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Life Cycle Assessment Tools to Measure Environmental Impacts:

Assessing Their Applicability to the Home Building Industry

Final Report

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Life Cycle Assessment Tools to Measure Environmental Impacts:

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Final Report

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December 2001

Acknowledgements

This project was performed under a cooperative agreement with HUD and the Vinyl Institute. This report was prepared by the NAHB Research Center, Inc. for the U.S. Department of Housing and Urban Development (HUD). Principal author was Richard Dooley; reviewing staff were Jeannie Leggett-Sikora, David Daquisto, and Mark Nowak. Thanks go to Ed Stromberg of HUD for his contributions and review.

This publication is based on information obtained during research conducted in 2001. Certain information, particularly World Wide Web site references and specifics of the life cycle assessment programs featured in the publication, is likely to change. Any references to costs or cost premiums should also be used with care.

FOREWORD

America's homebuilding industry faces many new challenges in the 21st century, particularly in the area of the environment. Not only must America's homebuilders comply with a large number of Federal, state, and local environmental regulations, they are being challenged to build environmentally friendly housing, i.e., housing that will actively support and promote a better environment. While such goals are quite laudable, there are no tools of demonstrated reliability for homebuilders to use as guidance to achieve these goals.

In the last decade, however, various organizations have developed computer-based modeling tools that attempt to qualify the potential environmental impacts and performance of various building materials. These models are generically known as Life Cycle Assessment (LCA) tools. LCAs have been developed to help user choose the most environmentally friendly building materials and building designs. Thus far, these tools have been used primarily by architects, designers, product manufacturers, and builders and engineers in the commercial building industry.

To date, there has been no systematic effort to examine the general validity of these tools or their applicability and utility for the residential building industry. Given the potential importance of these tools for America's homebuilders, HUD commissioned the NAHB Research Center to convene a meeting of experts to thoroughly examine these issues.

This publication presents the results of this examination. The report presents a critique of LCAs, and offers suggestions on how they could be made more useful. The results suggest that LCA tools are not ready, and may not be ready for some time, for homebuilders to use as a practical resource. I believe that this publication will make a significant contribution to our understanding of the potential role of this type of environmental assessment tool in the homebuilding process.

Lawrence L. Thompson
General Deputy Assistant Secretary for
Policy Development and Research

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EXECUTIVE SUMMARY

On April 20, 2001, a group of international experts met in Baltimore for a full-day workshop to discuss life cycle assessment (LCA) issues and the current state of LCA tools. In particular, the discussion focussed on the ways in which LCA tools affect and concern the home building industry. The tools thus far have been used primarily by architects, designers, product manufacturers, builders and engineers in the commercial building industry; the workshop was an opportunity to examine their usefulness for the residential building sector.

The workshop included a mix of participants of varied backgrounds. The goal was to have in the same room, not only LCA tool developers and LCA experts, but also professionals who are well versed in the environmental indicators (impact categories) that LCA tools attempt to profile via their algorithms.

In general, LCA tools take data and assumptions and produce an environmental rating for building products or systems. Five LCA tools developed around the world were highlighted at the workshop. Each tool has its own unique approach, design, and set of outputs. Tool developers briefly presented information on each tool to help forum participants understand each tool's breadth and idiosyncrasies.

Once details of each tool were presented, the forum participants had the opportunity to ask questions and express concerns about the tools in particular, and LCA in general. The day was split into four facilitated sessions, each focusing on a different topic area. The first session addressed data needs; the second concerned LCA methodologies; the third tried to determine the audience for the tools; and the fourth session concentrated on creating a list of recommendations to help make LCA tools more useful for the home building industry. Overall, the group felt that LCA tools are not useful to home builders in their current form. Information produced by the tools, however, might be useful to some people in the home building industry if its accuracy can be reasonably assured, and if results can be presented in a simple format, such as an eco-rating or a group of ratings. The usefulness of LCA tools to other groups that affect the product selection process was also examined.

ISSUES

The forum participants raised numerous issues during the course of the day. A full assessment of the issues brought up during the forum is contained in Section III of this document. Some of the key issues included:

- The information produced by the LCA tools is not valuable as stand-alone data. The data would need to be coupled with other information since the LCA data is not an absolute measure of product value;
- The data output is too complex for home builders to use in a timely manner;
- Input data is sparse and includes many assumptions that are hidden from the LCA tool user;
- Uncertainty in the results is not addressed; and

- The LCA tools and the data compilation requirements should at least meet international standards (i.e., ISO 14040 series) regarding LCA.

RECOMMENDATIONS

Participants offered many recommendations in the discussions that took place during the forum. Recommendations for increasing the usefulness of LCA tools to home builders include:

- Conduct market research to obtain supply chain feedback;
- Identify who has a market interest in using LCA tools;
- Increase data availability and transparency;
- Educate builders;
- Create benchmarks/inventory of real houses (site demonstrations);
- Conduct a case study to quantify the benefits of green building products;
- Investigate what the effect is of labeling a product as "green;"
- Understand the influence of "green" in the purchase decision process and long-term satisfaction of "green" home buyers;
- Connect "green" to a performance issue tangible to homeowners;
- Periodically repeat LCA forum;
- Educate building product manufacturers about the importance of LCA; and
- Assemble market research to understand the drivers in home building material selection.

RESEARCH CENTER CONCLUSIONS

LCA tools are designed to assess the environmental impacts associated with certain building products. The current tools, however, are in constant flux and the science is evolving. More work remains to be done in order to make LCA useful and applicable to the home building industry. The algorithms used for each impact category should be verified for accuracy, and the quantitative tools need to assess and report uncertainties in the results. Input data used by the tools needs to be improved; the amount of data and the data resolution should be enhanced. Assumptions, algorithms, and input data should be highly transparent in order to allow third-party and user review. A method should be developed and used to more comprehensively validate the LCA tools' accuracy. The proper role of LCA in decision-making needs to be more clearly defined and presented in a way that is relevant and helpful to builders if the tools are to find broad use in the residential sector.

LCA tools are currently designed to add environmental impact information to the building product purchase decision-making process. If builders are, in fact, the target audience of users, then the tools should include the following:

- A clear explanation that the tool does not include cost in its analysis (or an explanation of how cost is included), but is designed to capture only the environmental impacts of the building product;
- An explanation of the scale used in the output stage. For example, if a tool's output gives vinyl siding a number of 24 and for cementious siding, a number of 30 – on what scale is this analysis based? What are the units? Builders can understand the units used in costing a

product (e.g., dollars) or in sizing a product (e.g., inches). However, how do they gauge how much better or worse a product is based on the numbers in the tools' output? and
- Instructions, recommendations, or suggestions on how to factor the LCA results from the tool into an overall product selection decision.

The final point is particularly difficult. Presumably, when other factors are equal, the product selection decision should turn on results of the LCA. Unfortunately, other factors are rarely equal. LCA results, it is assumed, are not intended to outweigh all other factors; any other position would be unacceptable to most, if not all, builders. Still, without some usable guidance on how to address the trade-off between environmental performance and other product characteristics, builders could easily find the tool more frustrating than helpful. They might be best advised to consider their buyers' preferences and the extent to which their local market values "green" construction in determining how much to weigh data from, or whether to act upon, information developed through any LCA tool.

REPORT OVERVIEW

Section I of this report contains background information on LCA tools and the purpose of the LCA Forum. Section II explains how the forum was designed to elicit input from the meeting's participants and provides information on each of the tools highlighted during the event. Section III contains primary feedback obtained from participants during each of the facilitated discussions and recommendations regarding how to make the tools more applicable to the residential home building industry.

SECTION I – INTRODUCTION

A forum to discuss life cycle assessment (LCA) tools was held on April 20, 2001 at the Hyatt Regency Inner Harbor in Baltimore. Hosted by the NAHB Research Center, Inc., with support from the U.S. Department of Housing and Urban Development (HUD) and the Vinyl Institute, the forum brought together an international group of experts in various disciplines. Attachment A lists the thirty-three attendees. Participants were interested in how LCA tools evaluate potential environmental impacts of various building products and designs. The goal was to facilitate discussion among LCA experts and professionals well versed in the environmental indicators (e.g., indoor air quality, toxicology, solid waste) used in LCA analyses. Some of the tools refer to these indicators as "eco-indicators"; this report uses the more generic term "impact category" to refer to each environmental indicator.

During the last decade, several LCA tools have emerged which attempt to quantify the relative potential environmental impacts of building materials. These tools were developed to help users choose building materials and building designs. During the workshop, the group assessed the capability of five such tools that have been developed around the world:

- LCAid ™ (Australia)
- ATHENA™ (Canada)
- Building Research Establishment (BRE) Green Guide to Housing Specification (United Kingdom)
- Building for Environmental and Economic Sustainability (BEES 2.0) (United States)
- Life Cycle Explorer (United States)

According to the International Organization for Standardization (ISO) Environmental Management series, life cycle assessment is defined as a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle."[1]

[1] ISO 14040 – Environmental management – Life cycle assessment – Principles and framework, First Edition, 1997-06-15, p. 2.

For the interests of this report, LCA is a way to comprehensively assess a product or system's potential environmental impacts. In principle, an LCA tool includes all inputs (e.g., energy, water, and raw materials) and outputs (e.g., emissions to water, land, and air). Figure 1 shows the various phases during which a product could affect the environment.

Raw material acquisition ➔ Product manufacturing process ➔ Home building process ➔ Home maintenance and operation ➔ Home demolition ➔ Product reuse, recycling, or disposal

Figure 1. Building Product Phases Assessed in LCA

A growing number of builders use resource-efficient building products and advanced technologies in their new homes. Builders usually have different opinions regarding building products' resource-efficiency. The LCA tools discussed during the forum were designed in part to help users select the most resource-efficient product from the myriad of items available.

KEY ACRONYMS

Throughout this report a variety of acronyms will be used. Below is a list of the most commonly used acronyms; Attachment D contains a full list of acronyms used in the report.[2]

Life Cycle Assessment (LCA) – Compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle.

Life Cycle Inventory (LCI) – A phase of LCA involving the accounting of inputs and outputs across a given product or process life cycle.

