Life Cycle Assessment: Measuring Environmental Impact

Susan L. LeVan

Abstract

Environmental impact assessment is a major issue that faces every nation today. However, consistently and objectively measuring the environmental impact is difficult. During the past two decades, a process called life cycle assessment was developed that tried to make consistent and objective environmental assessments. The Society of Environmental Toxicology and Chemistry has now broadened the concept to include not only the inventory but also the environmental impact and improvement phases. The Society of Environmental Toxicology and Chemistry defines life cycle assessment as:

> . . .an objective process to evaluate the environmental burdens associated with a product process or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and materials uses and releases on the environment, and to evaluate and implement opportunities to affect environmental improvements.

Life cycle assessment has received both positive and negative feedback on its utility as a process to evaluate environmental impact. This paper provides a brief history and overview of life cycle assessment, illustrating how it has been used and misused, listing its benefits and limitations, and outlining possible applications to the forest products industry. Life cycle assessment provides an opportunity to assess some environmental impacts of various forest products; however, the process must be appropriately applied to gain the full benefit.

The author is Assistant Director, USDA Forest Serv.. Forest Prod. Lab., Madison, Wis. This paper was presented at the 49th Annual Meeting of the Forest Products Society, Portland, Oregon, June 1995.

Introduction

Public concern about the environmental consequences of producing and using various materials and products is increasing. The concerns range from the effect on old-growth forests and tropical forests to issues of air and water quality and landfill disposal sites. Governments are increasingly asked to incorporate these concerns into policy decisions, and corporations are increasingly held accountable. Consumers are aware that consumption of manufactured products have an effect on resources and the environment. These effects occur at every stage in a product's life cycle-from the extraction of the raw materials from the ground through the processing, manufacturing, and transportation phases, ending with use and disposal or recycling. The effects can either be direct (such as air emissions produced from automobile usage) or indirect (such as the pollution and impact on waterways from the production of electricity used in the manufacturing process). One popular methodology in use today is life cycle assessment (LCA), which quantifies these direct and indirect effects of products and processes.

Historical Overview

The first life cycle analysis was conducted in 1969 on beverage containers (12). The major objective of the analysis was to determine which type of container had the least effect on natural resources and the environment. The result was an accounting of the energy and materials flows, without determining the environmental impact. Figure 1 illustrates the general energy and materials balance diagram for "cradle-to-grave" analysis of a product and its distribution system.

The oil shortages of the early 1970s refocused the discipline on inventorying energy supply and demand for both fossil and renewable alternative fuels. Interest in the methodology waned after the energy crisis, but was rekindled in the 1980s as governments faced mountains of trash accumulating in their cities and countrysides. With landfill space at a premium and questions about the health effects and costs of alternative disposal methods, reducing waste at the source became a paramount issue.

Corporations were held accountable by consumers who wanted "greener" products. Companies found themselves scrambling to prove to the public that their products were greener than their competitors. Some of these companies, through industry trade associations, conducted LCA studies and advertised the results as a "mine is better than yours" statement. In the last several years, comparisons have been made on products such as high-density polyethylene milk jugs versus paperboard cartons; recycled polyethylene bags versus kraft paper grocery bags; coffee cans versus vacuum-packed wrappings with paper and plastic linings; recycled newsprint versus virgin fiber newsprint; and disposable diapers versus cloth diapers. However, these LCA inventory studies did not delve into the impact or degree of environmental consequences.

Many initial studies did not apply similar methodologies, so efforts began to standardize the process. Although many groups have tried to bring consistency to the procedures, the most notable is the Society of Environmental Toxicology and Chemistry (SETAC) who issued a report on technical guidelines for appropriate use of LCA. One major finding of the SETAC was that complete LCAs should be composed of three separate but interrelated components:

- *Life cycle inventory.*–Process for quantifying the energy, water, and natural resources used to extract, produce, and distribute the product, and the resulting air emissions, effluents, and solid wastes.
- *Life cycle impact analysis.*–Process to assess the ecological and human health effects of the environmental loadings identified in inventory.
- *Life cycle improvement analysis.*–Process to reduce the environmental burden associated with energy and raw materials use and environmental releases throughout a product's entire life cycle (8).

