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BEES® 4.0

Building for **E**nvironmental and **E**conomic **S**ustainability
Technical Manual and User Guide

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NIST
National Institute of Standards and Technology
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Building for **E**nvironmental and **E**conomic **S**ustainability Technical Manual and User Guide

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Abstract

The BEES (**B**uilding for **E**nvironmental and **E**conomic **S**ustainability) version 4.0 software implements a rational, systematic technique for selecting environmentally-preferred, cost-effective building products. The technique is based on consensus standards and designed to be practical, flexible, and transparent. The Windows-based decision support software, aimed at designers, builders, and product manufacturers, includes actual environmental and economic performance data for over 230 building products across a range of functional applications. BEES measures the environmental performance of building products using the environmental life-cycle assessment approach specified in International Organization for Standardization (ISO) 14040 standards. All stages in the life of a product are analyzed: raw material acquisition, manufacture, transportation, installation, use, and waste management. Economic performance is measured using the ASTM International standard life-cycle cost method (E917), which covers the costs of initial investment, replacement, operation, maintenance and repair, and disposal. Environmental and economic performance are combined into an overall performance measure using the ASTM standard for Multiattribute Decision Analysis (E1765). For the entire BEES analysis, building products are defined and classified based on the ASTM standard classification for building elements known as UNIFORMAT II (E1557).

Key words: Building products, economic performance, environmental performance, green buildings, life cycle assessment, life-cycle costing, multiattribute decision analysis, sustainable development

Disclaimer

Certain trade names and company products are mentioned throughout the text. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the product is the best available for the purpose.

The policy of the National Institute of Standards and Technology is to use metric units in all its published materials. Since this software product is intended for U.S. manufacturers and users of building products who evaluate performance using customary units, it is more practical and less confusing in some cases to use the customary rather than metric units. Where possible, however, both metric units and their customary equivalents are reported.

Acknowledgments

The BEES tool could not have been completed without the help of others. Thanks are due the NIST Building and Fire Research Laboratory (BFRL) for its support of this work from its inception in 1994. Thanks are due the U.S. Department of Agriculture Office of the Chief Economist for supporting development of BEES results for biobased products, and the U.S. Environmental Protection Agency (EPA) Pollution Prevention Division for its support over the years. Deserving special thanks is the BEES environmental data development team from Four Elements, LLC and First Environment, Inc. for its superb data development, documentation, and technical support. Special recognition is due Four Elements' Anne Landfield Greig, whose technical expertise, diligence, patience, and unwavering support have contributed in no small measure to the success of BEES. Jane Bare, of the EPA Office of Research and Development, Sustainable Technology Division, and her TRACI team (particularly Greg Norris of Sylvatica, Inc. and Tom Gloria, formerly of Five Winds International) were instrumental in developing the life cycle impact assessment methods incorporated into BEES, and continue to go out of their way to help the author adapt these methods to the practicalities of BEES. Thanks are also due Tom Gloria and Jennifer Cooper of Five Winds International for their technical support for the BEES Stakeholder Panel convened at NIST in May 2006, as well as Lawrence Berkeley National Laboratory for providing the Energy Star "Cool Roof" data used to analyze BEES roof covering alternatives. The author is particularly grateful for the key cooperation and support offered by a wide variety of industry associations and manufacturers with products represented in BEES. Their cooperation exceeded all expectations, and led to a significant expansion and refinement of the underlying BEES performance data. The comments of NIST BFRL colleagues Doug Thomas and Cindy Reed inspired many improvements. Special thanks are due Julie Wean for heroically incorporating more than 230 products, including their online documentation, into BEES 4.0, and for carefully helping test and review the tool. Thanks are also due Tessa Beavers for her outstanding administrative support.

Copyright Information

Getting Started

System Requirements

BEES 4.0 runs on Windows 95 and beyond personal computers with at least 60 MB of available disk space. ***At least one printer must be installed.***

Uninstalling BEES 3.0

While uninstalling BEES 3.0 is not necessary to run BEES 4.0, you may choose to do so. *All* BEES 3.0 files are contained in the folder in which you installed BEES 3.0 (usually C:\BEES30d). Thus, the entire BEES 3.0 program may be uninstalled by simply deleting that folder. If you choose to leave BEES 3.0 on your system, *do not* install BEES 4.0 to its folder.

Installing BEES 4.0

From Download Site. Once you've completed the BEES registration form, click Submit, and then click BEES40zip.exe to download the self-extracting file. If prompted during the download, choose to save the file, taking note of the folder to which it is saved. Once downloaded, from Windows Explorer, go to the folder containing BEES40zip.exe and double click on the file to begin the self-extraction process. Choose to unzip the file to a new folder by entering a new folder name when prompted. Click Unzip. Once unzipped, from Windows Explorer double click on the file SETUP.EXE in your new folder to begin the self-explanatory BEES 4.0 installation process. During installation, you will need to choose a folder in which to install BEES 4.0; you must choose a folder *different* from the one containing the setup file (SETUP.EXE). Once installation is complete, you are ready to run BEES 4.0 by selecting Start→Programs→BEES→BEES 4.0.

From CD-ROM. Install BEES by inserting the compact disc into your CD-ROM drive and running the BEES setup program, SETUP.EXE. Follow on-screen installation instructions. Once installation is complete, you are ready to run BEES 4.0 by selecting Start→Programs→BEES→BEES 4.0.

Running BEES

First time BEES users may find it helpful to read the BEES Tutorial, found in section 4 of this report. Section 4 is a document-based version of the BEES 4.0 Tutorial topic of the software’s on-line help system, with step-by-step instructions for running the software. The section also includes illustrations of the screen displays. Alternatively, first-time users may choose to double-click on the BEES 4.0 Help icon included in the BEES program group at installation for a self-contained electronic version of the entire online help system.

While running the BEES software, context-sensitive help is often available from the BEES Main Menu. Context-sensitive help is also available through Help buttons on many of the BEES windows.

Technical Support

For questions regarding the BEES model or software, contact blippiatt@nist.gov.

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1. Background and Introduction

Construction significantly alters the environment. According to the United Nations Environment Programme,[1] this industry sector consumes about half of the resources taken from nature worldwide, including 25 % of the wood harvest. Mining, quarrying, drilling, and harvesting these natural resources not only depletes them but pollutes the air and water, generates waste, and accounts for biological diversity losses. Once acquired, transporting raw materials to production facilities, then transforming them into building and construction products, generates further pollution and requires considerable energy consumption with its associated greenhouse gas emissions.

After production and transportation to a building site, many products generate waste at installation. Others have relatively short useful lives, leading to frequent disposal and manufacture of replacement products. Others contribute to unhealthy indoor air. Indoor pollutant concentrations have been found to be twice to five times as high as those outdoors. Yet other products influence building heating and cooling loads, largely responsible for building operating energy use, which accounts for 40 % of U.S. energy consumption. Worldwide, energy consumption by the built environment is responsible for 40 % of greenhouse gas emissions.

Selecting environmentally preferable building products is one way to reduce the negative environmental impacts associated with the built environment. However, while a 2006 poll by the American Institute of Architects showed that 90 % of U.S. consumers would be willing to pay more to reduce their home's environmental impact, they would pay only $4000 to $5000, or about 2 %, more.[2] Thus, environmental performance must be balanced against economic performance. Even the most environmentally conscious building product manufacturer or designer will ultimately weigh environmental benefits against economic costs. To satisfy their customers, manufacturers and designers need to develop and select building products with an attractive balance of environmental and economic performance.