Life Cycle Impact Assessment (LCIA) – A phase of LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product or system.

Life Cycle Cost (LCC) – A product's initial costs plus all future costs (operating, maintenance, repair and replacement costs, and functional-use costs) minus the product's salvage value (i.e., value of an asset at the end of economic life or study period). All costs are discounted to adjust for the time value of money.

ISO 14000 SERIES

The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies (ISO member bodies). ISO technical committees produce international standards on a variety of topics. Draft international standards adopted by the technical committees are circulated to member bodies for voting. Seventy-five percent of the member bodies voting must approve the Draft International Standard in order for it to become final.

[2] ISO 14040 - 14043 Standards.

The ISO 14000 series relates to numerous facets of environmental management. ISO 14040 – 14043 were prepared by Technical Committee ISO/TC 207, *Environmental Management Subcommittee SC 5, Life Cycle Assessment*. While ISO recognizes that LCA is still in a nascent stage of development, ISO 14040-14043 is a consensus-based, voluntary set of standards pertaining to LCA. ISO 14040 provides information on LCA principles and framework, while ISO 14041-14043 provides additional information regarding the various phases of LCA.

The standards are designed to guide the practitioner or analyst and are not legally binding or enforceable. They attempt to bring some consistency and credibility to the field as it emerges and takes shape.

ISO 14040 – Environmental management – Life cycle assessment – Principles and framework: Specifies the general framework, principles, and requirements for conducting and reporting life cycle assessment studies, but does not describe the life cycle assessment technique in detail.

ISO 14041 – Environmental management – Life cycle assessment – Goal scope and definition and inventory analysis: Specifies the requirements and procedures for the compilation and preparation of the definition of goal and scope for an LCA and for performing, interpreting, and reporting a life cycle inventory (LCI) analysis.

ISO 14042 – Environmental management – Life cycle assessment – Life cycle impact assessment: Describes and gives guidance on the general framework for the life cycle impact assessment (LCIA) phase of LCA, and the key features and inherent limitations of LCIA. It specifies requirements for conducting the LCIA phase and the relationship of LCIA to other LCA phases.

ISO 14043 – Environmental management – Life cycle assessment – Life cycle interpretation: Provides requirements and recommendations for conducting the life cycle interpretation in LCA or LCI studies. It does not describe specific methodologies for the life cycle interpretation phase of LCA and LCI studies.

SECTION II – LCA FORUM DESIGN

The overall goals of the forum were to:

- Determine the prospects and potential of LCA tools to provide valid, useful, and comprehensive information that could help the home building industry;
- Determine the status of LCA tool development as it pertains to the home building industry; and
- Identify the next steps that should be taken to meet the needs of LCA end-users.

Attachment B contains the forum's agenda. During the morning session, five developers of LCA tools were given approximately 20 minutes each to describe their tool and summarize its strengths and weaknesses.

The balance of the forum consisted of a series of facilitated discussions. Discussion following the presentations focussed on the availability and credibility of data used by LCA Tools. Main topics discussed during this session included the tools' transparency, degree of database commonality, and whether or not the tools should use industry-average data for a product line (e.g., vinyl windows) or specific product data for a specific manufacturer's product.

There were three additional facilitated discussions in the afternoon session. The first discussion focussed on the methodologies used by each tool to reach its respective output. The goal of this session was to explore ways to check the validity of results from each LCA tool. The group also discussed ways in which the LCA tools draw cause-and-effect relationships to assign specific impacts to particular products. In the second discussion, participants dealt with policy issues associated with the tools. For instance, part of the discussion addressed the purpose and value of the existing LCA tools, including who might use the tools and in what capacity. In the third session, the group formulated recommendations for the next steps that should be taken to make the tools more relevant to home builders and the home building industry. Descriptions of each tool can be found in Attachment C.

SECTION III – LCA FORUM RESULTS

As previously noted, after the LCA tool introductory session, the forum was split into four discussion sessions that sought answers to the following questions:

- **Session #1** - What is the availability and credibility of input data for LCA tools? Are there data gaps and, if so, how should data needs be prioritized? What methodological issues must be addressed?
- **Session #2** - How do the tools produce results from the raw data? For instance, how is a product rated on each impact category? In addition, how are individual ratings combined to produce an overall product rating? What are the impact categories based upon? Can the output of each model be validated?
- **Session #3** - How, where and by whom are existing LCA tools used? What is their purpose and value?
- **Session #4 –** What are some of the next steps that should be taken to help create tools that meet the needs of the home building industry?

The moderator asked the participants the primary questions and kept the discussion focussed throughout the day. Following is a synopsis of the answers provided by the participants.

SESSION #1 – DATA ANALYSIS

Quality of Data

The quality of input data to LCA software tools affects the quality of the results. In addition, lack of data can lead to inaccurate model results. For all intents and purposes, the quality of the LCA results is directly related to the quality and quantity of the input data. Many assumptions have to be made to fully quantify the inputs and outputs associated with a certain building product.

QUESTIONS ADDRESSED IN SESSION #1
- What is the availability and credibility of data needed as inputs to LCA tools?
- Are there data gaps and, if so, how should data needs be prioritized?
- What methodological issues must be addressed?

Analysis

For example, to determine the environmental impacts of mining ore to make steel c-shaped studs, assumptions need to be made about the distance between the mining site and the manufacturing facility, the process used to mine the ore, and the type of equipment used to mine the ore, among others. While assumptions help fill in the current LCA data gaps, they also contribute to uncertainty and inaccuracies in the results.

The quantity and quality of data available to LCA tools were just two of the main topics of discussion during Session I. Below is more information on other topics discussed in the session.

Gaps in Data

Since the highlighted software tools were developed and are used primarily in different countries, the data sources used by each tool differed. For instance, the BEES model relies partially on U.S. national averages for data related to the extraction of raw materials to the point of delivering those materials to the manufacturers' gates (known as “cradle-to-gate” data) and to the products after production (known as “gate-to-grave” data), and partially on manufacturing data. The ATHENA™ tool, on the other hand, uses LCI data developed from a national program in Canada. Table 1 provides information on the data sources for each of the LCA tools.

> According to the Society of Environmental Toxicology and Chemistry (SETAC), life-cycle assessment is “an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements.”

Table 1. LCA Tool Data Sources

TOOL	DATA SOURCE
LCAid ™ (Australia)	Materials phase: - DPWS LCA Database - Maintenance data from Department of Public Works and Services (DPWS) maintenance teams and material life cycle literature Construction phase: - Waste data during construction from literature - Operation phase (Water and waste calculation developed by DPWS from experience and literature; LCA of Australian energy supply; Links to thermal engines such as Ecotect or simply enter energy requirements from other thermal engines or benchmarks) Demolition phase: - Waste calculation developed by DPWS from literature
ATHENA™ (Canada)	Regionally specific life cycle inventory product databases owned by the ATHENA Institute and created with industry expert input.
Building Research Establishment Green Guide to Housing Specification (United Kingdom)	Associated database of LCA data available on the Internet.
Building for Environmental and Economic Sustainability (BEES 2.0) (United States)	Database owned by BEES.
Life Cycle Explorer (United States)	- Data and modeling approaches for window energy use are from a variety of publications, most of which are traceable to the U.S. Department of Energy's Lawrence Berkeley National Laboratory (LBL). - Data on regional heating system shares and efficiencies are from LBL. - Data on life cycle inventory flows from U.S. electricity generation, residential fuel combustion and pre-combustion, and transportation come from Franklin Associates, 2000. - Data on the material input and energy requirements for manufacturing window frames are from a Swiss research institute (SZFF/EMPA 1996 Study: Ecological Assessment of Window Constructions Using Various Frame Materials (without Glazing).) - Life cycle inventory data for glazings are from the University of Amsterdam's IVAM Research Agency (IVAM 1999: University of Amsterdam, Life Cycle Inventory Database on Building Materials.) - Life cycle inventory data for manufacturing raw material inputs used in window frame manufacturing are from the LCI databases found in SimaPro 4.0 available from PRe Consultants, NL.[3]

[3] "A Transparent Interactive Software Environment for Publishing Life Cycle Assessment Results: Demonstration Applied to Windows," Norris, G.A. and Yost, P., (to be published) Journal of Industrial Ecology.

Although some discrete United States (i.e., national) "cradle-to-gate" and the "gate-to-grave" data is available, data from manufacturers on processing operations is sparse at best. There are efforts underway to increase the amount of data worldwide. For example, the National Renewable Energy Laboratory (NREL) U.S. Database Project is planned to create a database that would contain regionally specific LCI data for the United States. Forum participants familiar with this project noted that the project had not yet begun and the completion of the LCI public database is still at least a few years away. Under the BEES project, the "BEES Please" initiative is designed to encourage manufacturers to provide more manufacturing data for inclusion in the BEES model.

Although many forum participants noted that the data used in the models should be regionally specific, there was not much concern or discussion regarding the tasks included in gathering and qualifying data as it becomes more defined. Certain assumptions are currently made at the national level. If the data becomes regional in scope, then those same assumptions will have to be made or the data will have to be reevaluated and more assumptions made to account for regional data variability.

SIX AREAS OF LCACCESS

- **Why LCA:** A broad overview of information to educate people about the concept of LCA.
- **LCA 101:** A detailed overview of how to organize and manage an LCA project.
- **Global LCI Directory:** International directory of existing LCI data sources and other sources of data that can be used to complete a life-cycle inventory.
- **LCA Resources:** A list of publications, books, standards, and links to other websites that contain additional information on both managing and conducting an LCA.
- **On-going Efforts:** A list of on-going efforts in the field of LCA.
- **Upcoming Events:** A calendar of LCA-related conferences, meetings, and activities. For further information go to http://www.epa.gov/ORD/NRMRL/lcaccess/index.htm

Analysis

Going from national averages to regional averages adds another layer of complexity to the data gathering process. As more flows are added and the level of aggregation is reduced, data requirements grow exponentially.