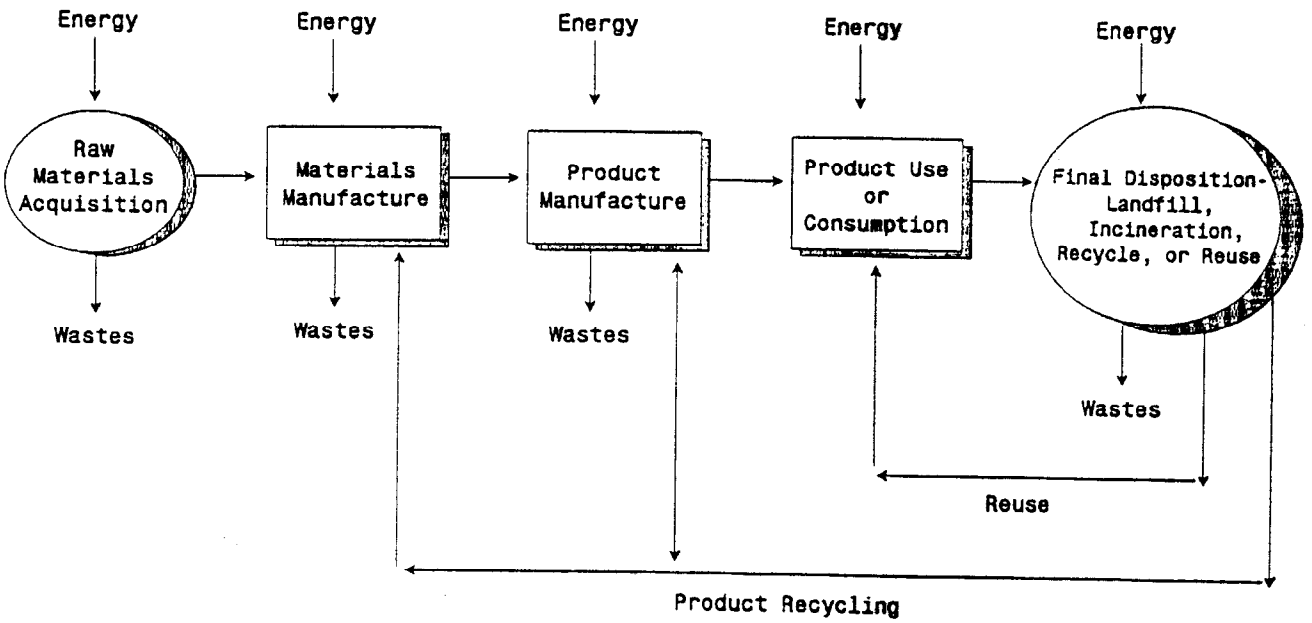

Figure 1–General materials flow for "cradle-to-grave" analysis of a product distribution system (12).

The three-tiered approach of SETAC goes beyond the traditional focus of the inventory stage that is prevalent in most LCA studies. However, determining the environmental impact is proving to be a difficult task, and most LCAs still only involve the inventory aspects. One of the best and most recent sources providing details of an LCA is by Vigon et al. (21), who outlines the guidelines and principles for LCA. Both the American Society of Testing and Materials (ASTM) and the International Standards Organization (ISO) have activities underway to address consistent methods and procedures and quantify environmental impacts. The ISO has formed an Environmental Management Technical Committee (TC 207). Their major objective is to develop standards that:

- promote a common approach to environmental management
- enhance an organization's ability to attain and measure improvements in environmental performance
- facilitate trade and remove trade barriers (5)

Despite all the activity in standards organizations and elsewhere, there is still debate within the LCA practitioner community whether a scientific basis exists for applying impact assessment techniques to LCA quantitative inventory data.

Wood and paper products

Research by the Western Wood Products Association (23, 24) indicates that customers of wood products ask questions regarding the impact of wood use on the environment. Such concern has been highlighted by the increased use of LCA by competitive materials. In response, the wood products sector has responded with its data effort to examine the unique characteristics of the wood products industry. The first limited life cycle inventory was conducted by the National Research Council, Committee on Renewable Resources for Industrial Manufacturing (CORRIM) (18). The CORRIM report compared the energy requirements for wood and possible substitute materials. CORRIM developed methods of systems analysis that would permit assessing the amount of energy required to produce different building construction materials. The CORRIM reported that in the 1970s it took nine times more energy to produce a steel stud than a wood stud, three times more energy for a concrete block wall than a wood stud wall, and 21 times more energy for a 102-mm concrete slab floor than a raised wood floor.

Peter Koch (14) reported that with the expected decline in timber harvests in the Pacific Northwest and substitution with nonrenewable materials, consumption of fossil fuel would increase 2.7×10^6 m^3 annually, with approximately 6.8×10^9 kg of carbon dioxide added to the atmosphere for each billion board feet of annual harvest reduction. Many authors have cited statistics that examine the amount of energy consumed and carbon dioxide emitted into the atmosphere to manufacture wood construction materials and compared these data with substitute materials. They highlight data that indicate wood uses less energy in its manufacturing process with lower carbon dioxide emissions than steel or concrete (1,2,4,11).

However, most previous studies have not been a complete LCA and have primarily compared inventory data for the manufacturing process. For wood products, a full LCA inventory would consist of all phases from the timber harvesting, debarking, through manufacturing and processing, use, and final disposal/recycling. Lubert et al. (16) illustrates flow diagrams for the phases between harvesting and chipping (Fig. 2) to final pulp production (Fig. 3). The most significant aspect of this flow diagram is the complexity of the details and intensive data demand to construct the energy and material balances around each phase. In addition, this represents only the production processes up to the pulping stage. A full LCA would involve many more processes for a paper product.

Richter and Sell (20) and Richter (19) conducted a comprehensive LCA from extraction to disposal or

Table 1.—Energy and emission values for exterior wall type (20).

Wall type	Width	Mass	U-value	Energy	Critical air volume	Disposal
	(m)	(kg/m^3)	(W/m^3K)	(Mj/m^2)	($\times 10^3$ m^3/m^2)	
Timber frame	0.23	79	0.32	840	1,333	Recyclable
Plastered brick	0.51	609	0.39	1,675	2,473	Road construction
Plastered isomodul	0.39	407	0.40	1,430	2,770	Road construction
Brick, with extension insulation	0.31	264	0.39	860	1,027	Road construction

recycling of wood as a raw material and construction component. Using the LCA methodology, Richter and Sell collected data for energy use and air emissions for the production of softwood lumber, glued-laminated timber, particleboard, and fiberboard. The LCA was regional in scope, using logging and transportation costs from Switzerland. The two major end-uses examined were four types of wall construction using timber, plastered brick (two designs), and brick with exterior insulation. The timber frame and brick with exterior insulation had similar energy use and emission levels (Table 1).