Identifying environmentally and economically balanced building products is not an easy task. Today, the green building decisionmaking process is based on little credible, scientific data. There is a great deal of interesting green building information available, so that in many respects we know what to *say* about green buildings. However, we still do not routinely quantify and synthesize the available information so that we know what to *do* in a way that is transparent, defensible, and environmentally sound.

In this spirit, the U.S. National Institute of Standards and Technology (NIST) Healthy and Sustainable Buildings Program began the **B**uilding for **E**nvironmental and **E**conomic **S**ustainability (BEES) project in 1994. The purpose of BEES is to develop and implement a systematic methodology for selecting building products that achieve the most appropriate balance between environmental and economic performance based on the decision maker's

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[1] United Nations Environment Programme, "Sustainable Building and Construction: Facts and Figures," *Industry and Environment: Sustainable Building and Construction*, Vol. 26, No. 2-3, April-September 2003.

[2] January 2006 survey cited in *Washington Post*, 8/6/06, p M3 (Green Buildings article by Sacha Cohen). %

values. The methodology is based on consensus standards and is designed to be practical, flexible, and transparent. The BEES model is implemented in publicly available decision-support software, complete with actual environmental and economic performance data for a number of building products. The intended result is a cost-effective reduction in building-related contributions to environmental problems.

In 1997, the U.S. Environmental Protection Agency (EPA) Environmentally Preferable Purchasing (EPP) Program began supporting the development of BEES for a number of years. The EPP program is charged with carrying out Executive Order 13423, "Strengthening Federal Environmental, Energy, and Transportation Management," which directs Executive agencies to reduce the environmental burdens associated with the $230 billion in products and services they purchase each year, including building products.

In 2002, the U.S. Department of Agriculture's Office of the Chief Economist, Office of Energy Policy and New Uses, began supporting the development of BEES results for biobased products. The 2002 Farm Bill authorized the creation of a program, known as BioPreferred, awarding Federal purchasing preference to biobased products, which it defined as commercial or industrial goods (other than food or feed) composed in whole or in significant part of biological products, forestry materials, or renewable domestic agricultural materials, including plant, animal, or marine materials. To address the questions of environmental and cost performance, candidate biobased products are now required by federal rule to be evaluated by BEES, and performance results shared with federal purchasers.[3] With permission from manufacturers, building-related biobased products evaluated to date under BioPreferred are included in BEES 4.0.

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[3] U.S. Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses, "Guidelines for Designating Biobased Products for Federal Procurement," *Federal Register*, 7 CFR Part 2902, Vol. 70, No. 7, January 11, 2005. For more information about BioPreferred, go to http://www.biobased.oce.usda.gov/fb4p/aboutus.aspx .

2. The BEES Model

The BEES methodology takes a multidimensional, life-cycle approach. That is, it considers multiple environmental and economic impacts over the entire life of the building product. Considering multiple impacts and life-cycle stages is necessary because product selection decisions based on single impacts or stages could obscure others that might cause equal or greater damage. In other words, a multidimensional, life-cycle approach is necessary for a comprehensive, balanced analysis.

It is relatively straightforward to select products based on minimum life-cycle economic impacts because building products are bought and sold in the marketplace. But how do we include life-cycle environmental impacts in our purchase decisions? Environmental impacts such as global warming, water pollution, and resource depletion are for the most part economic externalities. That is, their costs are not reflected in the market prices of the products that generated the impacts. Moreover, even if there were a mandate today to include environmental "costs" in market prices, it would be nearly impossible to do so due to difficulties in assessing these impacts in economic terms. How do you put a price on clean air and clean water? What is the value of human life? Economists have debated these questions for decades, and consensus does not appear likely.

While environmental performance cannot be measured on a monetary scale, it can be quantified using the evolving, multi-disciplinary approach known as environmental life-cycle assessment (LCA). The BEES methodology measures environmental performance using an LCA approach, following guidance in the International Organization for Standardization (ISO) 14040 standard for LCA.[4] Economic performance is separately measured using the ASTM International standard life-cycle cost (LCC) approach.[5] These two performance measures are then synthesized into an overall performance measure using the ASTM standard for Multiattribute Decision Analysis.[6] For the entire BEES analysis, building products are defined and classified based on UNIFORMAT II, the ASTM standard classification for building elements.[7]

2.1 Environmental Performance

Environmental life-cycle assessment is a "cradle-to-grave," systems approach for measuring environmental performance. The approach is based on the belief that all stages in the life of a

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[4] International Organization for Standardization (ISO), *Environmental Management--Life-Cycle Assessment--Principles and Framework*, International Standard 14040, 2006.

[5] ASTM International, *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems,* ASTM Designation E917-05, West Conshohocken, PA, 2005.

[6] ASTM International, *Standard Practice for Applying the Analytic Hierarchy Process to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems,* ASTM Designation E1765-02, West Conshohocken, PA, 2002.

[7] ASTM International, *Standard Classification for Building Elements and Related Sitework--UNIFORMAT II,* ASTM Designation E1557-05, West Conshohocken, PA, 2005.

product generate environmental impacts and must therefore be analyzed, including raw materials acquisition, product manufacture, transportation, installation, operation and maintenance, and ultimately recycling and waste management. An analysis that excludes any of these stages is limited because it ignores the full range of upstream and downstream impacts of stage-specific processes.

The strength of environmental life-cycle assessment is its comprehensive, multi-dimensional scope. Many green building claims and strategies are now based on a single life-cycle stage or a single environmental impact. A product is claimed to be green simply because it has recycled content, or accused of not being green because it emits volatile organic compounds (VOCs) during its installation and use. These single-attribute claims may be misleading because they ignore the possibility that other life-cycle stages, or other environmental impacts, may yield offsetting impacts. For example, the recycled content product may have a high embodied energy content, leading to fossil fuel depletion, global warming, and acid rain impacts during the raw materials acquisition, manufacturing, and transportation life-cycle stages. LCA thus broadens the environmental discussion by accounting for shifts of environmental problems from one life-cycle stage to another, or one environmental medium (land, air, water) to another. The benefit of the LCA approach is in implementing a trade-off analysis to achieve a genuine reduction in overall environmental impact, rather than a simple shift of impact.

The general LCA methodology involves four steps.[8] The *goal and scope definition* step spells out the purpose of the study and its breadth and depth. The *inventory analysis* step identifies and quantifies the environmental inputs and outputs associated with a product over its entire life cycle. Environmental inputs include water, energy, land, and other resources; outputs include releases to air, land, and water. However, it is not these inputs and outputs, or *inventory flows,* that are of primary interest. We are more interested in their consequences, or impacts on the environment. Thus, the next LCA step, *impact assessment*, characterizes these inventory flows in relation to a set of environmental impacts. For example, the impact assessment step might relate carbon dioxide emissions, a *flow*, to global warming, an *impact*. Finally, the *interpretation* step combines the environmental impacts in accordance with the goals of the LCA study.

2.1.1 Goal and Scope Definition

The goal of BEES LCAs is to generate environmental performance scores for building product alternatives sold in the United States. These will be combined with economic performance scores to help the building community select cost-effective, environmentally-preferred building products.

