typically involves concrete foundations, the use of steel nails and other fasteners, glass, and other non-wood materials, all environmental impacts associated with the mining and processing of limestone, sand and gravel, iron ore, and other raw materials must be determined. Next, the processes involved in converting wood to lumber, panels, or other wood products are considered, as are industrial processes for converting limestone to cement, iron ore to steel nails, silica to glass, and so on. Energy directly consumed in the industrial processes is accounted for as is energy needed to provide heating of manufacturing plants.

Since this LCA involves an analysis of wood-frame houses, all activities involved in the building construction process are also considered, and again, all emissions, effluents, solid wastes, and other releases associated with consumption of energy and all other materials are accounted for. Finally, all materials and processes involved in the use and maintenance of the building are considered, as are processes involved and/or materials recovered at the time of building demolition at the end of the useful life of the structure.

A life cycle inventory can be conducted for a period of time that is less than the full product life. For instance, a number of recent analyses have examined all of the steps involved up to completion of the shell of a residential structure. In this instance the system boundaries (dashed line in Figure 1) would encompass only the top four boxes; the use and maintenance and recycle/waste management stages would not be considered.

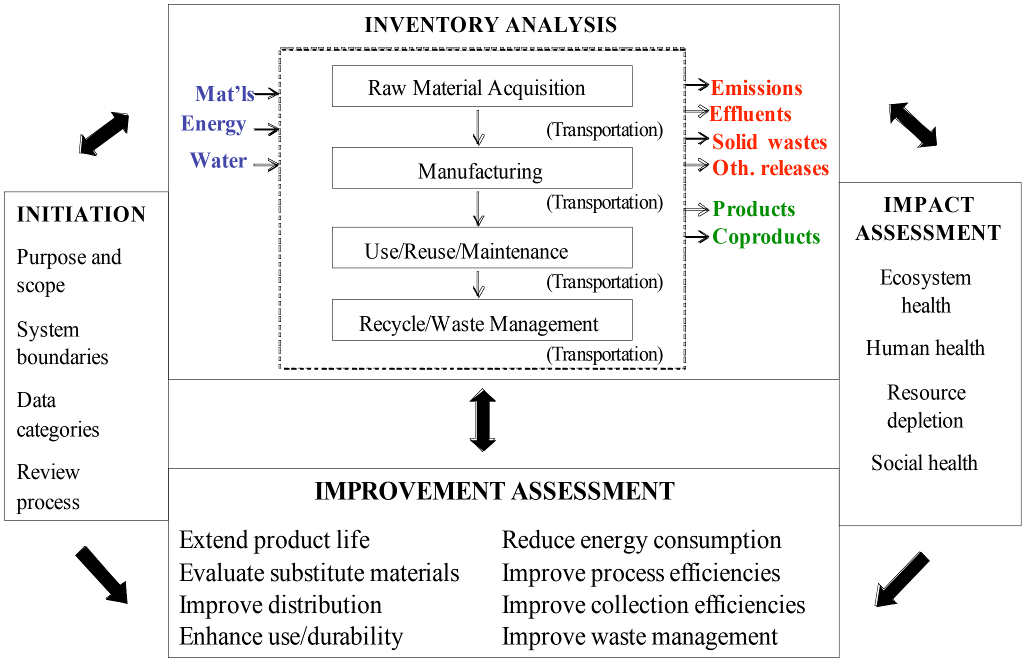
A number of international protocols as published by the International Organization for Standards (ISO) and the Society for Environmental Toxicology and Chemistry (SETAC) guide LCI practitioners, allowing analyses to be conducted using a uniform set of guidelines. These protocols help to eliminate bias on the part of analysts and ensure that results of like assessments from various regions can be compared.

The Impact Assessment (LCIA)

Figure 2 illustrates how the life cycle inventory fits within a life cycle analysis. The LCI, shown as the large box at the top center of Figure 2, provides essential data regarding resource use and emissions to air, water, and ground. The impact assessment examines aspects of product production and use that are not considered in the LCI: impacts upon ecosystem and human health, implications for long-term resource availability, and considerations relative to social equity and well being.

The bottom box of Figure 2 provides examples of how information from the life cycle inventory and impact assessment can be used. Such information is key to systematically identifying environmental burdens associated with a product or process; evaluating the probable impacts of a change in product or process design, product durability, or product life; allowing informed decision-making on the part of designers, architects, engineers,

Figure 2
Life Cycle Analysis – Steps in the Process and Applications of Findings



Source: Athena Sustainable Materials Institute 1997

and others who specify materials used in construction and other applications and who have interest in minimizing environmental impacts; gauging the potential impacts of government policies such as those that favor or disfavor certain products or materials in government purchasing or in government-financed projects.