In Richter and Sell's LCA of window frames, the environmental impacts differed depending on the level of recycling assumptions used in the analysis. The stepwise procedure rated the windows 1) after completion in the plant; 2) after being used under two different service-life and exposure conditions; and 3) with the assumption of different recycling and waste-disposal scenarios. The final disposal options significantly altered the results. Wood-based frames exhibited low energy use and emission levels until recycling options for the aluminum, steel, and polyvinyl chloride windows were considered. With high-level recycling rates, the environmental advantages of wood are equivalent to the other materials.

A current project underway in Canada is developing a systems model to assess the environmental consequences of using alternative materials for specific building designs. Their initial research is on structural assemblies using wood, steel, and concrete products in industrial and commercial buildings. This project focuses on comparing building assembly designs, rather than on comparing materials directly. Preliminary results compared a typical, nonload-bearing exterior infill wall assembly. The exterior opening was then compared using the infill material of either 20-gauge nonstructural steel studs or 2 by 4 wood studs. Results showed that the steel wall was three times more energy intensive, had three times greater carbon dioxide emissions, and 25 times more water demand. However, the solid waste generated during manufacturing and construction was greater for the wood wall assembly (17).

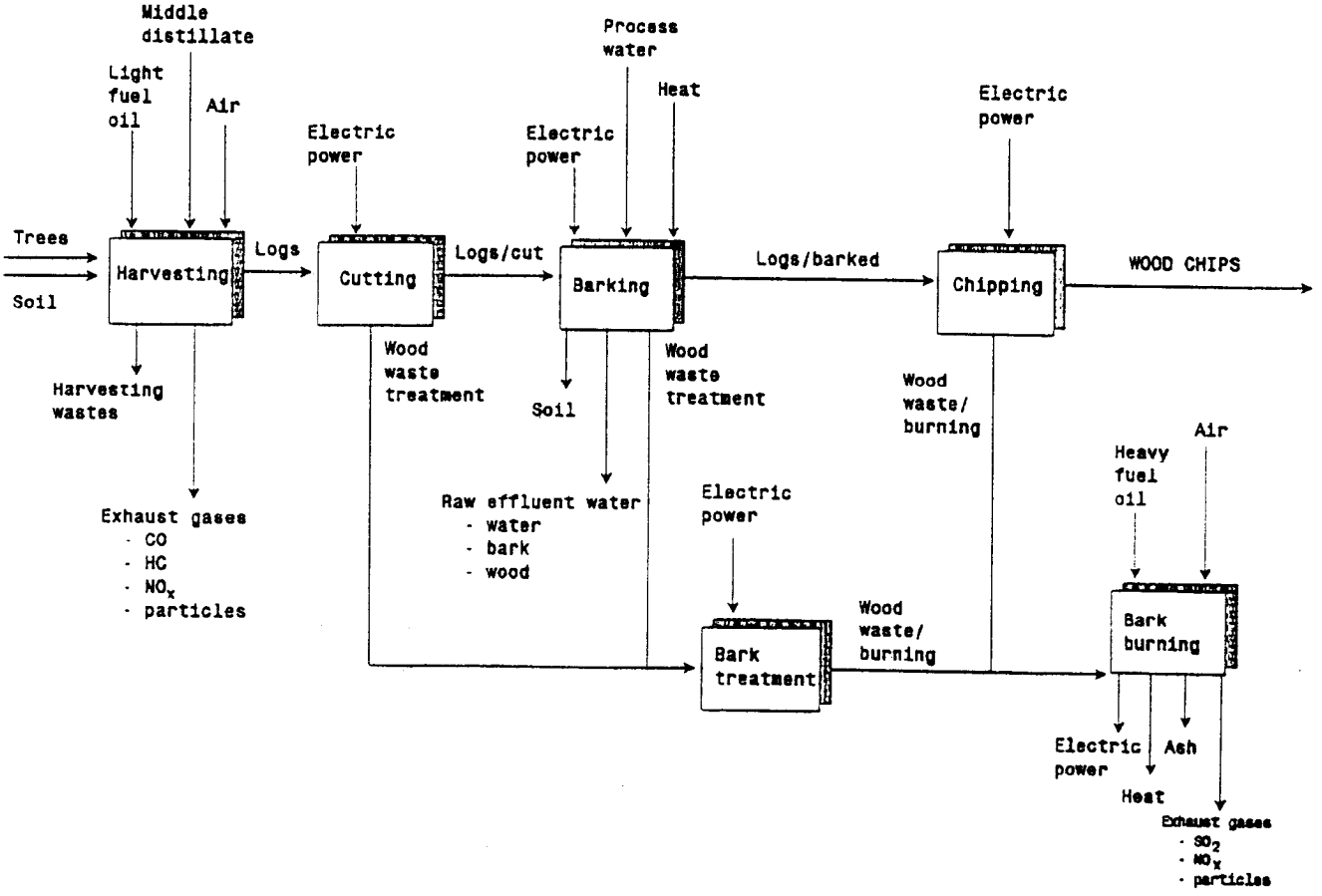

Figure 2.—Wood harvesting process flow (16).