One of the projects designed to help address the need for more LCI data is the U.S. EPA-sponsored LCAccess project. LCAccess (see sidebar) is a website designed to promote LCA and to help people make more informed decisions through better understanding of the human health and environmental impacts of products, processes, and activities. LCAccess strives to meet this goal by providing information on:

- EPA's role in LCA;
- The benefits of LCA;
- What is LCA and an overview of how to conduct an LCA;
- How to find LCI data sources (LCI Global Directory);
- Available LCA resources (e.g., documents, software tools, other related links);
- On-going efforts in the field of LCA (e.g., EPA, other U.S. efforts, international efforts); and
- Upcoming events.

LCAccess is in Phase II of its development; completion of such a system is at least a few years away. The website can be viewed at http://www.epa.gov/ORD/NRMRL/lcaccess/index.htm, with the exception of the Global LCI Directory, which was projected to be available by the end of 2001.

Comprehensiveness and Transparency of Data

Forum participants also discussed the concepts of comprehensiveness and transparency of the existing data. Given that there is currently a lack of data available to developers and the users of the LCA tools, certain assumptions need to be made to fill in data gaps. Some of the forum participants were concerned with the assumptions being made in the modeling process and wanted to know if the model's users could view the assumptions. With some LCA tools, assumptions are not made available to the user. This can lead to problems of misunderstanding the model's system boundaries or ability to predict how a certain building product impacts any of the model's impact categories.

Lack of ISO 14040 Conformance Among Input Data

The forum revealed that the tools are loosely tied, but do not adhere, to the ISO series' data compilation requirements.

> The International Organization for Standardization (ISO) developed a series of guidelines, 14040 – 14043, related to LCA. One of the goals of the group charged with creating these guidelines was to obtain input from throughout the world on the guideline's content. Although people criticize the *ISO Principles and Framework* as vague and difficult to attain, it is the closest document that the LCA community has to an international standard.

Analysis

For instance, Section 5.3.4 of ISO 14041 states that, "such data may be collected from the production sites associated with the unit processes within the system boundaries, or they may be obtained or calculated from published sources."[4] It was unclear from the forum's discussion whether or not all calculated data came from published sources.

Data Are National, Not Regional Averages

The data and assumptions used in LCA are typically based on general, national averages, or sometimes on data from other countries. The problem with national data is that, for example, the time and energy used in the mining and processing of raw materials can vary from site to site.

Analysis

Thus, using the national averages may only provide a user with a general notion of a building product's potential effect on one or more of the model's impact categories. The use of average

[4] ISO 14041 – Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis, First Edition, 1998-10-01, p. 6.

data raises additional theoretical problems. Environmental impacts are incurred or avoided at the margin, so the relevant parameter is how flows change as the output changes. This can be larger or smaller than average flows, but the difference cannot be determined without knowing more about the production process. In other words, even if the data and algorithms are correct, the true environmental impacts of a decision may differ from the impacts determined by LCA.

Section 5.3.6 of ISO 14041 addresses the issue of data quality: "Data quality requirements should be included for the following parameters:

- Geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the study (i.e., local, regional, national, continental, global); and
- Technology coverage: technology mix (e.g., weighted average of the actual process mix, best available technology or worst operating unit)."[5]

According to the forum participants, the NREL U.S. Database Project is designed to provide regional data, but it will take a few years before the data from that project is available to LCA tool users. Because each new flow must be mapped for each process, going from national averages to regional averages adds another order of magnitude to the task of data collection.

The NREL project's goal is to produce public LCI databases for commonly used materials, products and processes. It has a focus on user needs in that it strives to:

- Support public and private sector efforts to develop decision-support systems and tools;
- Provide regional benchmarks for generating or assessing company, plant, or new technology data; and
- Provide the foundation for subsequent life cycle assessment tasks.[6]

Phase I of the U.S. Database Project began May 1, 2001. Project partners include the U.S. General Services Administration (GSA), U.S. Department of Energy (DOE), and U.S. Department of Defense (DOD). An advisory committee consisting of public and private sector representatives familiar with LCA will review the work of the consultant team of ATHENA Sustainable Materials Institute, Franklin Associates, Ltd., and Sylvatica and offer comments as the project progresses. Phase II of the project will involve both government and private sources and will expand the scope of the databases.

Analysis

The availability of accurate data in the current and foreseeable future is important to the usefulness of LCA tools. Because some LCA tool users will not pay attention to the caveats offered along with the tool's results, users may believe that the conclusions are scientifically valid and definitively project a product's impact on one (or more) of the impact categories. In

[5] ISO 14041 – Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis, First Edition, 1998-10-01, p. 7.

[6] Personal communication with Wayne Trusty, ATHENA Institute, 6/27/01.

order to make LCA tools more reliable for use by home builders, more accurate input data and fewer caveats on the output are necessary.

50-Year Horizons versus Shorter Time Horizons

Participants recommended changing the 50-year life cycle used by LCA tools to more accurately reflect buyers' actions.

Analysis

For instance, when determining whether to make use of a commonly-used building product (e.g., vinyl siding) or one marketed as more environmentally friendly (e.g., cementitious siding), buyers typically focus on the up-front costs. If a buyer were to consider a product's future costs in the decision-making process, they would likely use the time frame in which they would live in the home. Recent data suggests this period averages about 12 years.

Section 5.3.6 of ISO 14041 states that, "In all studies, the following additional data quality requirements shall be considered in a level of detail depending on goal and scope definition:

- Representativeness: qualitative assessment of degree to which the data set reflects the true population of interest (i.e., geographical coverage, time period and technology coverage)."[7]

The forum participants also noted that current LCA tools go well beyond the purchaser's time horizon, in that they examine a product's life cycle throughout fifty years. Thus, LCA results on cementitious siding based on the 50-year time horizon may indicate that it costs less environmentally and economically than vinyl siding. A five-year horizon comparing the two siding products favors vinyl siding. Most home buyers do not live in a house for 50 years so are less apt to consider the LCA results. In addition, LCA tools may not adequately take into account the market acceptance or desirability of a material. For instance, cementitious siding may need to be maintained more often than vinyl siding after five years. If a person building a home is planning to sell the home in five to ten years, the issue of resale value becomes very important from the buyer's perspective. Very little data is available on the market valuation of environmentally preferable alternative products, complicating the buyer's analysis.

LCA tool developers noted that the discrepancy between the time horizon used by the tools and the time horizon used by home buyers underscored the need to educate future home buyers and builders on the LCA results and to show how future generations are impacted by today's buying and building decisions.

Lastly, homeowners often remodel for aesthetic reasons making a physically sound product (e.g., a shag carpet) functionally obsolete. So although the product makers created a product that would last fifty years, real-world factors reduced the product's effective life to less than half of that. It is unclear how LCA tools take or should take such issues into account.

[7] ISO 14041 – Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis, First Edition, 1998-10-01, p. 7

Proprietary and Company-Specific Data

The LCA data currently provided by manufacturers is often reviewed and validated by consultants. These professionals generally have background knowledge and expertise in economics, engineering, and environmental issues. There is a certain amount of trust built into the data review process.

Individual companies or industry organizations currently hold much of the data needed by LCA tools. To accurately calculate an individual product's impact on the environment, the tools need specific details regarding what type and amount of chemicals and other materials go into the product. Legal counsel for these companies and organizations often resist releasing the manufacturing data because they are concerned with liability and/or proprietary issues. For instance, the manufacturing data could be used by U.S. EPA to conduct mass balance calculations and might bring a company under greater scrutiny by the regulators. In addition, if the data is provided to the government, a company's competitor might obtain the proprietary data through a Freedom of Information Act (FOIA) request. Opening the company to increased regulatory scrutiny or losing market share are barriers that may not be overcome with the monetary incentives used by tool developers.

Analysis

However, when it comes to knowledge of a specific industry's processes (e.g., the manufacture of insulated concrete forms), the consultants rely on industry professionals to verify the data's accuracy as well as the description of the product's process-mapping.

In addition, forum participants stated that certain assumptions are then built into the data analysis, which can lead to inaccurate model results because two companies' manufacturing processes may be markedly different for the same end product. One problem is that a company's trade secrets may be built into its manufacturing process, and to reveal those secrets to the LCA community may lead to competitive disadvantage for that company. On the other hand, not revealing the difference in the manufacturing processes to LCA tool developers could make one company's product appear less desirable than competitors' products given the assumed manufacturing processes built into the LCA's tool. In essence, the current state of LCA tools generally does not take into account the inherent variability of the manufacturing processes across producers. Also, the people charged with verifying the accuracy of the data are not experts in each particular industry, making it difficult for them to identify potential problems with the company's data and assumptions.

Given that LCA is formally in its nascent stages (e.g., ISO 14040 was approved June 16, 1997), it is time consuming to populate the databases with useful and reliable data. This is critical because of the LCA tool's heavy reliance on accurate data. For example, it took approximately $70,000 to collect a limited dataset for windows for the Life Cycle Explorer LCA tool. Therefore, a very large sum of money would likely be needed to gather the appropriate data to accurately compare many different building products.

Database Standardization

Forum participants noted that it would be beneficial both from the LCA tool user's and the manufacturer's points of view to have consistency in the data dictionaries across all databases used by LCA tools. Such consistency could lead to a greater amount of data available for use by an LCA tool and could help address the regional variability of some of the data.

Analysis

Each tool highlighted during the LCA forum used its own LCI data, and there is no standardization of the databases to allow for one tool to easily use the database created for another tool.

Usage Phase of Materials

In general, LCA tools do not take into account the ways in which building products are maintained and operated. Certain assumptions are built into a product's dataset related to how it is used because it is difficult to determine the frequency and type of maintenance that will be done on that product.

Analysis

For instance, how often will a homeowner shampoo a carpet or clean a hardwood floor? What types of chemicals are in the cleaning solutions used on the product? Clearly, these are homeowner-specific considerations, and general maintenance and operation assumptions are difficult to incorporate into the LCA tools. Related to indoor air quality (an impact category for at least one of the LCA tools), the amount of outgassing that occurs during the product's maintenance/usage phase may exceed the amount of outgassing derived from the product itself.