The scoping phase of any LCA involves defining the boundaries of the product system under study. The manufacture of any product involves a number of unit processes (e.g., ethylene production for input to the manufacture of the styrene-butadiene bonding agent for stucco walls). Each unit process involves many inventory flows, some of which themselves involve other, subsidiary unit processes. The first product system boundary determines which unit processes

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[8] International Organization for Standardization (ISO), *Environmental Management--Life-Cycle Assessment--Principles and Framework,* International Standard 14040, 2006.

are included in the LCA. In the BEES system, the boundary-setting rule consists of a set of three decision criteria. For each candidate unit process, mass and energy contributions to the product system are the primary decision criteria. In some cases, cost contribution is used as a third criterion.[9] Together, these criteria provide a robust screening process, as illustrated in Figure 2.1, showing how five ancillary materials (e.g., limestone used in portland cement manufacturing) are selected from a list of nine candidate materials for inclusion in the LCA. A material must have a large contribution to at least one decision criterion to be selected. The weight criterion selects materials A, B, and C; the energy criterion adds material E; and cost flags material I. As a result, the unit processes for producing ancillary materials A, B, C, E, and I are included in the system boundaries.

Ancillary material	***Weight***	***Energy***	***Cost (as a flag when necessary)***	***Included in system boundaries?***
A	▓	▓	▓	Yes
B	▓	▓	▓	Yes
C	▓			Yes
D	░	░		No
E	░	▓		Yes
F	░	░		No
G		░		No
H				No
I			▓	Yes

	negligible contribution
░	small contribution
▓	large contribution

Figure 2.1 Decision Criteria for Setting Product System Boundaries

The second product system boundary determines which inventory flows are tracked for in-bounds unit processes. Quantification of *all* inventory flows is not practical for the following reasons:

- An ever-expanding number of inventory flows can be tracked. For instance, including the U.S. Environmental Protection Agency's Toxic Release Inventory (TRI) data would result in tracking approximately 200 inventory flows arising from polypropylene production alone.

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[9] While a large cost contribution does not directly indicate a significant environmental impact, it may indicate scarce natural resources or numerous subsidiary unit processes potentially involving high energy consumption.

Similarly, including radionucleide emissions generated from electricity production would result in tracking more than 150 flows. Managing such large inventory flow lists adds to the complexity, and thus the cost, of carrying out and interpreting the LCA.

- Attention should be given in the inventory analysis step to collecting data that will be useful in the next LCA step, impact assessment. By restricting the inventory data collection to the flows actually needed in the subsequent impact assessment, a more focused, higher quality LCA can be carried out.

Therefore, in the BEES model, a focused, cost-effective set of inventory flows is tracked, reflecting flows that the U.S. EPA Office of Research and Development has deemed important in the subsequent impact assessment step.[10]

Defining the unit of comparison is another important task in the goal and scoping phase of LCA. The basis for all units of comparison is the *functional unit*, defined so that the products compared are true substitutes for one another. In the BEES model, the functional unit for most building products is 0.09 m^2 (1 ft^2) of product service for 50 years. For example, the functional unit for the BEES floor covering alternatives is *covering 0.09 m^2 (1 ft^2) of floor surface for 50 years*. The following BEES product categories have different functional units:

- Roof Coverings: Covering 9.29 m^2 (1 square, or 100 ft^2) of roof surface for 50 years
- Concrete Beams and Columns: 0.76 m^3 (1 yd^3) of product service for 50 years
- Office Chairs: Seating for 1 person for 50 years
- Adhesive and Mastic Remover: Removing 9.29 m^2 (100 ft^2) of mastic under vinyl or similar flooring over 50 years
- Exterior Sealers and Coatings: Sealing or coating 9.29 m^2 (100 ft^2) of exterior surface over 50 years
- Transformer Oils: Cooling for one 1 000 kV·A transformer for 30 years
- Fertilizer: Fertilizing 0.40 ha (1 acre) for 10 years
- Carpet Cleaners: Cleaning 92.9 m^2 (1 000 ft^2) of carpet once
- Floor Stripper: Removing three layers of wax and one layer of sealant from 9.29 m^2 (100 ft^2) of hardwood flooring once
- Roadway Dust Control: Controlling dust from 92.9 m^2 (1 000 ft^2) of surface area once
- Bath and Tile Cleaner: Using 3.8 L (1 gal) of ready-to-use cleaner once
- Glass Cleaners: Using 3.785 m^3 (1 000 gal) of ready-to-use glass cleaner once[11]
- Grease and Graffiti Remover: Using 3.8 L (1 gal) of grease and graffiti remover once

For three building elements—roof coverings, wall insulation, and exterior wall finishes—functional units may be further specified to account for important factors affecting their influence on building heating and cooling loads (e.g., local climate, fuel type). Otherwise, all product alternatives are assumed to meet minimum technical performance requirements (e.g.,

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[10] U.S. Environmental Protection Agency, *Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI): User's Guide and System Documentation*, EPA/600/R-02/052, U.S. EPA Office of Research and Development, Cincinnati, OH, August 2002.

[11] While it is unrealistic to assume a need for such a large quantity at a given time, this amount is used so that the environmental impacts for the product are large enough to be reported in the BEES results.

acoustic and fire performance). The functional unit provides the critical reference point to which all inventory flows are scaled.

Scoping also involves setting data requirements. Data requirements for the BEES study include:

- Geographic coverage: The data are U.S. average data.
- Time period coverage: The data are a combination of data collected specifically for BEES 4.0 within the last two years and data from the new, critically-reviewed U.S. LCI Database, developed using a common, ISO 14040-consistent research protocol.[12]
- Technology coverage: For generic products, the most representative technology is evaluated. When data for the most representative technology are not available, an aggregated result is developed based on the U.S. average technology for that industry.

2.1.2 Inventory Analysis

Inventory analysis entails quantifying the inventory flows for a product system. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land, and water. Data categories are used to group inventory flows in LCAs. For example, in the BEES model, flows such as aldehydes, ammonia, and sulfur oxides are grouped under the air emissions data category. Figure 2.2 shows the categories under which data are grouped in the BEES system. Refer to the BEES environmental performance data files, accessible through the BEES software, for a detailed listing of the 504 inventory flow items included in BEES.

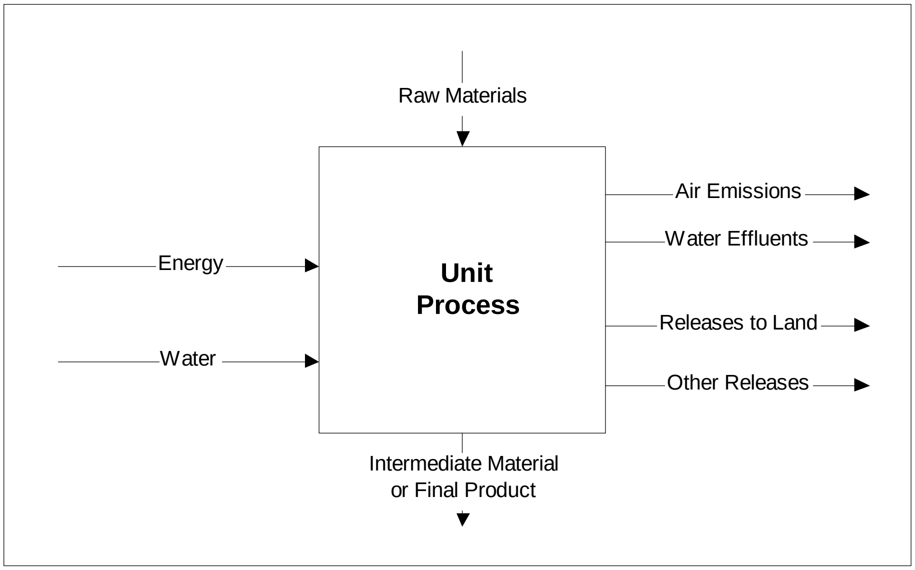

Figure 2.2 BEES Inventory Data Categories

A number of approaches may be used to collect inventory data for LCAs. These range from:[13]

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[12] U.S. Department of Energy, National Renewable Energy Laboratory, *U.S. Life-Cycle Inventory Database*, http://www.nrel.gov/lci/.