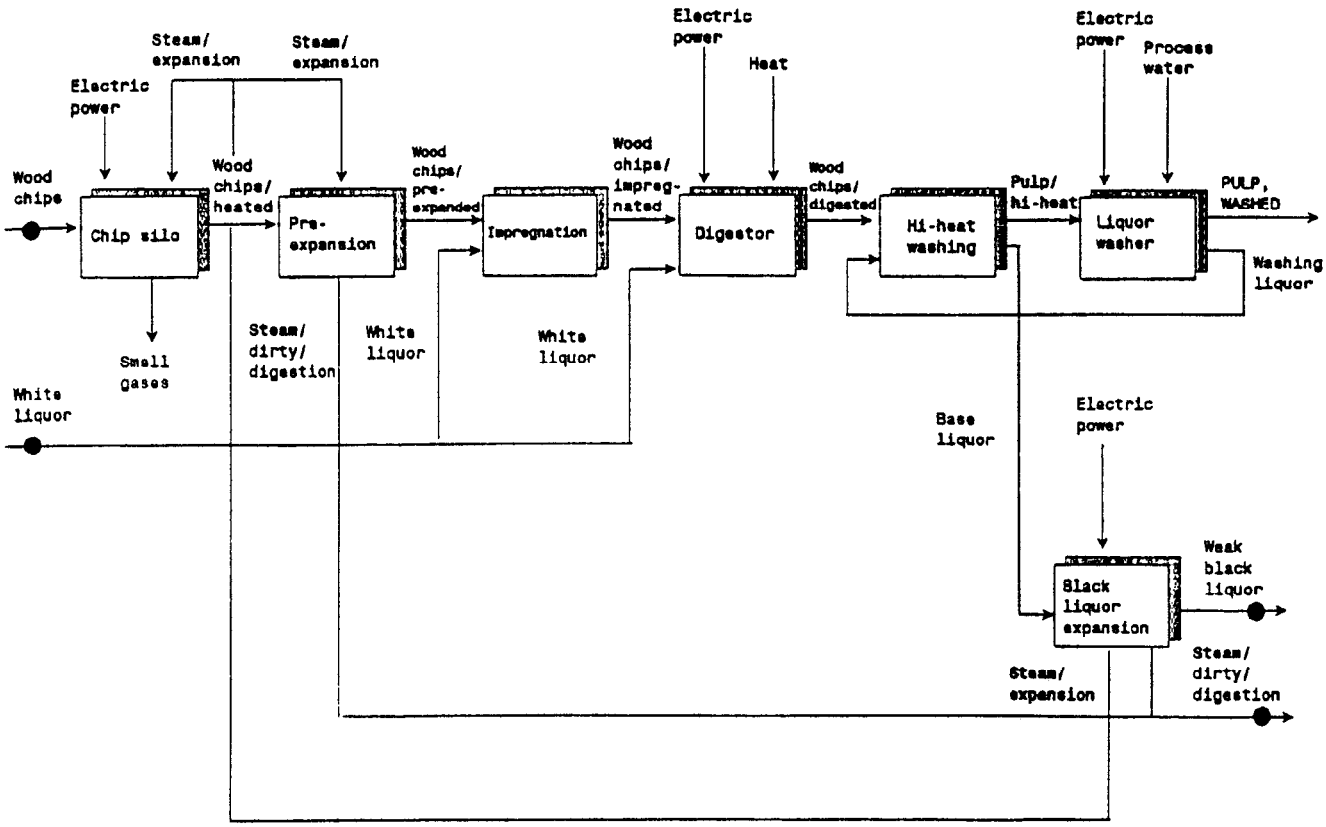

Figure 3.—Pulp reduction process flow diagram (16).

In the area of preservative-treated wood, Erlandsson et al. (7) reported on an LCA conducted on utility poles. These authors concluded that poles made of concrete, steel, and aluminum lead mainly to emission in the air, and treated wood poles lead mainly to leaching of preservatives. A comparison of the environmental burdens between these materials is extremely difficult.

In the wood products sector, most LCAs have been on paper products, particularly packaging containers. The number of analyses is too numerous to consider in depth. However, one of the most complete analyses to date compared the environmental burdens of disposal diapers with cloth diapers. Results from this LCA are discussed in depth to highlight some of the advantages and disadvantages of the LCA methodology.

Disposable versus cloth diapers

The work was conducted for the American Paper Institute, Diaper Manufacturers Group, by Franklin Associates Ltd. (9), a leading authority on life cycle inventory procedures. The purpose of the study was to determine the comparative energy consumption, water requirements, and environmental emissions associated with the three predominant types of children's diaper systems: single-use diapers containing absorbent gels, commercially laundered cloth diapers, and home-laundered cloth diapers. Basis of comparison was daily usage of each system with 9.7 cloth diapers per day and 5.4 single-use diapers per day. Total energy consumption, water requirements, and environmental emissions (including atmospheric, wastewater particulates, and solid waste) were determined.

Figures 4 through 8 show the net energy requirements, water volume requirements, solid waste burden, atmospheric emissions, and wastewater particulates, respectively, from the study by Franklin Associates Ltd. (9). The results indicate that home laundering consumed the greatest amount of energy, with the commercial laundering only slightly more than the single-use system. Commercial laundering consumed the largest volume of water, followed by home laundering. With respect to the environmental waste burden, single-use systems were the largest solid-waste burden; home laundering produced the most atmospheric emissions as a result of energy

consumption in the home dryer; the wastewater particulates were about equal for both cloth diapering systems and exceeded the single-use diapers by five times.