In addition, the LCA tools face great difficulties taking into account how a product acts within the building system, for example, with respect to the operational energy. A window's operational energy is only partly determined by heat loss through the window; it is also a function of the efficiency of the HVAC and duct systems. However, the tools do not allow the user to enter that efficiency data. Some of the tools isolate a product's performance and potential environmental impacts and have problems taking into account the building as a system, e.g., how changes to a building's design or orientation, or how the use of other products in the house could alter the product's impacts. Analyzing the window and the HVAC system separately can be misleading because there are strong performance interactions, but analyzing them together can make results even more complex and harder to interpret.

Finally, the extended usage phase characteristic of building materials introduces a whole new dimension of complexity. Energy sources and associated pollutant flows will change throughout this period, but the models are essentially static. As power plants become cleaner, for example, the environmental impact of <u>any</u> window is reduced. The impacts depend on future events that are difficult or impossible to predict. This problem is much less significant when LCA is applied to disposable or short-lived products.

SESSION #2 – LCA TOOL METHODOLOGIES

Assumptions Built Into LCA Methodology

As noted before, because of LCI data gaps, various assumptions are built into each tool. In addition, there are assumptions inherent in the algorithms used to calculate a product's potential effect on an impact category. Forum participants noted that there should be transparency in that the user should be able to determine what assumptions are used for each of the impact categories. They indicated that background information should be made available so that each user can determine whether or not an assumption is appropriate, such as how a product's outgassing contributes to ozone depletion or global climate change.

QUESTIONS ADDRESSED IN SESSION #2

- How do the tools produce results from the raw data? For instance, how is a product rated on each ecoindicator?
- In addition, how are individual ratings combined to produce an overall product rating?
- What are the ecoindicators based upon?
- Can the output of each model be validated?

Analysis

If a tool is truly attempting to capture a product's environmental life cycle costs, it should consistently use the same algorithms to calculate the product's impacts on each impact category. The end-user can then change the tool's settings to determine for which impact category data is to be displayed. For instance, one person using a tool may not be interested in a product's impact on global climate change but may be interested in ozone depletion, while another person using the same tool is interested in eutrophication but not in ozone depletion.

Forum participants noted that although the end results should not change across impact categories, the way in which the conclusions are displayed should be adaptable to the user's preferences; the tools should not impose a fixed approach to how the data should be displayed.

Participants also commented that the combination of the individual impact category results into a single LCA score needs to be reassessed. If a tool attempts to create a single score to simplify conclusions, then the methodology it uses to weight the individual impact categories needs to be transparent.

Double Counting Issues

Forum participants indicated there are two primary issues regarding double counting. First, solely considering LCA, it was unclear whether or not the tools guard against inappropriately applying a product's potential effects to more than one impact category. For instance, if a product is given one LCA score for global climate change, and another score for ozone depletion, it is unclear whether or not some of the product’s contribution to global climate change is also included in the product’s ozone depletion score.

Second, one of the tool developers acknowledged that there is no way to tell how much double counting is done on a case-by-case basis as it pertains to the merging of LCC and LCA. Market prices already reflect some of a product’s resource utilization and even environmental impacts. Therefore, when a product goes through separate LCA and LCC analyses, overlap can occur. It is difficult for tool developers to quantify the amount of overlap partially because it is difficult to quantify a product's environmental impacts.

Analysis
Section 5.3.3.d of ISO 14042 states that “the impact categories, category indicators and characterization models should avoid double counting unless required by the goal and scope definition, for example when the study includes both human health and carcinogenicity.”[8] In addition, double counting becomes an even larger issue as the use of LCC spreads. For example, the environmental impacts of a window may be attributed to the window, the heat pump, and the power plant. The fact that these impacts can only be avoided once is easily lost as multiple actors weigh them in isolation.

ISO 14040 Conformance on Methodology

Similar to the issue related to data acquisition, developers loosely base the LCA tools on the ISO 14040 Principles and Framework. They note, however, that the tools do not entirely conform to the standard because of the vague nature of ISO 14040 and because it would be difficult to adhere to every part of the international standard. For instance, forum participants noted that at least one of the tools reviewed for ISO 14040 conformance failed to conform to the issues of transparency and uncertainty analysis.

Analysis
Section 10.2.3.d states that “in addition, for comparative assertions disclosed to the public, the report shall include the following items: the results of the uncertainty and sensitivity analyses.”[9] Section 7 of ISO 14042 also addresses the potential need for additional techniques and information that may be needed to “better understand the significance, uncertainty, and sensitivity of the tool’s results.”[10] Failure to address these issues can rob the results of a meaningful context, and lead users to act as if the data were more reliable than it really is.

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[8] ISO 14042 – Environmental management – Life cycle assessment – Life cycle impact assessment, First Edition, 2000-03-01, p. 6.
[9] ISO 14042 – Environmental management – Life cycle assessment – Life cycle impact assessment, First Edition, 2000-03-01, p. 12.
[10] ISO 14042 – Environmental management – Life cycle assessment – Life cycle impact assessment, First Edition, 2000-03-01, p. 10.

Validity Testing

When asked how the tool's results were being validated, tool developers told forum participants that the best way to confirm the accuracy of a tool's results was to run the tests as often as possible on as many products as possible, i.e., repeatability was the key. If a tool was used numerous times to determine a product's potential environmental impacts, and the outputs from each run were similar, then tool developers concluded that the tool accurately portrays that product's impacts. Conversely, if the run's results do not make intuitive sense, or if the results are markedly different from one run to another, then this would alert the developers to the need for reassessment of the model's algorithms and for recalibrating the model.

One of the group's participants commented that one of the hallmarks of good science is that a result can be tested independently and proven to be right or wrong. Given the approach of the tool developers, it can be very difficult to disprove outputs of the LCA tools.

Analysis

As was noted before, LCA must invoke numerous assumptions related to the impact categories. For instance, one set of scientists believes that global climate change will increase the global temperature by "x" degrees in 30 years, while another set of scientists thinks that the temperature will increase by "x+3" degrees. It is the role of the tool developers to determine what algorithms and assumptions to build into the tool. The tool developer, in turn, must rely on his/her expertise to make up for the lack of agreement in the scientific community. However, it may take many years to come to consensus on the correct set of assumptions, if consensus is reached at all.

From another perspective, the application of flow coefficients to derive, aggregate and compare impacts from production in itself is just arithmetic and accounting. "Validation" in this setting requires examination and verification of the flow coefficients themselves, as well as the algorithms and equations used to translate these flows into particular impact categories. The complexity of the models and multidisciplinary nature of LCA make this very challenging. A few of the many areas requiring assessment to validate a model are:

- Relative global warming potential of different gases;
- Environmental impact of mineral extraction methods;
- Toxic impact of disposing of materials such as lead or particulates; and
- Carcinogenicity related to ozone depletion.

Different Tool, Different Approach and Application

By highlighting the five different LCA tools during the forum, it became apparent that each tool had its own unique application. Therefore, while each tool could be called an LCA tool, there was little consistency in the methodologies used from one tool to another. In addition, while one tool considered the building as a system, other tools considered primarily the product's individual attributes rather than how that specific product performed within the building system. Forum participants suggested that it would be less confusing for the users if there was consistency in methodology between the various tools.

Unequal Uncertainty Across Impact Categories

Some forum participants indicated that there is no one right answer as it pertained to the model outputs. Rather, the tools should be used to show relative impacts when comparing two products' potential effects on an impact category. In addition, there is a different degree of certainty related to each impact category, i.e., the amount of scientific knowledge and certainty reflected in the algorithms varies across impact categories.

Analysis

Scientists are in general agreement on the algorithms associated with the smog impact category, but there is a much greater range of scientific opinion when it comes to the eutrophication impact category.

Section 8 of ISO 14042 notes that regarding the limitation of LCIA, "category indicators may vary in precision among impact categories, due to differences:

- Between the characterization model and the corresponding environmental mechanism, e.g., spatial and temporal scales;
- In the use of simplifying assumptions; and
- Within available scientific knowledge."[11]

For example, the characterization model may focus on one point in the cause-effect chain (such as emissions to air of VOCs) which is different from the environmental mechanism of concern (such as inhalation of ozone molecules, O_3). The influence of VOC release upon O_3 inhalation will vary, depending on factors such as emissions timing (summer versus winter) and location (rural versus urban). Thus, time and space uncertainty about releases introduces uncertainty in the expected connection between releases (the object of LCIA characterization) and the actual endpoints of concern (e.g., human health in this case). Such uncertainties and their potential strength of influence can vary by impact category.[12] It appears none of the tools can deal with this explicitly.

There is also cumulative uncertainty as a tool attempts to combine the individual impact category scores into more comprehensive LCA scores, yet no tool attempts to characterize the overall uncertainty in its outputs. Life cycle assessment is intentionally an elaborate and very detailed process that the tools attempt to simplify as much as possible. However, tool developers must take care so that the process is not simplified to the extent that the conclusions are inaccurate or not useful, or portray only worst-case scenarios.

The overall uncertainty is further complicated if the data is not separated and classified into separate types of flows at the impact level. For example, emissions to air, land, or water need to be separated for certain impacts such as eutrophication, to account for the dramatically different influences they have on the environment. Likewise, the use of average data, as is common

[11] ISO 14042 – Environmental management – Life cycle assessment – Life cycle impact assessment, First Edition, 2000-03-01, p. 10.
[12] Personal communication with Greg Norris, Sylvatica, 11/26/01.

practice, should consider the period or rate of discharge and the existing conditions. A discharge into healthy waters will produce different results than the same discharge into an already polluted or marginally-polluted system. Likewise, a large, short-term discharge would not likely have the same impact as a slow release over time, even though they may have the same "average" size. With the right effort it may be possible to reduce the uncertainty contributed at this level, although it is unknown if the data exists to do so or whether it would take heroic efforts to gather it at this level.

It should also be noted that the selection and modeling of impact categories used in LCA is still being refined. For example, the Eco-Indicator 95 method was developed for the Dutch government with the best scientific knowledge at that time. When designers used that method to help determine building products' environmental impacts, they may have chosen certain products based on the Eco-Indicator 95 output. However, after further review, the Eco-Indicator 95 method has been significantly revised and has been replaced by the Eco-Indicator 99 method. This is an example of the state of impact categories. There is much we still do not know, and the LCA tools for use in the building industry should explain or acknowledge that questions remain regarding which impact categories should be used, and how those categories should be modeled.