Practical Applications of LCA

The Athena Sustainable Materials Institute and the National Renewable Energy Laboratory provide several examples of current applications of LCA in North America. Other examples can be found throughout the U.S. and Canadian industrial sector where a number of corporations are actively involved in the use and development of LCA.

The Athena Sustainable Materials Institute is a Canadian based organization that is recognized for its extensive contributions toward building a Canadian and U.S. LCA database for a broad array of wood and non-wood building materials. Among many programs of Athena is one that allows direct use of Athena software to carry out assessments of various design options for a building, thereby allowing designers to minimize environmental impact.

The National Renewable Energy Laboratory (NREL), an entity of the U.S. Department of Energy, is working with the U.S. Environmental Protection Agency and with Athena on an initiative known as the U.S. Database Project, available online at: http://www.epa.gov/ORD/NRMRL/lcaccess/dataportal.htm. The objective is to create a publicly available, national LCI database for commonly used materials, products, and processes. The purpose is to 1) support public and private sector efforts to develop environmentally oriented decision support systems and tools; 2) provide regional benchmark data for use in assessing environmental performance of companies, manufacturing plants, and production processes, and in evaluating the environmental attributes of new technologies or products; and 3) provide a firm foundation to subsequent life-cycle assessment tasks such as impact assessment. *Ultimately the database could also provide the foundation for a national product-labeling program in which building materials and other products would bear a label – very similar to the label found today on food packages – that would summarize environmental impacts in the form of seven to ten easy to understand indices.*

Findings of Recent LCA Studies

The primary use of a life cycle assessment is to guide product and process improvement for purposes of improving environmental performance. One "product" that has been the focus of a number of LCA studies is the residential house. There is a remarkable similarity of findings of research groups from all over the world that have studied the relative environmental impact of various construction materials. In every case, wood has been shown to have a substantial advantage in relation to other materials in terms of energy consumption per unit of finished products and to generate vastly lower emissions in the process of raw material to product conversion. For example, a 1992 Canadian assessment of alternative materials for use in constructing a 110,000 ft^2 building showed all-wood construction on a concrete foundation to require only 35% as much energy as steel construction on a concrete foundation. Furthermore, the liberation of carbon dioxide associated with building the steel structure was over 3.1 times that when building with wood. In the same year a New Zealand study found office and industrial buildings constructed of timber to require only 55% as much energy as steel construction and approximately 66 to 72% as much energy as concrete construction. When residential buildings were considered, wood-frame construction with wood-framed windows and wood fiberboard cladding was found to require only 42% as much energy as a brick-clad, steel-framed dwelling built on a concrete slab and fitted with aluminum-framed windows. Accordingly, large differences in carbon dioxide emission were noted. A 1993 Canadian comparison of wood and steel-frame construction for light-frame commercial structures, which examined a wide range of factors in addition to energy, again showed low environmental impacts of wood construction relative to steel (Table 1).

Wood has been shown to have a substantial advantage in relation to other materials in terms of energy consumption per unit of finished products and to generate vastly lower emissions in the process of raw material to product conversion.

Table 1
Comparative Emissions in Manufacturing Wood vs. Steel -Framed Interior Wall

Emission/Effluent	Wood Wall	Steel Wall
Energy Consumption (GJ)	3.6	11.4
Air Emissions		
Carbon dioxide (kg)	305	965
CO (g)	2,450	11,800
SO_X (g)	400	3,700
NO_X (g)	1,150	1,800
Particulates (g)	100	335
VOCs (g)	390	1,800
CH_4 (g)	4	45
Water and Effluents		
Water Use (L)	2,200	51,000
Suspended solids (g)	12,180	495,640
Non-ferrous metals (mg)	62	2,532
Cyanide (mg)	99	4,051
Phenols (mg)	17,715	725,994
Ammonia (mg)	1,310	53,665
Halogenated organics (mg)	507	20,758
Oil and grease (mg)	1,421	58,222
Sulfides (mg)	13	507
Solid Wastes (kg)	125	95

Source: Meil 1993

The values shown in Table 1 are dramatic, and they show that although wood construction clearly has environmental impacts, these impacts are minuscule compared to those of steel. When use of recycled steel is considered, the differences between wood and steel narrow, but wood retains a significant advantage. As part of the wood vs. steel wall comparison, load-bearing wood and steel-framed walls were examined in which the steel contained 50% recycled steel content.[1] In this case the steel-framed wall was found to be "some four times as energy intensive, and correspondingly ... at least that much more environmentally damaging, despite its recycled steel content."