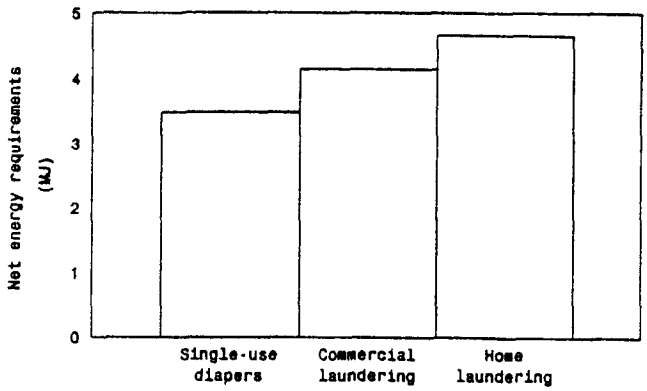

Figure 4.—Net energy requirements of three diapering systems using LCA methodology (9).

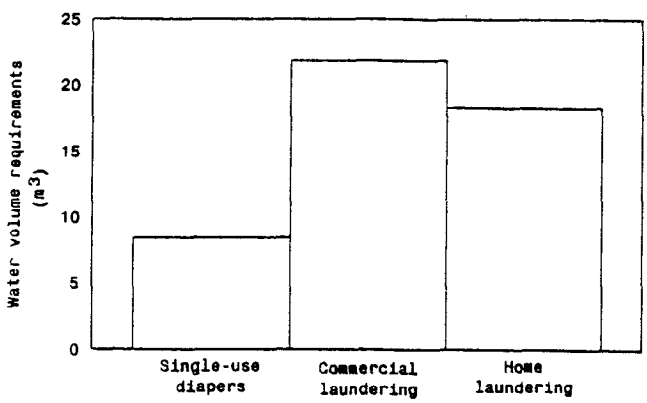

Figure 5.—Cumulative water requirements of three diapering systems using LCA methodology (9).

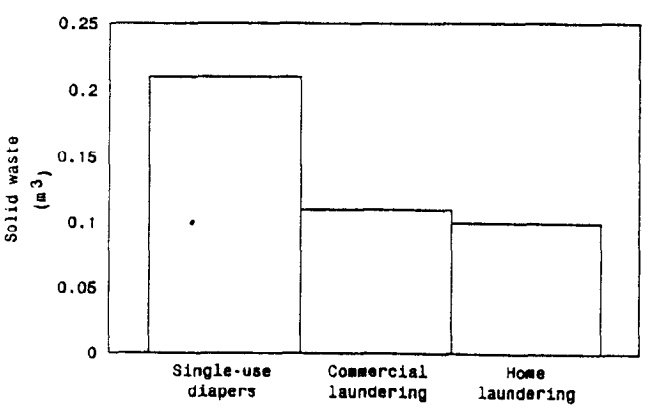

Figure 6.—Cumulative solid-waste volume of three diapering systems using LCA methodology (9).

If the energy requirements are calculated using a closed thermodynamic energy balance, which includes internal or embodied energy, the energy results are altered slightly. In the current procedures, the internal energy content of the fossil fuels was already included; however, a closed thermodynamic balance requires assigning an energy value to raw cotton and trees and including these in total energy requirements. The energy requirements using the thermodynamic energy balance is given in Figure 9, which shows no significant difference in the energy requirements between the three diapering systems. Thus, the primary differences between the three comparative diapering systems is the environmental waste burden.

In a follow-up study to this initial one, Johnson (13) reported on the chemical and natural resource inputs required to plant, maintain, and harvest cotton lands for cloth diapers and softwood forests for

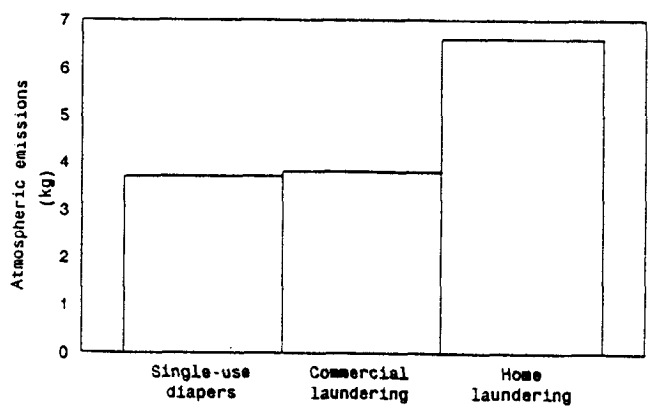

Figure 7.—Cumulative atmospheric emissions of three diapering systems using LCA methodology (9).

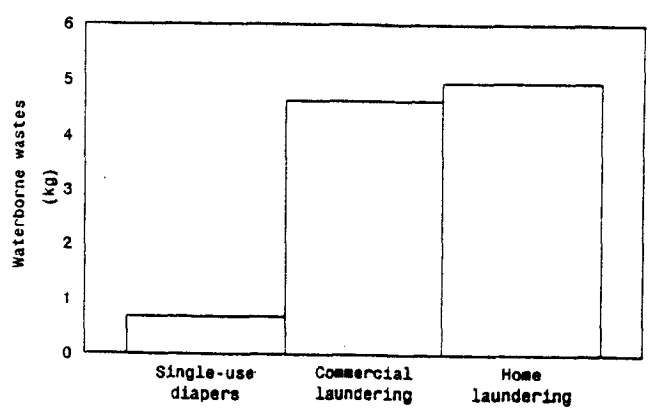

Figure 8.—Cumulative wastewater particulates of three diapering systems using LCA methodology (9).