In addition, each LCA tool differs in the number and type of impact categories it uses for its analysis. For instance, LCAid™ includes "heavy metals" as one of its impact categories, whereas BEES does not incorporate that impact category, but it does contain the category "human toxicity." This inconsistency regarding impact categories across LCA tools indicates how hard it can be to compare results or to determine whether two tools are analyzing the same thing.

LCAID™ IMPACT CATEGORIES

- Acidification
- Carcinogenesis
- Eutrophication
- Greenhouse effect
- Heavy Metals
- Ozone Depletion
- Pesticides
- Summer smog
- Winter smog

BEES IMPACT CATEGORIES

- Acid rain
- Ecological toxicity
- Eutrophication
- Global warming
- Human toxicity
- Indoor air quality
- Ozone depletion
- Resource depletion
- Smog
- Solid waste

Overall, the uncertainty in results from any of the tools could be quite large. Perhaps more importantly, they are unknown and very poorly understood, at best. Whether a useful and realistic analysis of uncertainty can ever be conducted here remains to be seen. The authors of the Eco-Indicator 95 report may sum up the uncertainty best in the following statements:

> *"Despite all the precautionary measures taken, there is a fairly large degree of uncertainty in the impact tables. These uncertainties are very difficult to quantify. In the same paragraph they state that "It does not seem impossible for the Eco-indicator to be erroneous by a factor of 2 in some cases because of uncertainties in the impact table. This estimate cannot, however, be backed up."*

There is No Right Answer – There's a Goal of Simply Continuously Improving the Tools

The forum participants noted that users should not try to compare a building product's impact category value to the product's value for that same impact category using another LCA tool as one might do when comparing the gas mileage of two different cars. Forum participants noted that users should pick an LCA tool and work within it, looking at the scores of different products to help guide the decision-making process. In addition, since no one right answer exists when trying to determine a building product's impact category value, users should look at relative, as opposed to absolute, improvement when comparing two products' impacts. In essence, LCA tools should be used to identify where the surprises exist.

Fine-Tune within Product Categories

Significant environmental differences can exist between manufacturers and products within building material categories. For example, one carpet manufacturer may produce a significantly superior product regarding environmental impacts when compared to another carpet manufacturer. Currently, the LCA tools combine all of the data related to carpets and compare that product category to other related product categories (e.g., hardwood flooring products).

To more accurately portray a particular product's potential environmental impacts, an individual product's LCA data is necessary. The "BEES Please" program is attempting to gather individual product data. The program is new and the extent to which manufacturers will participate remains to be seen.

SESSION #3 – LCA TOOL AUDIENCE

Clarify LCA Tool's Limitations

Given that there is uncertainty and numerous assumptions built into each product's LCA, each tool should emphasize up front the tool's capabilities as well as its weaknesses. For instance, a user should know the uncertainty range that should be applied to a product's impact category's value.

QUESTIONS ADDRESSED IN SESSION #3
- How and where are existing LCA tools used?
- What is their purpose and value?
- Who uses the tools (e.g., builders, policy makers)?

Analysis

If a product has a value of 150 for the "smog" impact category but the uncertainty is ±50 for that value, the effective range with uncertainty included would be 100 to 200. Thus, if another product scored 200 for smog, that would put that product's value in the same range as the first product. From a statistical standpoint, the products may not differ at all. Once again, Section 10 of ISO 14042 notes that the results of uncertainty analyses shall accompany reports that contain comparative assertions to the public.

What You Get is a Generic Result

Related to the point of LCA tool's limitations, the tools currently provide generic results for building product categories, not for an individual company's products.

The tool's output should acknowledge that within a product category there can be a range of results, and a particular product's impact may differ markedly from another product's impact even though they are lumped together. The significance of this approach depends on how much variation exists between products within a product category relative to the variation across product categories.

A Single Group Should Advise Home Builders on Which Products are Best, Based on the LCA Tool's Results

The consensus among the group was that builders would not take the time to use these tools in their current form. Therefore, numerous participants suggested that the NAHB Research Center or a similar organization should perform the LCA analyses on products using the existing LCA tools and make results available to the home builders.

People Make Choices Every Day When Buying Products – LCA is Yet Another Metric to Add to the Decision-Making Process

The assumption of the LCA tool developers is that price signals in a competitive market do not adequately and accurately portray the environmental impacts associated with building materials. Thus, LCA results should be used in combination with other metrics, such as first costs and LCC to help identify the best possible product for the application.

LCA Output Should Be Very Simple for the Home Builder, and This May Not Be Possible in the Immediate Future

The main issue is that in order to have a simple LCA output, very complex processes and impacts need to be radically simplified. One builder suggested that the best way to help builders utilize the LCA tool's results would be to create an easy-to-use system showing an individual product's LCA results. For instance, when a builder is selecting between blown-in cellulose insulation and fiberglass batt insulation, a simple number (or a small set of numbers) stamped on each product could help in comparing each product's potential environmental impacts.

Builders and Contractors Obtain Product Information from Building Suppliers

In the past, builders selected individual products from numerous suppliers and manufacturers who provided them with performance information. The group discussion revealed that often many builders now rely on building product suppliers to learn about a product's performance. Therefore, the LCA results should be understandable to the building product supplier, and education efforts should be directed toward suppliers.

For many LCA tools, the focus has been on applying the concepts to commercial building where architects and designers are often involved early in the construction/design process. However, in residential construction, the supplier and distributor are key elements to product selection. They have the materials and the information for the builders on what a product can or cannot do.

Potential Audiences

Below is a list of other potential end-users for LCA tools as suggested by the group.

- Specifiers
- Product developers
- Architects
- State/local/federal government personnel
- Interior designers
- Educators/academia
- Builders – Large and small volume
- Financial community (eventually)
- Realtors
- Code/regulatory personnel
- Utilities
- Developers
- Engineers
- Consultants
- Home buyers
- Pre-schoolers
- Green building program developers
- Subcontractors
- For builders – the question is "small" or "large" builder; "Custom" or "production"

SESSION #4 – RECOMMENDATIONS AND CONCLUSIONS

> **QUESTION ADDRESSED IN SESSION #4**
> - What are some of the next steps that should be taken to help home builders better understand LCA tools' capabilities?

There are still a number of questions associated with LCA tools and their application to the home building industry. The forum concluded with the participants producing a list of action items illustrating how LCA tools can help the home building industry—in particular, the home design and building product selection processes. Following is a description of the action items offered by the forum participants.

Conduct Market Research to Obtain Supply Chain Feedback

Since builders are unlikely to use LCA tools, and builders rely on product suppliers and distributors to provide relevant information on a product's performance, focus groups should be conducted with suppliers and distributors. These focus group sessions should attempt to identify the information needed by suppliers and distributors in order for them to relay necessary information to builders during the product selection process.

Identify Who Has a Market Interest in Using LCA Tools

From the list of potential end users identified in Session III, determine who could bring about change in the product selection phase of the home building process, what groups would be interested in effecting change, and why. In addition, the group felt further market research is needed to help product manufacturers better understand what would motivate those groups to use LCA tools.

Increase Data Availability and Transparency

Ensure that the NREL U.S. Database Project produces a regional-level database that is fully transparent allowing the end-users or reviewers to assess the quality of the data.

Educate Builders

Create educational materials about the concept of LCA and the pros and cons of using LCA tools to select products. Since builders and developers look to the NAHB Research Center for reliable technical, information related to home building issues, the Research Center would be a good candidate to lead this educational effort. Part of the process could include participating in the NREL U.S. Database Project.

Create Benchmarks/Inventory of Real Houses (Site Demonstrations)

Conduct a literature search to identify case studies of homes built using LCA in the building design or product selection process. The search results could be compiled in a publication and marketed to key groups involved in the product selection and home design processes. In the event there is a lack of such cases for study, demonstration or field evaluation homes could be built in order to obtain real-world field results.

Conduct a Case Study to Quantify the Benefits of Green Building Products

Work with builders in using LCA to help select products and to design and build homes. Monitor those homes for certain criteria (e.g., IAQ, energy usage, durability) and compare to conventional homes. Participants noted that the project should be geographically representative, establish a target objective to demonstrate, and include economic

RESEARCH CENTER CONCLUSIONS

- LCA tools are designed to assess the environmental impacts associated with certain building products. However, the current tools are in constant flux and the science is evolving. More work remains to be done in order to make LCA useful and applicable to the home building industry.
- The algorithms used for each ecoindicator should be verified for accuracy and quantitative tools need to assess and report uncertainties in the results.
- The input data used by the tools needs to be improved in that the amount of data and the data resolution should be enhanced. Assumptions, algorithms, and input data should be highly transparent in order to allow third party and even user review.
- A method should be developed and used to more comprehensively validate the LCA tools' accuracy.
- The proper role of LCA in decision-making needs to be clearly defined and presented in a way that is relevant to builders if the tools are to find broad use in the residential sector.

analyses. Forum participants noted that the Green Building Advisor is a case study template to consider. The Green Building Advisor, created by BuildingGreen, Inc., is a software tool that helps the user identify green design strategies for building projects. Linked screens describe each strategy in detail and provide information on relative costs.

Investigate What the Effect is of Labeling a Product as "Green"

Conduct a study that determines if labeling a product as "green" (e.g., similar to an Energy Star label) has an effect on buyer decisions. Work would include investigating whether buyers demand more information about green products, or if a name indicating environmental friendliness is sufficient. The results of this study could help determine if LCA results would be useful to buyers. The product to be labeled green could be the one that receives the best LCA scores within a product line.

Understand the Influence of "Green" in the Purchase Decision Process and Long-Term Satisfaction of "Green" Home Buyers

Conduct focus groups with home buyers to identify the drivers in the purchase and product selection decisions. For instance, do buyers emphasize the IAQ aspects of building products, or do they place more importance on energy efficiency or durability? Overall, increase public awareness of LCA's pros and cons.