A 2004 study by the Consortium for Research on Renewable Industrial Materials (CORRIM) compared wood and steel houses built to Minneapolis code standards and wood and concrete houses built to Atlanta code standards. In Table 2, comparative data is shown for above-grade walls (the focus is above-grade since the foundations were made of the same materials in each location regardless of the method of framing). The results mirror those of earlier studies, showing substantial environmental advantages of wood construction. Another difference that is not shown in Table 2 is that in the case of wood framing, most of the energy used in product manufacture is bioenergy, whereas no bioenergy is used in producing steel or concrete elements. As a result a typical steel-framed house in Minneapolis uses 281 percent more non-bioenergy than a comparable wood-framed house. Similarly, a typical concrete house constructed in Atlanta uses 250 percent more non-bioenergy than a comparable wood-frame house.

[1] Currently the maximum recycled content that technology allows in steel studs is about 40 percent.

Table 2
Environmental Performance Indices for Above -Grade Wall Designs

Minneapolis House	Wood Frame	Steel Frame	Difference	Steel vs. Wood (% Change)
Embodied energy (GJ)	250	296	46	18
Global warming potential (CO_2 kg)	13,009	17,262	4,253	33
Air emission index (index scale)	3,820	4,222	402	11
Water emission index (index scale)	3	29	26	867
Solid Waste (total kg)	3,496	3,181	-315	- 9

Atlanta House	Wood Frame	Concrete	Difference	Concrete vs. Wood (% Change)
Embodied energy (GJ)	168	231	63	38
Global warming potential (CO2 kg)	8,345	14,982	6,637	80
Air emission index (index scale)	2,313	3,373	1,060	46
Water emission index (index scale)	2	2	0	0
Solid Waste (total kg)	2,325	6,152	3,827	164

Source: Lippke et al. 2004.

These results do not indicate that wood should be used to the exclusion of all other materials, but rather that production and use of all materials have environmental impacts that must be considered when formulating environmental policies. In the future, it can be expected that development of building design and construction technology will seek to take maximum advantage of the properties of each raw material, thereby designing buildings so as to minimize the total environmental impact. What comparative studies do show is that as environmental performance increases in importance, wood will clearly play a key role in buildings of the future.

Numerous studies of paper production, use, and disposal have also been done. One of the more interesting is an extensive examination of paper recycling conducted by a team in England. In this study, that included consideration of LCI data as well as an economic assessment, the following options were compared:

- recycling to make a similar grade of paper
- recycling to make a lower grade of paper
- incineration of recovered paper to generate energy
- composting of recovered paper
- landfilling of recovered paper with recovery of methane to produce electricity

The findings were surprising to many. The research team concluded that if environmental externalities are given little value (i.e. if the environmental costs assigned to release of pollutants such as carbon dioxide, sulfur dioxide, nitrogen dioxide, or other pollutants are low), then it makes sense to recycle as much paper as possible. On the other hand, if environmental costs are valued more highly, then the best course is to incinerate as much paper as possible for purposes of generating energy. The reason for this result lies in the fact that production of energy from paper reduces the need for energy production from petrochemicals while also generating much lower quantities of pollutants. As environmental costs of pollutants rise, the value of pollution avoided increasingly favors paper incineration. This result indicates that blind pursuit of increased paper recycling is not necessarily the best environmental strategy.

The Bottom Line

Environmental life cycle analysis (LCA) provides a mechanism for systematically evaluating the environmental impacts linked to a product or process and in guiding process or product improvement efforts. LCA-based information also provides insights into the environmental impacts of raw material and product choices, and maintenance and end-of-product-life strategies. Because of the systematic nature of LCA and its power as an evaluative tool, the use of LCA is increasing as environmental performance becomes more and more important in society. It is likely that LCA will soon become widely used within American industry and by those involved in crafting national and regional environmental policy.

A new U.S. life cycle database will soon extend to a wide range of industries, and already includes considerable information related to wood products manufacturing. The database will allow manufacturers to benchmark performance against industry averages and to gain access to information that will aid in development of facility-specific life cycle inventories. This kind of information will soon become the standard basis for investment decisions vis-à-vis environmental performance.

Dr. Jim Bowyer is a professor within the University of Minnesota's Department of Bio-based Products (part time) and an Elected Fellow of the International Academy of Wood Science. He is the current Chairman of the Tropical Forest Foundation, Chairman of the Minnesota Bio-fiber Council, Scientific Advisor to the Temperate Forest Foundation and Past President of the Forest Products Society (93-94), and of the Society of Wood Science and Technology (87-88).

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