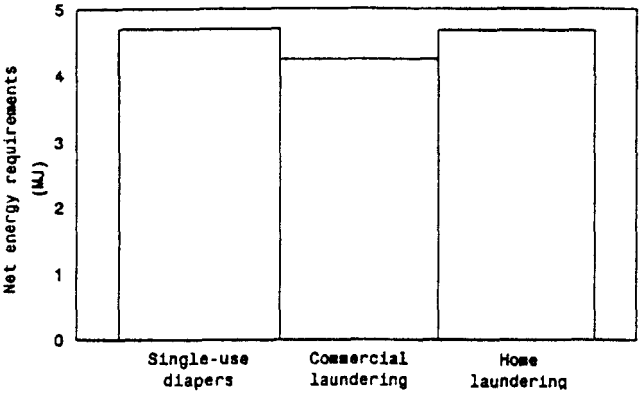

Figure 9.—Net energy requirement using a closed thermodynamic balance of three diapering systems using LCA methodology (9).

paper diapers. Johnson found that greater chemical and water usage existed for cotton, whereas softwood pulp had higher energy requirements. Again, this highlights the environmental trade-off between two similar fibers. The question in assessing environmental burden is, "How do you compare one environmental burden with another?"

Problems and limitations

Data

From the previous examples, it is apparent that LCA is a data-intensive methodology. In many cases, two similar analyses will not arrive at the same level of environmental burdens. In many reports, limitations are described, such as out-of-date information, omission of certain phases, and omission of packaging forming, filling, and transportation stages. Such limitations do not inspire confidence in the robustness of the data. In addition, the SETAC guidelines stress reliance on primary data, which are obtained directly from the plant operator. However, most LCA studies require a large range of material products. It is impossible to collect primary data for every single input; the time needed to produce such a report would be excessive. Most LCA studies conducted by experts in the field rely on accumulated databases that are not published and therefore not available for peer review. This presents major problems in credibility and reliability of the information. In addition, because LCA represents a static analysis, databases most be updated routinely to reflect current advances in manufacturing and processing technologies. Given the complexity of some analysis, data management is an enormous task and needs to be unified and systematically assembled. All interested users should be able to access these databases.

Boundary conditions

Setting boundary conditions in an LCA is problematic at best. Because the primary difference between ordinary analysis and LCA is defining indirect impacts on the environment, the critical issue in setting boundary conditions has to do with the information a researcher can use to establish rational expectations regarding the potential influence on the results of adding details and expanding the scope. The SETAC guidelines of excluding components, comprising less than 5 percent of the inputs, assumes that the components excluded do not have an associated significant environmental burden. For example, the amount of electricity used in a particular activity might be a small input. However, if the electricity is produced from a high sulfur coal plant, it is entirely possible that the environmental burden might far outweigh the proportion of that activity's contribution to the product. Thus, the assumption that environmental burdens do not occur outside the boundary condition can be a major source of concern. Such an assumption routinely leads an opposing material or product representative to widen the boundary conditions and add more details. For example:

> . . .recent reports assessing the relative life cycle environmental impacts of cloth and disposable diapers devote considerable effort to tracing the indirect impacts of each alternative in greater depth than previous studies, although they arrive at mixed and different conclusions. Moreover, the study prepared for the National Association of Diapers Services, which concludes that the overall environmental impact of cloth diapers is less than disposables, devotes nearly six pages (out of a total of 40 pages in the summary report) to describing why its results are superior to previous-because its boundaries are more expansive than earlier assessments (3).

Environmental burdens

Most LCAs target consumer and producer decisions that are connected to a wide variety of activities that potentially cause environmental burdens. The public is generally paying the costs of these environmental burdens because the true economic cost cannot be determined. These environmental burdens include use of energy, emissions into air and water, use of natural resources, and production of wastes.

The measure of environmental burden is not direct and needs to take into consideration geographical and local sensibilities. For example, with the single-use cloth diaper study using the closed thermodynamic energy balance, the environmental burden involved use of water or generation of solid waste. For consumers to choose between these two environmental burdens, they must choose from the two evils and trade off environmental burdens. The use of single-use disposable diaper systems rather than commercial or home-laundered diapers in the U.S. Southwest during times of drought would probably be the preferable choice to a consumer, while in New Jersey, plagued with landfill problems, the cloth diaper system would likely be the most preferable. The relevant question is not "Which diapering choice is better for the nation?" but "Which diapering choice is environmentally better for a particular set of circumstances?"

Most current work underway in SETAC, ISO, and ASTM involves environmental impact measuring. Currently, five environmental ranking systems are under development. All systems compile the materials and processes used in making products, multiply those activities by environmental impact factors, and sum the results for one or more different stages in the product life cycle. For example, the Swedish Environmental Institute developed a tool called the Environmental Priority Strategies for product development (10). In this system, an environmental index is assigned to each type of material used in a product. The three life cycle stage components are summed to obtain the overall index for a material in a unit called the environmental load unit, which is expressed as a function of weight of the material used. However, assigning the indices to each type of material can be influenced by the criteria and priority in developing the indices. Other systems use different weighting systems for establishing environmental impact. The primary problem is that no two systems give the same answer when applied to the same product. This is primarily because there is no agreement on the environmental impact factors that are applied.