Connect "Green" to a Performance Issue Tangible to Homeowners

In order to quantify the environmental performance of building products, develop a system to tie products to tangible aspects of performance. For example, quantify the VOC reduction from using a certain product (low- or no-VOC paint) over a conventional product (standard paint).

Educate Building Product Manufacturers about the Importance of LCA

Although there are some building product manufacturers that think LCA is an important tool in product development and improvement, the majority of manufacturers think LCA is just another gimmick to help sell more products. In general, manufacturers need to be educated on the concepts of LCA and how those concepts apply to manufacturers and their products. Use manufacturer trade associations to help spread the word within the industry by incorporating educational sessions during regularly scheduled national or regional events.

Another idea is to work with product manufacturers to voluntarily create a one- to two-page document similar to an MSDS for each product (similar to Europe's Environmental Declarations). The documents would simply state, "Here are the environmental ingredients based on an LCA."

Assemble Market Research to Understand the Drivers in Home Building Material Selection

Survey home builders to determine the primary factors for product selection when building a home. When is cost the overriding issue, and when do other factors such as product durability, aesthetic value, reduction of callbacks, ease of maintenance or environmental impacts outweigh cost? This could be an ongoing project to determine how to create a demand for "green" building materials from builders and home buyers.

Periodically Repeat LCA Forum

Forum participants noted that the open dialogue between LCA tool developers, impact category experts, and potential users was a very positive step toward understanding the issues of using LCA. Many participants thought that a follow-up forum to further refine and prioritize the list of recommendations would be useful.

Analysis – How We See Home Builders Using These Tools

Home builders take many factors into account, particularly purchase price and installed cost, when deciding which building product to purchase for a project. In addition, for each product they may also consider its:

- Aesthetic appeal
- Color
- Durability
- Ease of installation
- Ease of maintenance and operation
- Environmental impacts
- Local availability
- Manufacturer
- Size
- Usability
- Warranty

Most importantly, builders will base their analysis on what a particular client or the marketplace desires. There is no guarantee that a builder will want or need to use LCA tools. However, like a tape measure can give the builder a product's size, and a price tag can give the product's cost, the LCA tools can give a builder a product's environmental impact analysis.

LCA tools are currently designed to add environmental impact information to the building product purchase decision-making process. If builders are, in fact, the target audience of users, then the tools should include the following:

- A clear explanation that the tool does not include cost in its analysis (or an explanation of how cost is included), but is designed to capture only the environmental impacts of the building product.
- An explanation of the scale used in the output stage. For example, if a tool's output gives vinyl siding a number of 24 and for cementious siding a number of 30 – on what scale is this analysis based? What are the units? Builders can understand the units used in costing a product (e.g., dollars) or in sizing a product (e.g., inches). However, how are they to gauge how much better or worse a product is based on the numbers in the tools' output?
- Instructions, recommendations, or suggestions on how to factor the LCA results from the tool into an overall product selection decision.

The final point is particularly difficult. Presumably when other factors are equal, the product selection decision should turn on results of the LCA. Unfortunately, other factors are rarely equal. Presumably, the LCA results are not intended to outweigh all other factors; any other position would be unacceptable to most, if not all, builders. Still, without some usable guidance on how to address the trade-off between environmental performance and other product characteristics, builders could easily find the tool more frustrating than helpful. They might be best advised to consider buyers' preferences and the extent to which their local market values "green" construction in determining how much to weigh data from, or whether to act upon information developed through, any LCA tool.

ATTACHMENT A – ATTENDEE LIST

NAME	COMPANY	CITY, STATE (COUNTRY)
Jane Anderson	Building Research Establishment Environmental Assessment Method (BREEAM)	Garston, UK
John Burrows	Canadian Wood Council	Ottawa, Canada
Scott Chubbs	International Iron & Steel Institute	Brussels, Belgium
David Dacquisto	NAHB Research Center, Inc.	Upper Marlboro, MD
Graham Davis	Habitat for Humanity International	Colorado Springs, CO
Mark Decot	U.S. Department of Energy	Washington, DC
Richard Dooley *	NAHB Research Center, Inc.	Upper Marlboro, MD
Chris Fennell *	NAHB Research Center, Inc.	Upper Marlboro, MD
Bill Franklin	Franklin Associates	Prairie Village, KS
Kurt Frantzen	University of South Florida	Tampa, FL
Bill Freeman, Jr.	Resilient Floor Covering Institute	Lancaster, PA
Brian Glazebrook	EcoBalance	Bethesda, MD
Ruth Heikkinen	U.S. Environmental Protection Agency	Washington, DC
Dominique Hes	Center for Design - RMIT	Melbourne, Australia
Mike Levy	Environmental Strategies & Solutions	McLean, VA
Bobbi Lippiatt	National Institute of Standards and Technology (NIST)	Gaithersburg, MD
Chris Long	U.S. Environmental Protection Agency - Research Triangle Park	Research Triangle Park, NC
Jamie Lyons	NAHB Research Center, Inc.	Upper Marlboro, MD
Medgar Marceau	Construction Technology Labs	Chicago, IL
Greg Norris	Sylvatica	North Berwick, ME
Mark Nowak	NAHB Research Center, Inc.	Upper Marlboro, MD
John Ritterpusch	NAHB	Washington, DC
Bev Sauer	Franklin Associates	Prairie Village, KS
Bob Schubert	Virginia Tech	Blacksburg, VA
Tim Skone	Science Applications International Corporation (SAIC)	Reston, VA
Ed Stromberg	U.S. Department of Housing and Urban Development	Washington, DC
Jeff Terry	Vinyl Institute, Inc.	Arlington, VA
Joel Todd	The Scientific Consulting Group, Inc.	Gaithersburg, MD
Wayne Trusty	ATHENA Institute	Ontario, Canada
D'Lane Wisner	PolyOne	Cleveland, OH
Steven Young	Five Winds International	Ontario, Canada

* Facilitator

ATTACHMENT B – LCA FORUM AGENDA

8:00 – 8:20 a.m.	Registration & refreshments
8:20 – 8:30	Forum opening remarks and agenda review
8:30 – 10:30	Overview of existing LCA tools (LCAid™; BEES 2.0; ATHENA™; LCExplorer; Green Guide)
10:30 – 10:45	Break
10:45 – 12:30 p.m.	Facilitated discussion – What is the availability and credibility of the data needed in the LCA tools? Are there data gaps and, if so, should we prioritize our data needs? What methodological issues must be addressed?
12:30 – 1:00	Lunch
1:00 – 2:45	Facilitated discussion – How do the tools get from the raw data to the end result? For instance, how does a product get rated on each impact category? In addition, how are those individual ratings combined to produce an overall product rating? What are the impact categories based on? Can one validate the output of each model?
2:45 – 3:00	Break
3:00 – 4:00	Facilitated discussion – Assess the purpose and value of existing LCA tools. How and where are they used, and who uses them (e.g., builders, policy makers)?
4:00 – 4:15	Break
4:15 – 5:00	Facilitated discussion (Action item development) – participants recommend what needs to be done next in order to meet the home building industry's needs
5:00 – 5:15	Forum closing remarks

ATTACHMENT C – LCA TOOL DESCRIPTIONS

The LCA Forum was not intended to determine which of the five highlighted tools is superior; rather, it used the tools as examples of how LCA can be applied to the home building design and product selection processes. Tool developers emphasized to forum participants that each tool had a unique application and cautioned against comparing the various LCA outputs to one another. Following is a capsule summary of each tool.

LCAID™

LCAid™ is a software package created by the Australian Department of Public Works and Services (DPWS). It is a tool that can be used to evaluate the environmental performance and impacts of designs and options over the entire life cycle of a building, development, system or object. Figure C1 illustrates the environmental issues and scope considered by LCAid™.[13]

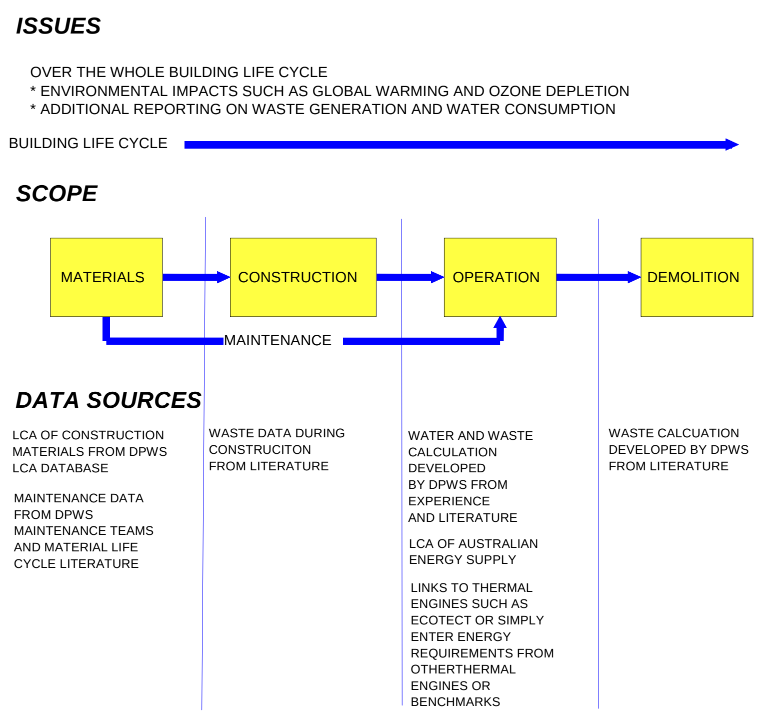


Figure C1. Environmental Issues and Scope of LCAid™

[13] Personal correspondence with Dominique Hes, Center for Design – RMIT, April, 2001.

LCAid™ Scope and Issues

The software package was created to help building designers and to provide a benchmark of building performance after construction. Data can be input manually, and in what is a unique feature of this tool, data can be imported from 3-D architectural drawing (Computer Aided Drafting or CAD) packages.