[13] U.S. Environmental Protection Agency, Office of Research and Development, *Life Cycle Assessment: Inventory Guidelines and Principles*, EPA/600/R-92/245, February 1993.

- Unit process- and facility-specific: collect data from a particular process within a given facility that are not combined in any way
- Composite: collect data from the same process combined across locations
- Aggregated: collect data combining more than one process
- Industry-average: collect data derived from a representative sample of locations believed to statistically describe the typical process across technologies
- Descriptive: collect data whose representation may be unknown but which are qualitatively descriptive of a process

Since the goal of BEES LCAs is to generate U.S. average results, generic product data are primarily collected using the industry-average approach. Manufacturer-specific product data are primarily collected using the unit process- and facility-specific approach, then aggregated to preserve manufacturer confidentiality. Data collection for BEES 4.0 was done under contract with Four Elements, LLC and First Environment, Inc. using the Simapro LCA software. These data represent the closest approximations currently available of the burdens associated with the production, use, and disposal of BEES products. For generic products, assumptions regarding the associated unit processes were verified through experts in the appropriate industries to assure the data were correctly incorporated in BEES. For manufacturer-specific products, a U.S. Office of Management and Budget-approved *BEES Please* Questionnaire was completed by manufacturers to collect inventory data from their manufacturing plant(s); these data were validated by Four Elements, then associated upstream and downstream data added to yield cradle-to grave inventories. For more information about the *BEES Please* program, visit http://www.bfrl.nist.gov/oae/software/bees/please/bees_please.html.

2.1.3 Impact Assessment

The impact assessment step of LCA quantifies the potential contribution of a product's inventory flows to a range of environmental impacts. There are several well-known LCA impact assessment approaches.

2.1.3.1 Impact Assessment Methods

Direct Use of Inventories. In the most straightforward approach to LCA, the impact assessment step is skipped, and the life cycle inventory results are used as-is in the final interpretation step to help identify opportunities for pollution prevention or increases in material and energy efficiency for processes within the life cycle. However, this approach in effect gives the same weight to all inventory flows (e.g., to the reduction of carbon dioxide emissions and to the reduction of lead emissions). For most impacts, equal weighting of flows is unrealistic.

Critical Volumes (Switzerland). The "weighted loads" approach, better known as the Swiss Critical Volume approach, was the first method proposed for aggregating inventory flow data.[14]

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[14] K. Habersatter, *Ecobalance of Packaging Materials - State of 1990*, Swiss Federal Office of Environment, Forests, and Landscape, Bern, Switzerland, February 1991, and Bundesamt fur Umweltschutz, *Oekobilanzen von Packstoffen,* Schriftenreihe Umweltschutz 24, Bern, Switzerland, 1984.

The critical volume for a substance is a function of its load and its legal limit. Its load is the total quantity of the flow per unit of the product. Critical volumes can be defined for air and water, and in principle also for soil and groundwater, providing there are legal limit values available.

This approach has the advantage that long lists of inventory flows, especially for air and water, can be aggregated by summing the critical volumes for the individual flows within the medium being considered--air, water, or soil. However, the Critical Volume approach has been abandoned for the following reasons:

- Fate and exposure are not considered.
- The underlying assumption that the residual risk at threshold levels is the same for all substances does not hold.[15]
- Legal limit values are available only for certain chemicals and pollutants. Long-term global effects such as global warming are excluded since there are no universal legal limits for the chemicals involved.

Ecological Scarcity (Switzerland). A more general approach has been developed by the Swiss Federal Office for the Environment (FOEN) and applied to Switzerland, Sweden, Belgium, The Netherlands, and Germany.[16] With this approach, "Eco-Points" are calculated for a product, using the "Eco-Factor" determined for each inventory flow. Eco-Factors are based on current annual flows relative to target maximum annual flows for the geographic area considered. The Eco-Points for all inventory flows are added together to give one single, final measure of impact.

The concept used in this approach is appealing but has the following difficulties:

- It is valid only in a specific geographical area.
- Estimating target flows can be a difficult and time-consuming exercise.
- The underlying assumption that the residual risk at target levels is the same for all substances does not hold.[17]
- The scientific calculation of environmental impacts is combined with political and subjective judgment, or valuation. The preferred approach is to separate the science from the valuation.

*Environmental Priorities System (Sweden)***.** The Environmental Priority Strategies in Product Development System, the EPS System, was developed by the Swedish Environmental Research Institute.[18] It takes an economic approach to assessing environmental impacts. The basis for the evaluation is the Environmental Load Unit, which corresponds to the willingness to pay 1

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[15] M.A. Curran et al., *BEES 2.0, Building for Environmental and Economic Sustainability: Peer Review Report*, NISTIR 6865, Washington, DC, 2002.

[16] R. Frischknecht et. al, "Swiss Ecological Scarcity Method: The New Version 2006," Berne, Switzerland, 2006.

[17] M.A. Curran et al, 2002.

[18] B. Steen, *A Systematic Approach to Environmental Priority Strategies in Product Development (EPS). Version 2000*, CPM Report 1999:4 and 5, CPM, Chalmers University, Göteborg 1999.

European Currency Unit. The final result of the EPS system is a single number summarizing all environmental impacts, based on:

- Society's judgment of the importance of each environmental impact.
- The intensity and frequency of the impact.
- Location and timing of the impact.
- The contribution of each flow to the impact in question.
- The cost of decreasing each inventory flow by one weight unit.

The EPS system combines indices of ecological, sociological, and economic effects to give a total effect index for each flow. The total effect index is multiplied by the amount of the flow to give the "environmental load unit." Although this methodology is popular in Sweden, its use is criticized due to its lack of transparency and the quantity and quality of the model's underlying assumptions.

*Eco-Indicator 99***.** The Eco-Indicator 99 method is a "damage-oriented" approach to life cycle impact assessment that has been developed in The Netherlands by Pré Consultants.[19] It is appealing for its emphasis on simplifying the subsequent life cycle assessment step, namely, weighting of the relative importance of environmental impacts. To this end, a very limited number of environmental damage categories, or "endpoints," are evaluated: Human Health, Ecosystem Quality, and Resources. Damage models are used to evaluate products in relation to these three impact categories. While the Eco-Indicator 99 method offers promise for the future, it has been criticized to date due to the many assessment gaps in the underlying damage models. In addition, the approach has a European focus at present.