These limitations and current attempts to use LCAs as the sole means of evaluating environmental impact have lead to a lack of confidence in LCA studies, primarily because of the lack of robustness. In addition, the misuse of LCA methodology with the conflicting claims of "more environmentally friendly than the competition" by marketing executives is turning LCA into just another marketing ploy.

Advantages and applications

Despite difficulties in dealing with certain aspects of the LCA procedures, LCA is a valuable tool. There is a need to establish comprehensive baselines of information on a product's or process's resource requirements, energy requirements, energy consumption, and emission loadings. There is a critical need to identify areas within a product's life cycle where the greatest reduction in environmental burdens can be achieved. There is a critical need to study product manufacturing processes and identify and minimize direct pollution and other environmental burdens. Thus, LCA is a valuable engineering tool to study the direct pollution caused by products and processes.

Some companies are using LCA at various stages of the life cycle to determine where the greatest reduction in environmental burdens can be achieved. Designing for Environment is a method by which environmental considerations and constraints are integrated into existing processes and product design practices (6). This involves comparing the energy and emissions of the various stages of the life cycle process (extraction, manufacturing, distribution, use, and disposal or recycle). For example, the Life Cycle Centre of the Institute for Product Development in Denmark conducted a study of portable telephones (15). For this particular product, the greatest: energy consumption was in the use phase rather than the production process or extraction (Fig. 10). This led engineers to focus design considerations on such things as increasing power efficiency in power amplifications and making use of

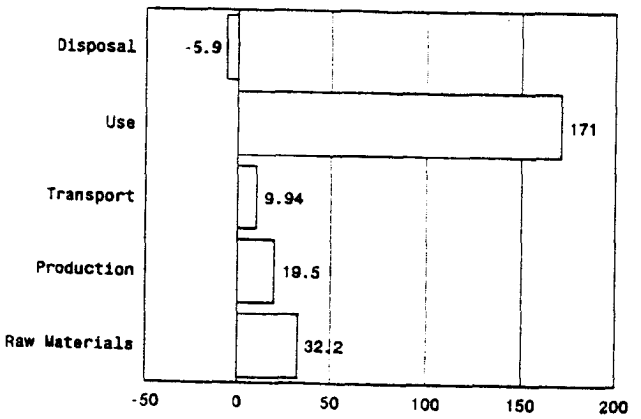

Figure 10.—Energy costs of different life cycle phases for portable telephones (15).

digital transmissions using time slots. All these modifications would result in increased energy efficiency during use. There are many other examples of using LCA to identify areas where improving the design can reduce the environmental burden. Thus, companies can emphasize particular aspects of the life cycle phases to minimize waste, conserve energy, eliminate hazardous materials, and conserve materials using LCA.

New directions

Eco-labeling

Eco-labeling is a designation awarded to products that are judged to be environmentally preferred compared with alternative products. Germany, Canada, Japan, Nordic countries, and the European Community have either government-funded eco-labeling programs or will have them in the near future. The United States has no national program, although several private efforts are underway. A concern of private efforts is that eco-labels may be based on different appraisal methods that could lead to confusion about which products are actually better for the environment.

The use of eco-labeling schemes, with the LCA of products at the heart, appears to be the most logical approach to encourage consumer confidence and activity in selecting products with the minimum environmental impact. Thus, increased activity and emphasis are being placed on certification standards in both ASTM and ISO. Estimates regarding the cost of certification indicates that 20 percent of the cost is for third-party certification (5). However, standards are not available at this time, primarily because major issues and questions need to be resolved before certification is fully established in the United States (5). Major questions include the following:

- Will certifiers have access to compliance data and systems?
- What will be the obligation of certifiers to report noncompliance to the authorities?
- Are certifiers to judge the adequacy and performance of systems, and if so, how will they be trained and what performance levels will be established for them to test against?
- Should certifiers be allowed to make their findings public or should manufacturers be mandated to be certified as a condition of certification?
- Who establishes the product criteria for certifiers to test?
- How can it be assured that certifiers remain objective and independent from regulators, activists, and those that seek certification?

Life cycle assessment model

Another activity currently being developed by the U.S. Department of Energy (22) is an integrated model that uses LCA methodology but also overlays economic considerations to assess the implications of an LCA analysis and determine the best method to reduce environmental burdens. The methodology combines LCA with life cycle costs.

Life cycle costs are defined as the internal and external costs associated with a product or process throughout its entire life cycle. Internal costs are those directly incurred by an organization, such as labor, capital investment, and regulatory compliance. External costs are those not directly incurred by the organization, such as resource depletion, water pollution, and ozone depletion.

Life cycle cost assessment is a method in which associated costs, either conventional, liability, or environmental, are attached to the various inputs and outputs of the life cycle inventory. Three examples of the different categories of life cycle costs are: Conventional (capital, labor, energy, regulatory compliance, waste disposal, and air emission control); Liability (legal counsel, penalties/fines, personal injury, remediation activities, economic loss, and property damage); and Environmental (global warming, ozone depletion, photochemical smog, acid depletion, water pollution, and chronic health effects).