LCAid™ uses Eco-Indicator 95, which provides global and some general environmental impacts of building materials. Eco-Indicator 95 was produced for the National Reuse of Waste Research Programme (NOH) in the Netherlands and includes the following impact categories:

- Acidification
- Carcinogenesis
- Eutrophication
- Greenhouse effect
- Heavy Metals
- Ozone Depletion
- Pesticides
- Summer smog
- Winter smog

The tool can report results in two different ways: a comparison can be made to a benchmark building, or the environmental impact of each lifecycle stage can be presented to determine the stage having the greatest environmental impact.

GREEN GUIDE FOR HOUSING SPECIFICATION

The *Green Guide for Housing Specification* was developed by Britain's Building Research Establishment Ltd., (BRE). It is a tool that assesses the environmental impacts of over 150 various materials and components most commonly used in home construction. The Guide takes environmental issues into account, then adds measurements and user-defined weighting to arrive at environmental impacts, measured as "Ecopoints" for each building material being assessed. Figure 3 is a sample output screen showing the comparative Ecopoints for floor finishing options. A lower score translates into a decreased environmental impact.

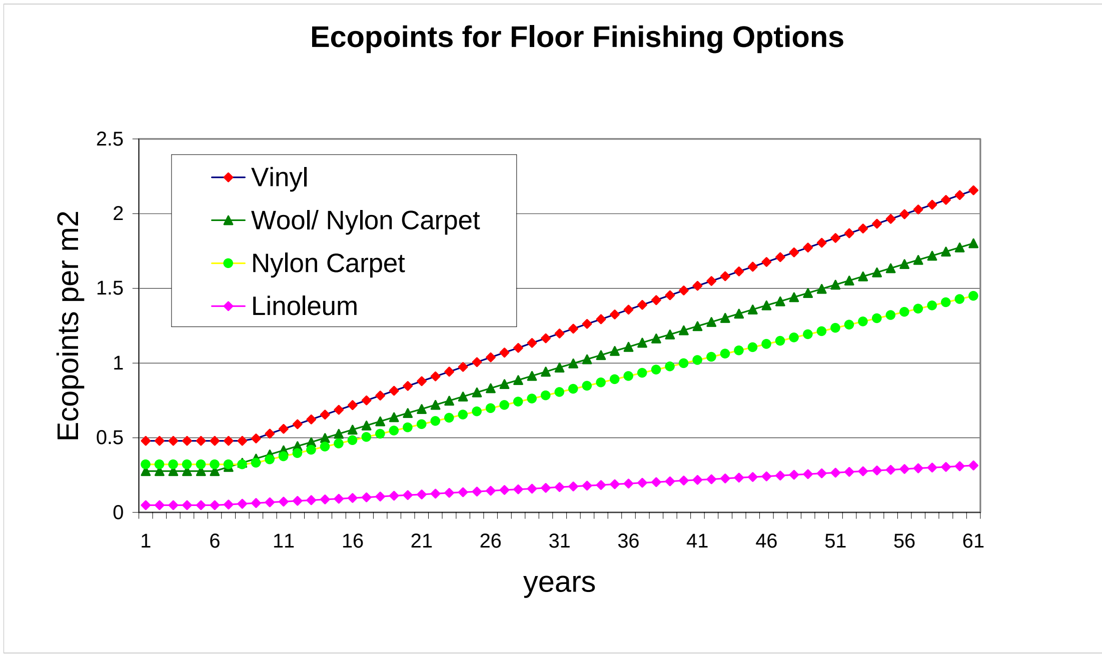
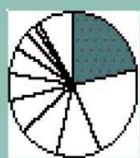


Figure C2. Green Guide Output Screen for Floor Finishing Options

For each building material category (e.g., wall, roof, floor), the environmental impacts are plotted on a simple environmental rating scale running from A (good) to C (poor) along with simple costs and service life estimates. Twelve different environmental impacts are individually scored, together with an overall summary rating, which enables users to select materials and components according to overall environmental performance over the life of the home. Since ratings are also given for individual environmental issues, such as climate change, the user can alternatively select materials and components on the basis of personal preferences or priorities, or take specification decisions based on the performance of a material against a particular environmental parameter. Figure 4 provides a sample page from the guide indicating the relative ratings for external wall options.[14]

The materials and components have been arranged into construction categories (e.g., external wall construction, internal walls, and upper floor construction) so that users can compare and select from similar systems or material specifications. Ratings are based only on a specification's performance within its respective construction category.

[14] Personal communication with Jane Anderson, BREEAM, 7/12/01.



External walls	Summary Rating	Climate change	Fossil fuel depletion	Ozone depletion	Freight transport	Human toxicity	Waste disposal	Water extraction	Acid deposition	Ecotoxicity	Eutrophication	Summer smog	Minerals extraction	Cost	Typical replacement interval	Recycled input	Recyclability	Currently recycled	Energy saved by recycling
Framed wall construction																			
Brickwork outer leaf, insulation, steel frame, plasterboard, paint	**A**	A	A	A	A	A	B	A	A	A	A	A	A	£50–£70	60	C	A	A	A
Brickwork, timber frame with insulation, plasterboard, paint	**A**	A	A	A	A	A	B	A	A	A	A	A	A	£50–£68	60	C	A	A	A
Canadian Cedar weatherboarding, timber frame with insulation, plasterboard, paint	**B**	A	A	A	C	A	A	A	A	A	A	A	A	£52–£72	30	C	B	B	B
Clay tiles, battens, timber frame with insulation, plasterboard, paint	**A**	A	A	B	A	A	A	A	A	A	A	A	A	£60–£79	60	C	A	C	A
Concrete tiles, battens, timber frame with insulation, plasterboard, paint	**A**	A	A	A	A	A	A	B	A	A	A	A	A	£67–£81	60	C	A	C	A
Painted, pre-treated softwood weather boarding, timber frame with insulation, plasterboard, paint	**A**	A	A	A	A	A	A	A	A	A	C	C	A	£43–£62	30	C	B	C	B
PVC weatherboarding, timber frame with insulation, plasterboard, paint	**C**	C	C	C	A	C	A	A	C	C	A	A	A	£57–£82	30	C	C	C	C
Terracotta rainscreen cladding, aluminium framework, insulation, aerated blockwork wall, plasterboard/plaster, paint	**A**	B	A	A	A	B	A	A	B	A	A	A	A	£155–£220	30	A	A	A	A

Figure C3. Sample Output from Green Guide for External Wall Options

To ensure that credible, similar comparisons are made, a "functional unit" of comparison has been defined for each category. To compare dissimilar building materials, the software evaluates the amount of material that is needed to build similar functional units. For instance, in the case of external walls the functional unit of "1 m^2 of wall" satisfies UK Building Regulations. Thus, the environmental impacts of 1 m^2 of each external wall specification listed have been assessed and compared with each wall including sufficient insulation to give a U value of 0.45 W/m^2K.

Using functional units for comparing specifications means that variables such as the mass of material needed to fulfill a particular function, such as structural stability, are taken into account. This is important because comparing the environmental impacts of, for example, one ton of structural steel and one ton of structural concrete would be misleading since less steel may be needed to perform the same function.

BEES 2.0

The Building for Environmental and Economic Sustainability (BEES) 2.0 software tool measures the environmental performance of building products. It was developed by the National Institute of Standards and Technology (NIST) with support from the United States Environmental Protection Agency (EPA) Environmentally Preferable Purchasing Program and the Partnership for Advancing Technology in Housing (PATH).

BEES 2.0 analyzes a product's life cycle, including raw material acquisition, manufacture, transportation, installation, use, and recycling and waste management. Up to ten environmental impacts are measured across the life cycle stages, including:

- Acid rain
- Ecological toxicity
- Eutrophication
- Global warming
- Human toxicity
- Indoor air quality
- Ozone depletion
- Resource depletion
- Smog
- Solid waste

BEES measures economic performance using life cycle costing, which covers the costs of initial investment, replacement, operation, maintenance and repair, and disposal. The life cycle cost method sums these costs over a fixed period of time. Figure C4 shows the overall BEES 2.0 approach to LCA.

BEES uses multi-attribute decision analysis to wrap environmental impacts together with economic performance to form an overall performance measure. The BEES user specifies a weighting factor used to combine environmental and economic performance scores based on the relative importance to the user or based on defaults provided with the software. The user then may test the sensitivity of the overall scores to different sets of weighting factors.

LEED vs. BEES Study

The U.S. Green Building Council has developed the Leadership in Energy and Environmental Design (LEED) building rating tool that places certain values on building products; LEED is not an LCA software tool. LEED is used by some architects and building designers to build sustainable commercial structures. A study was conducted comparing the ways in which one LCA tool (BEES 2.0) valued a building's components to the relative values LEED placed on those same building materials. Although both tools attempted to assess the product's environmental impacts throughout its life cycle, preliminary results indicate that product values differed markedly in some cases. The study's final conclusions are expected to be published by the end of 2001.