Environmental Problems. The Environmental Problems approach to impact assessment was developed within the Society for Environmental Toxicology and Chemistry (SETAC). It involves a two-step process:[20,21,22,23]

- Classification of inventory flows that contribute to specific environmental impacts. For example, greenhouse gases such as carbon dioxide, methane, and nitrous oxide are classified as contributing to global warming.
- Characterization of the potential contribution of each classified inventory flow to the corresponding environmental impact. This results in a set of indices, one for each impact, that is obtained by weighting each classified inventory flow by its relative contribution to the impact. For instance, the Global Warming Potential index is derived by expressing each contributing inventory flow in terms of its equivalent amount of carbon dioxide.

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[19] M. Goedkoop and R. Spriensma, *The Eco-indicator'99: A Damage Oriented Method for Life Cycle Impact Assessment*, VROM Zoetermeer, Nr. 1999/36A/B, 2nd edition, April 2000.

[20] Guinée et al., *LCA - An operational guide to the ISO-standards,* CML, Leiden, The Netherlands, 2001.

[21] SETAC-Europe, *Life Cycle Assessment,* B. DeSmet, et al. (eds), 1992.

[22] SETAC, *A Conceptual Framework for Life Cycle Impact Assessment*, J. Fava, et al. (eds), 1993.

[23] SETAC, *Guidelines for Life Cycle Assessment: A "Code of Practice,"* F. Consoli, et al. (eds), 1993.

The Environmental Problems approach does not offer the same degree of relevance for all environmental impacts. For global and regional effects (e.g., global warming and acidification) the method may result in an accurate description of the potential impact. For impacts dependent upon local conditions (e.g., smog, ecological toxicity, and human health) it may result in an oversimplification of the actual impacts because the indices are not tailored to localities. Another drawback of this method is the unclear environmental importance of the impacts, making the subsequent weighting step difficult.

2.1.3.2 Characterizing Impacts in BEES

The BEES model uses the Environmental Problems approach where possible because it enjoys some general consensus among LCA practitioners and scientists.[24] The U.S. EPA Office of Research and Development has developed TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts), a set of state-of-the-art, peer-reviewed U.S. life cycle impact assessment methods that has been adopted in BEES 4.0.[25] Ten of the 11 TRACI 1.0 impacts follow the Environmental Problems approach: Global Warming Potential, Acidification Potential, Eutrophication Potential, Fossil Fuel Depletion, Habitat Alteration, Criteria Air Pollutants, Human Health, Smog, Ozone Depletion, and Ecological Toxicity. Water Intake, the eleventh impact, is assessed in TRACI 1.0 using the Direct Use of Inventories Approach. BEES also assesses Indoor Air Quality, an impact not included in TRACI because it is somewhat unique to the building industry. Indoor Air Quality is assessed using the Direct Use of Inventories approach, for a total of 12 impacts for all BEES products. Note that some flows characterized by TRACI did not have exact matches in the Simapro LCA software used to develop life cycle inventories for BEES. Where discrepancies were found, a significance analysis was conducted to assess the relevance of the mismatched flows. Proxy flows or alternative characterization factors were developed for those mismatched flows found to be relevant, and validated with TRACI developers.

If the BEES user has important knowledge about other potential environmental impacts, it should be brought into the interpretation of the BEES results. The twelve BEES impacts are discussed below.

Global Warming Potential. The Earth absorbs radiation from the Sun, mainly at the surface. This energy is then redistributed by the atmosphere and ocean and re-radiated to space at longer wavelengths. Some of the thermal radiation is absorbed by “greenhouse” gases in the atmosphere, principally water vapor, but also carbon dioxide, methane, the chlorofluorocarbons, and ozone. The absorbed energy is re-radiated in all directions, downwards as well as upwards, such that the radiation that is eventually lost to space is from higher, colder levels in the atmosphere. The result is that the surface loses less heat to space than it would in the absence of the greenhouse gases and consequently stays warmer than it would be otherwise. This

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[24] SETAC, *Life-Cycle Impact Assessment: The State-of-the-Art*, J. Owens, et al. (eds), 1997.

[25] U.S. Environmental Protection Agency, *Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI): User’s Guide and System Documentation*, EPA/600/R-02/052, U.S. EPA Office of Research and Development, Cincinnati, OH, August 2002. For a detailed discussion of the TRACI methods, see J.C. Bare *et al*, "TRACI: The Tool for the Reduction and Assessment of Chemical and other environmental Impacts," *Journal of Industrial Ecology*, Vol. 6, No. 3-4, 2003.

phenomenon, which acts rather like a 'blanket' around the Earth, is known as the greenhouse effect.

The greenhouse effect is a natural phenomenon. The environmental issue is the increase in the greenhouse effect due to emissions generated by humankind. The resulting general increase in temperature can alter atmospheric and oceanic temperatures, which can potentially lead to alteration of circulation and weather patterns. A rise in sea level is also predicted due to thermal expansion of the oceans and melting of polar ice sheets.

Global Warming Potentials, or GWPs, have been developed to characterize the increase in the greenhouse effect due to emissions generated by humankind. LCAs commonly use those GWPs representing a 100-year time horizon. GWPs permit computation of a single index, expressed in grams of carbon dioxide per functional unit of a product, that measures the quantity of carbon dioxide with the same potential for global warming over a 100-year period:

$$\text{global warming index} = \Sigma_i\ m_i \times GWP_i, \text{ where}$$

m_i = mass (in grams) of inventory flow i, and

GWP_i = grams of carbon dioxide with the same heat trapping potential over 100 years as one gram of inventory flow i, as listed in Table 2.1. [26]

Table 2.1 BEES Global Warming Potential Characterization Factors

Flow *(i)*	***GWP_i*** *(CO_2-equivalents)*
Carbon Dioxide (CO_2, fossil)	1
Carbon Tetrachloride (CCl_4)	1800
Carbon Tetrafluoride (CF_4)	5700
CFC 12 (CCl_2F_2)	10 600
Chloroform ($CHCl_3$, HC-20)	30
Halon 1301 (CF_3Br)	6900
HCFC 22 (CHF_2Cl)	1700
Methane (CH_4)	23
Methyl Bromide (CH_3Br)	5
Methyl Chloride (CH_3Cl)	16
Methylene Chloride (CH_2Cl_2, HC-130)	10
Nitrous Oxide (N_2O)	296
Trichloroethane (1,1,1-CH_3CCl_3)	140

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[26] U.S. Environmental Protection Agency, *TRACI*, 2003.

Acidification Potential. Acidifying compounds may in a gaseous state either dissolve in water or fix on solid particles. They reach ecosystems through dissolution in rain or wet deposition. Acidification affects trees, soil, buildings, animals, and humans. The two compounds principally involved in acidification are sulfur and nitrogen compounds. Their principal human source is fossil fuel and biomass combustion. Other compounds released by human sources, such as hydrogen chloride and ammonia, also contribute to acidification.