Life cycle cost assessment is used to integrate economic and environmental cost information into the LCA framework to provide an overview of the implications of the LCA and guide decision makers. An integrated model is being developed by Sandia National Laboratories and other U.S. Department of Energy laboratories. This computer-based decision support tool will allow users to assess the cost and environmental effects associated with the life cycle of a product or process (22).

Concluding remarks

LCA procedures alone are not leading consumers to make environmental choices between similar products. In fact, the proliferation of conflicting life cycle analyses on the same products are causing consumer confusion and a lack of confidence in the LCA methodology. The problem lies with the complexities in using LCA, the data intensity of the method, and the level of detail chosen in selecting

the appropriate boundary conditions. LCA as part of a national eco-labeling scheme is one way to alleviate some confusion and concern regarding the proliferation of this tool as a marketing strategy. The most appropriate use of LCA is for evaluation of direct environmental burdens for particular processes.

Literature cited

1. Arima, T. 1991. Life cycle of timber residential swellings and environmental conservation. Wood Industry 46:635-640.
2. _____. 1993. Carbon dioxide emission and carbon storage for building materials and construction in Japan. Wood Design Focus 4(2):9-12.
3. Arnold, F.L. 1993. An evaluation of environmental life cycle assessment. Environmental Law Institute. Prepared under Cooperative Agreement CR-829539-01 by Economic Analysis and Innovation Div., Environmental Protection Agency. (May)
4. Buchanan, A.H. 1993. Concrete, steel, or timber: an environmental choice. Wood Design Focus 4(2):5-8.
5. Cascio, J. 1994. International Environmental Management standards (ISO 9000's Less Tractable Siblings). *In:* 1994 IEEE Inter. Symp. on Electronics and the Environment. San Francisco, Calif.
6. Chakrabarti, P. 1994. Designing revolution: policy for a clean and healthy electronics industry. *In:* 1994 IEEE Inter. Symp. on Electronics and the Environment. San Francisco, Calif.
7. Erlandsson, M., K. Odeen, and M.-L. Edlund. 1992. Environmental consequences of various materials in utility poles—A life cycle analysis. Doc. No: IRG/WP/3726–92. Inter. Res. Group on Wood Preserv.
8. Fava, J.A., R. Denison, B. Jones, et al., eds. 1991. A technical framework for life-cycle assessments. Soc. of Environmental Toxicology and Chemistry, Washington, D.C. 134 pp.
9. Franklin Associates, Ltd. 1992. Energy and environmental profile analysis of children's single use and cloth diapers. Franklin Associates, Ltd., Prairie Village, Kan. 114 pp.
10. Graedel, T.G. 1994. Prioritizing impacts: the second stage of life cycle assessment 1994. *In:* 1994 IEEE Inter. Symp. on Electronics and the Environment. San Francisco, Calif.
11. Honey, B.G. and A.H. Buchanan. 1992. Environmental impacts of the New Zealand building industry. Res. Rept. 92-2. Dept. of Civil Engineering, Univ. of Canterbury, Christchurch, New Zealand.
12. Hunt, R.G., J.D. Sellers, and W.E. Franklin. 1992. Resource and environmental profile analysis: A life cycle environmental assessment for products and procedures. Environ. Impact Assess. Rev. 12:245–269.
13. Johnson, B.W. 1994. Inventory of land management inputs for producing absorbent fiber for diapers: a comparison of cotton and softwood land management. Forest Prod. J. 44(6):39-45.
14. Koch, P. 1992. Wood versus nonwood materials in U.S. residential construction: some energy-related global implications. Forest Prod. J. 42(5):31-42.
15. Legarth, J., L. Altin, H. Eriichsen, et al. 1994. Proc. 1994 IEEE Inter. Symp. on Electronics and the Environment. San Francisco, Calif.
16. Lubbert, B., Y. Virtanen, M. Muhlberger, et al. 1991. Life-cycle analysis: an international database for eco-profile analysis. WP–91–30. Inter. Inst. for Applied Systems Analysis, Laxenburg, Austria.
17. Meil, J.K. 1993. Environmental measures as substitution criteria for wood and nonwood building products. Forintek Canada Corp., Ottawa, Ontario, Canada.
18. National Academy of Sciences. 1976. Renewable resources for industrial materials. Washington, D.C. 35 pp.
19. Richter, K. 1993. Life cycle analysis of wood and wooden products. VDI Berichte 1060:155-165.
20. _____ and J. Sell. 1992. Life-cycle analysis: a useful approach to promote wood as a construction material. Wood Design Focus 4(2):14-17.
21. Vigon, B.W., D.A. Tolle, B.W. Cornaby, et al. 1994. Life-Cycle Assessment: Inventory Guidelines and Principles. Lewis Publishers, Ann Arbor, Mich.
22. Warren, J.L. and K.A. Weitz. 1994. Development of an integrated life-cycle cost assessment model. *In:* 1994 IEEE Inter. Symp. on Electronics and the Environment. San Francisco, Calif.
23. Western Wood Products Association. 1993. Life cycle assessment and building materials. Wood Design Focus 4(2):12-13.
24. _____. 1994. Life cycle study breaks new ground. Out of the Woodworks 1(2):1-4.

Life Cycle Environmental Impact Analysis for Forest Products

Forest Products Society
2801 Marshall Court
Madison, WI 53705-2295 USA
phone: (608) 231-1361
fax: (608) 231-2152