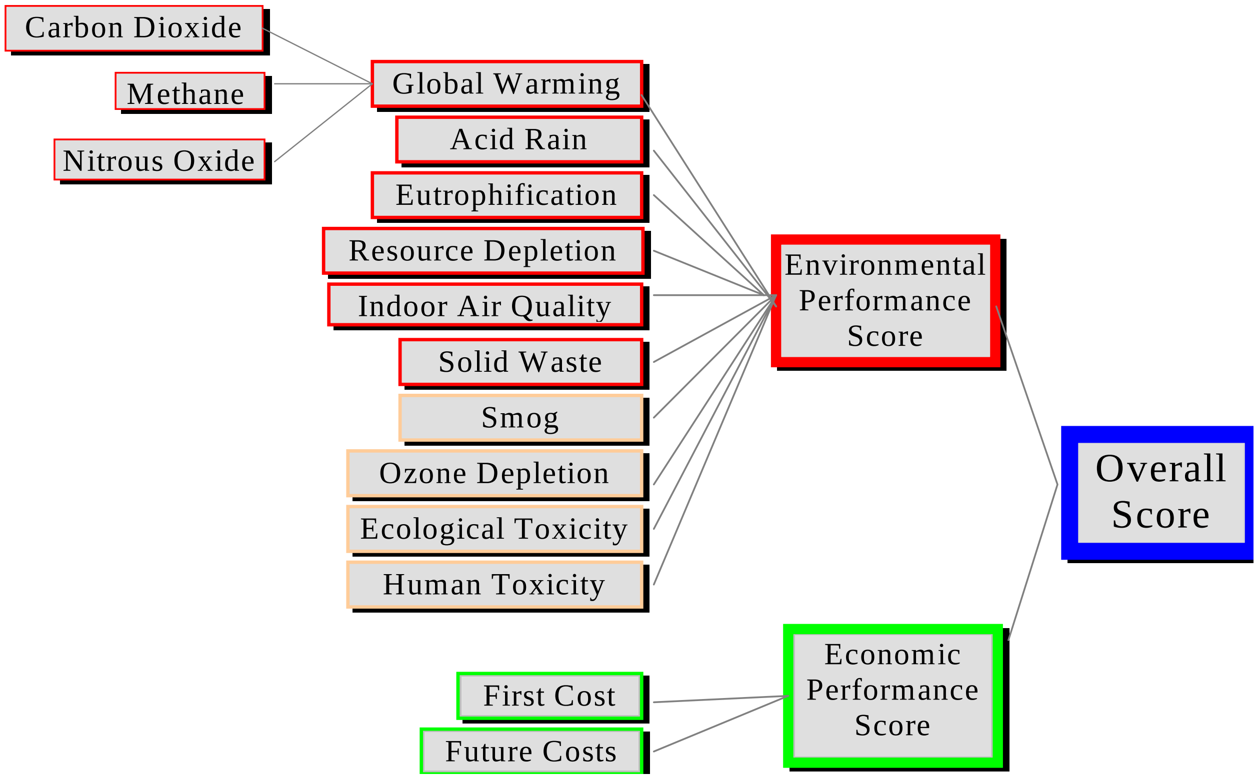


Figure C4. BEES Approach to LCA

ATHENA™

ATHENA™ is an environmental assessment tool being developed by the ATHENA Sustainable Materials Institute in Canada. It does not assess environmental impacts of individual building products. Instead, ATHENA™ allows the users to look at the life cycle environmental effects of a complete structure or of individual assemblies and to experiment with alternative designs and different material mixes to arrive at the best scenario.

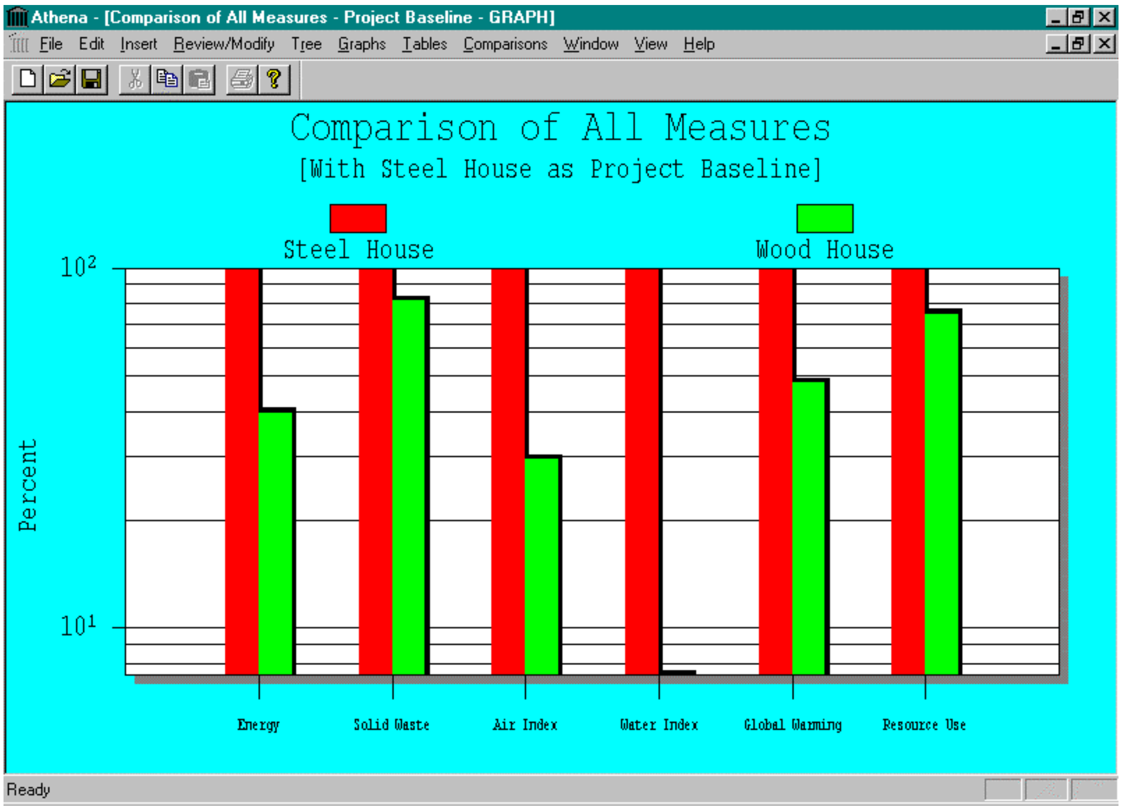


Figure C5. Example Results Screen for ATHENA™

Manufacturers can also use the model to benchmark processes and assess the environmental effects of alternative technologies or production processes.

ATHENA™ allows comparisons of *conceptual* building designs in a holistic, life cycle framework. It includes vertical and horizontal structural assemblies using wood, steel, and concrete products. The model datasets encompass typical assemblies, standard structural products, and existing typical technologies for producing products. The datasets currently focus on Canada, with the intention to include data from the United States in the future.

In the latest version of ATHENA™, environmental measures are calculated and presented (for structural assemblies only) for the first three stages (e.g., manufacturing, construction, operations and maintenance) in a building's life cycle. Also included are transportation costs within and between stages. Figure C5 shows an example results screen from the ATHENA™ model.

LIFE CYCLE EXPLORER

Life Cycle Explorer (LCE) is a software tool (currently in prototype mode) developed by Sylvatica that portrays the life cycle environmental performance of windows. Its analysis begins at manufacturing inputs and ends at the window disposal phase. It is intended to allow users to compare the relative performance of alternative products. It also shows the characteristics that are the primary influence on a window's environmental performance. Figure C6 is a sample output screen comparing different window types over their lifetime.

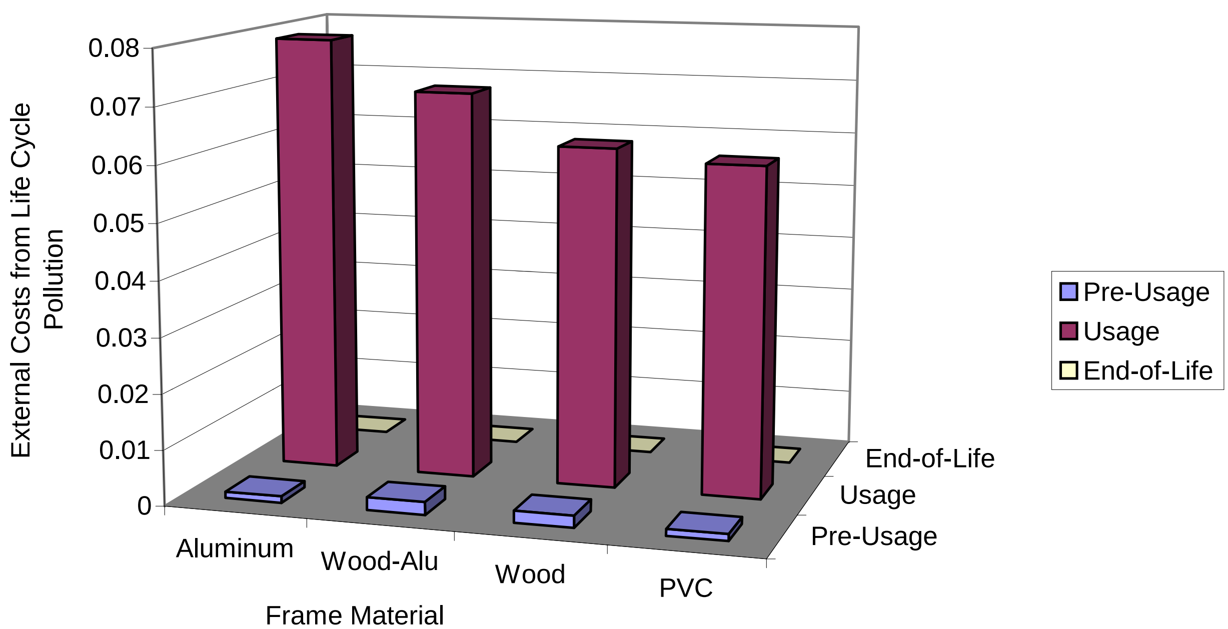


Figure C6. Example Output Screen from Life Cycle Explorer

The LCE does not determine which window is best from an environmental perspective; however, it can provide answers to many questions that one might wish to ask when making such a decision. Some of the questions the LCE attempts to answer include:

- Which are the most important pollutants or environmental impacts in the window life cycles?
- Which parts of the window life cycle are most influential environmentally?
- Which design aspects of a window are most influential environmentally?
- Which processes or material components of a window are most influential environmentally?
- How does a specific window design or alternative compare with other specific designs/alternatives?

ATTACHMENT D – ACRONYMS

BEES	Building for Environmental and Economic Sustainability
BRE	Building Research Establishment
CAD	Computer Aided Design
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DPWS	Australian Department of Public Works and Services
EPA	United States Environmental Protection Agency
GSA	General Services Administration
HUD	United States Department of Housing and Urban Development
IAQ	Indoor Air Quality
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCE	Life Cycle Explorer
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LEED	Leadership in Energy and Environmental Design
NIST	National Institute of Standards and Technology
NOH	National Reuse of Waste Research Programme
NREL	National Renewable Energy Laboratory
PATH	Partnership for Advancing Technology in Housing
ROI	Return on Investment

SETAC	Society of Environmental Toxicology and Chemistry
VOC	Volatile Organic Compound