Characterization factors for potential acid deposition onto the soil and in water have been developed like those for the global warming potential, with hydrogen ions as the reference substance. These factors permit computation of a single index for potential acidification (in grams of hydrogen ions per functional unit of product), representing the quantity of hydrogen ion emissions with the same potential acidifying effect:

$$\text{acidification index} = \Sigma_i\, m_i * AP_i, \text{ where}$$

m_i = mass (in grams) of inventory flow i, and

AP_i = millimoles of hydrogen ions with the same potential acidifying effect as one gram of inventory flow i, as listed in Table 2.2.[27]

Table 2.2 BEES Acidification Potential Characterization Factors

***Flow** (i)*	***AP_i*** *(Hydrogen-Ion Equivalents)*
Ammonia (NH_3)	95.49
Hydrogen Chloride (HCl)	44.70
Hydrogen Cyanide (HCN)	60.40
Hydrogen Fluoride (HF)	81.26
Hydrogen Sulfide (H_2S)	95.90
Nitrogen Oxides (NO_x as NO_2)	40.04
Sulfur Oxides (SO_x as SO_2)	50.79
Sulfuric Acid (H_2SO_4)	33.30

Eutrophication Potential. Eutrophication is the addition of mineral nutrients to the soil or water. In both media, the addition of large quantities of mineral nutrients, such as nitrogen and phosphorous, results in generally undesirable shifts in the number of species in ecosystems and a reduction in ecological diversity. In water, it tends to increase algae growth, which can lead to lack of oxygen and therefore death of species like fish.

Characterization factors for potential eutrophication have been developed like those for the global warming potential, with nitrogen as the reference substance. These factors permit

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[27] *ibid*.

computation of a single index for potential eutrophication (in grams of nitrogen per functional unit of product), representing the quantity of nitrogen with the same potential nutrifying effect:

$$\text{eutrophication index} = \Sigma_i\, m_i \times EP_i, \text{ where}$$

m_i = mass (in grams) of inventory flow i, and

EP_i = grams of nitrogen with the same potential nutrifying effect as one gram of inventory flow i, as listed in Table 2.3.[28]

Table 2.3 BEES Eutrophication Potential Characterization Factors

***Flow** (i)*	***EP_i*** *(nitrogen-equivalents)*
Ammonia (NH_3)	0.12
Nitrogen Oxides (NO_x as NO_2)	0.04
Nitrous Oxide (N_2O)	0.09
Phosphorus to air (P)	1.12
Ammonia (NH_4^+, NH_3, as N)	0.99
BOD5 (Biochemical Oxygen Demand)	0.05
COD (Chemical Oxygen Demand)	0.05
Nitrate (NO_3^-)	0.24
Nitrite (NO_2^-)	0.32
Nitrogenous Matter (unspecified, as N)	0.99
Phosphates (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$, H_3PO_4, as P)	7.29
Phosphorus to water (P)	7.29

Fossil Fuel Depletion. Some experts believe fossil fuel depletion is fully accounted for in market prices. That is, market price mechanisms are believed to take care of the scarcity issue, price being a measure of the level of depletion of a resource and the value society places on that depletion. However, price is influenced by many factors other than resource supply, such as resource demand and non-perfect markets (e.g., monopolies and subsidies). Furthermore, fossil fuel depletion is at the heart of the sustainability debate.

Fossil fuel depletion is included in the TRACI set of impact assessment methods adopted by BEES 4.0. It is important to recognize that this impact addresses only the depletion aspect of fossil fuel extraction, not the fact that the extraction itself may generate impacts. Extraction impacts, such as methane emissions from coal mining, are addressed in other impacts, such as global warming.

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[28] *ibid*.

To assess fossil fuel depletion, TRACI follows the approach developed for the Eco-Indicator 99 method, which measures how the amount of energy required to extract a unit of energy for consumption changes over time. Characterization factors have been developed permitting computation of a single index for potential fossil fuel depletion--in surplus megajoules (MJ) per functional unit of product--and assess the surplus energy requirements from the consumption of fossil fuels:

$$\text{fossil fuel depletion index} = \Sigma_i\, c_i \times FP_i, \text{ where}$$

c_i = consumption (in kg) of fossil fuel i, and

FP_i = MJ input requirement increase per kilogram of consumption of fossil fuel i, as listed in Table 2.4.[29]

Table 2.4 BEES Fossil Fuel Depletion Potential Characterization Factors

***Flow** (i)*	***FP_i*** *(surplus MJ/kg)*
Coal (in ground)	0.25
Natural Gas (in ground)	7.80
Oil (in ground)	6.12

While uranium is a major source of energy in the United States, it is not, at present, included in the TRACI assessment of the depletion of nonrenewable fuel resources. As impact assessment science continues to evolve over time, it is hoped that uranium will become part of that assessment. Future versions of BEES will incorporate improved impact assessment methods as they become available.

Indoor Air Quality. Indoor air quality impacts are not included in traditional life-cycle impact assessments. Most LCAs conducted to date have been applied to relatively short-lived, non-building products (e.g., paper and plastic bags), for which indoor air quality impacts are not an important issue. However, the indoor air performance of building products is of particular concern to the building community and should be explicitly considered in any building product LCA.

Ideally, characterization factors would be available for indoor air pollutants as they are for other flows such as global warming gases. However, there is little scientific consensus about the relative contributions of pollutants to indoor air performance. In the absence of reliable characterization factors, a product's total volatile organic compound (VOC) emissions are often used as a measure of its indoor air performance. Note that a total VOC measure equally weights the contributions of the individual compounds that make up the measure. Also, reliance on VOC emissions alone may be misleading if other indoor air contaminants, such as particulates, aerosols, and mold, are also present. Finally, total VOC measures are highly dependent on the

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[29] U.S. Environmental Protection Agency, *TRACI*, 2003.

analytical method used and there is no single analytical method than can measure the entire range of VOCs, rendering the term "total" somewhat misleading.

Indoor air quality is assessed for the following building elements currently covered in BEES: floor coverings, interior wall finishes, chairs, carpet cleaners, glass cleaners, bath and tile cleaner, floor stripper, and adhesive and mastic remover.[30] Recognizing the inherent limitations from using total VOCs to assess indoor air quality performance, estimates of total VOC emissions are used as a proxy measure. The total VOC emissions over an initial number of h (e.g., for floor coverings, combined product and adhesive emissions over the first 72 h) is multiplied by the number of times over the product category's use period those "initial h" will occur (to account for the possibility of product replacements), to yield an estimate of total VOC emissions per functional unit of product. The result is entered into the life cycle inventory for the product, and used directly to assess the indoor air quality impact. The rationale for this particular approach is that VOC emissions are at issue for a limited period of time after installation. The more installations required then, the greater the indoor air quality impact.

Indoor air quality is discussed in the context of sheathing and insulation products. Sheathing products are often made of wood, which is of concern for its formaldehyde emissions. Formaldehyde is thought to affect human health, especially for people with chemical sensitivity. Composite wood products using urea-formaldehyde adhesives have higher formaldehyde emissions than those using phenol-formaldehyde adhesives, and different composite wood products have different levels of emissions. Composite wood products include oriented strand board (OSB) and softwood plywood, both included as sheathing products in BEES. Most OSB is now made using a methylene diphenylisocyanate (MDI) binder, and is modeled as such in BEES. OSB using an MDI binder emits no formaldehyde other than the insignificant amount naturally occurring in the wood itself.[31] Softwood plywood also has extremely low indoor formaldehyde emissions because it uses phenol-formaldehyde binders and because it is used primarily on the exterior shell of buildings.[32] Thus, assuming formaldehyde emission is the only significant indoor air concern for wood products, neither of the two composite wood products as modeled in BEES are thought to significantly affect indoor air quality.

Indoor air quality is also an issue for insulation products. The main issues are the health impacts of fibers, hazardous chemicals, and particles released from some insulation products. These releases are the only insulation-related indoor air issues considered in BEES. As a result of its listing by the International Agency for Research on Cancer as a "possible carcinogen," fiberglass products are now required to have cancer warning labels. The fiberglass industry has responded by developing fiberglass products that reduce the amount of loose fibers escaping into the air. For cellulose products, there are claims that fire retardant chemicals and respirable particles are hazardous to human health. Mineral wool is sometimes claimed to emit fibers and chemicals that

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[30] While indoor air quality is considered for glass cleaners and bath and tile cleaner, manufacturers of all products currently in these categories, all of whom produce biobased products, report zero VOC emissions during their use. Indoor air quality data provided by manufacturers of products in the grease and graffiti remover category is incompatible; as a result, indoor air quality is not assessed for this category.

[31] Alex Wilson and Nadav Malin, "The IAQ Challenge: Protecting the Indoor Environment," *Environmental Building News,* Vol. 5, No. 3, May/June 1996, p 15.

[32] American Institute of Architects, *Environmental Resource Guide,* Plywood Material Report, May 1996.

could be health irritants. For all these products, however, there should be little or no health risks to building occupants if they are installed in accordance with manufacturers' recommendations. Assuming proper installation, then, none of these products as modeled in BEES are thought to significantly affect indoor air quality.[33]

All other BEES building elements are primarily exterior elements, or interior elements made of inert materials, for which indoor air quality is not an issue.

Note that due to limitations in indoor air science, the BEES indoor air performance scores are based on heuristics. If the BEES user has better knowledge about indoor air performance, it should be brought into the interpretation of the results.

Habitat Alteration. The habitat alteration impact measures the potential for land use by humans to lead to damage of Threatened and Endangered (T&E) Species. In TRACI 1.0, the set of U.S. impact assessment methods adopted in BEES, the density of T&E Species is used as a proxy for the degree to which the use of land may lead to undesirable changes in habitats. Note that this approach does not consider the original condition of the land, the extent to which human activity changes the land, or the length of time required to restore the land to its original condition. As impact assessment science continues to evolve, it is hoped that these potentially important factors will become part of the habitat alteration assessment. Future versions of BEES will incorporate improved habitat alteration assessment methods as they become available.

Inventory data are not readily available for habitat alteration assessment across all life cycle stages; the use and end-of-life stages offer the only reliable inventory data for this impact to date. These two stages, though, may be the most important life cycle stages for habitat alteration assessment due to their contributions to landfills. Indeed, an informal evaluation of two interior wall products found that post-consumer landfill use accounted for more than 80 % of the total habitat alteration impact for both products. In BEES, habitat alteration is assessed at the use and end of life stages only, based on the landfilled waste (adjusted for current recycling practices) from product installation, replacement, and end of life. Future versions of BEES will incorporate more life cycle stages as consistent inventory data become available.

Characterization factors have been developed permitting computation of a single index for potential habitat alteration, expressed in T&E Species count per functional unit of product:

$$\text{habitat alteration index} = \Sigma_i \, a_i \times \text{TED, where}$$

a_i = surface area (in m^2 disrupted) of land use flow i, and

TED = U.S. T&E Species density (in T&E Species count per m^2), as listed in Table 2.5.[34]

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[33] Alex Wilson, "Insulation Materials: Environmental Comparisons," *Environmental Building News,* Vol. 4, No. 1, January/February 1995, pp.15-16

[34] U.S. Environmental Protection Agency, *TRACI, 2003*.

Table 2.5 BEES Habitat Alteration Potential Characterization Factors

***Flow** (i)*	***TED** (T&E count/m^2)*
Land Use (Installation Waste)	6.06E-10
Land Use (Replacement Waste)	6.06E-10
Land Use (End-of-Period Waste)	6.06E-10

Water Intake. Water resource depletion has not been routinely assessed in LCAs to date, but researchers are beginning to address this issue to account for areas where water is scarce, such as the Western United States. It is important to recognize that this impact addresses only the depletion aspect of water intake, not the fact that activities such as agricultural production and product manufacture may generate water pollution. Water pollution impacts, such as nitrogen runoff from agricultural production, are addressed in other impacts, such as eutrophication.

In TRACI 1.0, the set of U.S. impact assessment methods adopted in BEES, the Direct Use of Inventories approach is used to assess water resource depletion. Water intake from cradle to grave is recorded in the BEES life cycle inventory for each product (in liters per functional unit), and is used directly to assess this impact.

Criteria Air Pollutants. Criteria air pollutants are solid and liquid particles commonly found in the air. They arise from many activities including combustion, vehicle operation, power generation, materials handling, and crushing and grinding operations. They include coarse particles known to aggravate respiratory conditions such as asthma, and fine particles that can lead to more serious respiratory symptoms and disease.[35]

Disability-adjusted life years, or DALYs, have been developed to measure health losses from outdoor air pollution. They account for years of life lost and years lived with disability, adjusted for the severity of the associated unfavorable health conditions. TRACI characterization factors permit computation of a single index for criteria air pollutants, with disability-adjusted life years (DALYs) as the common metric:

$$\text{criteria air pollutants index} = \Sigma_i\, m_i \times CP_i\text{, where}$$

m_i = mass (in grams) of inventory flow i, and

CP_i = microDALYs per gram of inventory flow i, as listed in Table 2.6.[36]

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[35] *ibid.*

[36] *ibid.*

Table 2.6 BEES Criteria Air Pollutant Characterization Factors

***Flow** (i)*	***CP_i*** *(microDALYs/g)*
Nitrogen Oxides (NO_x as NO_2)	0.002
Particulates (>PM10)	0.046
Particulates (<=PM 10)	0.083
Particulates (unspecified)	0.046
Sulfur Oxides (SO_x as SO_2)	0.014

Human Health. There are many potential human health effects from exposure to industrial and natural substances, ranging from transient irritation to permanent disability and even death. Some substances have a wide range of different effects, and different individuals have widely varying tolerances to different substances. BEES adopts and extends the TRACI 1.0 approach to evaluating human health impacts. Note that this approach does not include occupational health effects.

TRACI developers have computed Toxicity Equivalency Potentials (TEPs), which are characterization factors measuring the relative health concern associated with various chemicals from the perspective of a generic individual in the United States. For cancer effects, the TRACI system's TEPs are expressed in terms of benzene equivalents, while for noncancer health effects they are denominated in toluene equivalents. In order to synthesize all environmental impacts in the next LCA step (interpretation), however, BEES requires a combined measure of cancer and noncancer health effects because three of its four impact importance weight sets are available only at the combined level. The BEES 2.0 Peer Review Team suggested that to address this need, threshold levels for toluene and benzene be obtained from the developers of the TRACI TEPs and be given equal importance in combining cancer and noncancer health effects.[37] Threshold levels were thus obtained and used to develop a ratio converting benzene equivalents to toluene equivalents (21 000 kg toluene/kg benzene).[38]

The "extended" TRACI characterization factors permit computation of a single index for potential human health effects (in grams of toluene per functional unit of product), representing the quantity of toluene with the same potential human health effects:

$$\text{human health index} = \Sigma_i\, m_i \times HP_i, \text{ where}$$

m_i = mass (in grams) of inventory flow i, and

HP_i = grams of toluene with the same potential human health effects as one gram of inventory flow i.

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[37] M.A. Curran *et al., BEES 2.0, Building for Environmental and Economic Sustainability: Peer Review Report*, 2002.

[36] Personal correspondence with Edgar Hertwich, International Institute for Applied Systems Analysis, Laxenburg, Austria, 6/20/2002.

There are more than 200 flows included in the BEES human health impact assessment. A sampling of the most important of these flows and their characterization factors are reported in Table 2.7, sorted in descending order of toluene equivalents.[39] Flows to air are preceded with the designation "(a)" and flows to water with the designation "(w)."

As discussed in section 2.1.4, NIST convened a BEES Stakeholder Panel in May 2006 to develop a new impact importance weight set for BEES 4.0. To permit a more refined human health impact assessment, the panel judged the importance of cancer and noncancer human health effects separately. If the BEES user chooses to interpret its LCA results using the Stakeholder Panel weight set, the cancer-related flows are assessed in terms of benzene equivalents. To view the human health cancer flows and their benzene-based characterization factors, open the file EQUIV12.DBF under the File/Open menu item in the BEES software.

Smog Formation Potential. Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level, where they react with sunlight to produce photochemical smog. One of the components of smog is ozone, which is not emitted directly, but rather produced through the interactions of volatile organic compounds (VOCs) and oxides of nitrogen (NO_x). Smog leads to harmful impacts on human health and vegetation. In BEES, the smog impact does not account for indoor VOCs that make their way outdoors. Rather, indoor VOCs are evaluated under the BEES Indoor Air Quality impact.

Characterization factors for potential smog formation have been developed for the TRACI set of U.S. impact assessment methods, with nitrogen oxides as the reference substance. These factors permit computation of a single index for potential smog formation (in grams of nitrogen oxides per functional unit of product), representing the quantity of nitrogen oxides with the same potential for smog formation:

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[39] U.S. Environmental Protection Agency, *TRACI, 2003*. As discussed, TRACI benzene equivalents have been converted to toluene equivalents.

Table 2.7 Sampling of BEES Human Health Characterization Factors

***Flow** (i)*	***HP$_i$*** *(toluene-equivalents)*
Cancer--(a) Dioxins (unspecified)	38 292 661 685 580
Noncancer--(a) Dioxins (unspecified)	2 286 396 218 965
Cancer--(a) Diethanol Amine ($C_4H_{11}O_2N$)	2 532 000 000
Cancer--(a) Arsenic (As)	69 948 708
Cancer--(a) BenzoCancer--(a)pyrene ($C_{20}H_{12}$)	34 210 977
Noncancer--(a) Mercury (Hg)	19 255 160
Noncancer--(w) Mercury (Hg^+, Hg^{++})	18 917 511
Cancer--(a) Carbon Tetrachloride (CCl_4)	17 344 285
Cancer--(w) Arsenic (As^{3+}, As^{5+})	17 210 446
Cancer--(w) Carbon Tetrachloride (CCl_4)	16 483 833
Cancer--(a) Benzo(k)fluoranthene	12 333 565
Cancer--(w) Hexachloroethane (C_2Cl_6)	8 415 642
Cancer--(w) Phenol (C_6H_5OH)	8 018 000
Noncancer--(a) Cadmium (Cd)	4 950 421
Cancer--(a) Trichloropropane (1,2,3-$C_2H_5Cl_3$)	3 587 000
Cancer--(a) Chromium (Cr III, Cr VI)	3 530 974
Cancer--(a) Dimethyl Sulfate ($C_2H_6O_4S$)	2 976 375
Cancer--(a) Cadmium (Cd)	1 759 294
Cancer--(a) Indeno (1,2,3,c,d) Pyrene	1 730 811
Noncancer--(a) Lead (Pb)	1 501 293
Cancer--(a) Dibenzo(a,h)anthracene	1 419 586
Cancer--(a) Benzo(b)fluoranthene	1 356 632
Cancer--(a) Benzo(bjk)fluoranthene	1 356 632
Cancer--(a) Lead (Pb)	748 316
Cancer--(a) Ethylene Oxide (C_2H_4O)	650 701

$$\text{smog index} = \Sigma_i\ m_i \times SP_i\text{, where}$$

m_i = mass (in grams) of inventory flow i, and

SP_i = grams of nitrogen oxides with the same potential for smog formation as one gram of inventory flow i.

There are more than 100 flows included in the BEES smog assessment. A sampling of the most important of these flows and their characterization factors are reported in Table 2.8, sorted in descending order of nitrogen oxides equivalents.[40] To browse the entire list of smog flows and factors, open the file EQUIV12.DBF under the File/Open menu item in the BEES software.

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[40] *ibid.*

Table 2.8 Sampling of BEES Smog Characterization Factors

***Flow** (i)*	***SP_i*** *(nitrogen oxides-equivalents)*
Furan (C_4H_4O)	3.54
Butadiene (1,3-$CH_2CHCHCH_2$)	3.23
Propylene ($CH_3CH_2CH_3$)	3.07
Xylene (m-$C_6H_4(CH_3)_2$)	2.73
Butene (1-$CH_3CH_2CHCH_2$)	2.66
Crotonaldehyde (C_4H_6O)	2.49
Formaldehyde (CH_2O)	2.25
Propionaldehyde (CH_3CH_2CHO)	2.05
Acrolein (CH_2CHCHO)	1.99
Xylene (o-$C_6H_4(CH_3)_2$)	1.93
Xylene ($C_6H_4(CH_3)_2$)	1.92
Trimethyl Benzene (1,2,4-$C_6H_3(CH_3)_3$)	1.85
Acetaldehyde (CH_3CHO)	1.79
Aldehyde (unspecified)	1.79
Butyraldehyde ($CH_3CH_2CH_2CHO$)	1.74
Isobutyraldehyde ($(CH_3)_2CHCHO$)	1.74
Ethylene Glycol ($HOCH_2CH_2OH$)	1.40
Acenaphthene ($C_{12}H_{10}$)	1.30
Acenaphthylene ($C_{12}H_8$)	1.30
Hexanal ($C_6H_{12}O$)	1.25
Nitrogen Oxides (NOx as NO_2)	1.24
Glycol Ether (unspecified)	1.11
Methyl Naphthalene (2-$C_{11}H_{10}$)	1.10
Xylene (p-$C_6H_4(CH_3)_2$)	1.09
Toluene ($C_6H_5CH_3$)	1.03

Ozone Depletion Potential. The ozone layer is present in the stratosphere and acts as a filter absorbing harmful short wave ultraviolet light while allowing longer wavelengths to pass through. A thinning of the ozone layer allows more harmful short wave radiation to reach the Earth's surface, potentially causing changes to ecosystems as flora and fauna have varying abilities to cope with it. There may also be adverse effects on agricultural productivity. Effects on man can include increased skin cancer rates (particularly fatal melanomas) and eye cataracts, as well as suppression of the immune system. Another issue is the uncertain effect on the climate.

Characterization factors for potential ozone depletion are included in the TRACI set of U.S. impact assessment methods, with CFC-11 as the reference substance. These factors permit computation of a single index for potential ozone depletion (in grams of CFC-11 per functional unit of product), representing the quantity of CFC-11 with the same potential for ozone depletion:

$$\text{ozone depletion index} = \Sigma_i\, m_i \times OP_i, \text{ where}$$

m_i = mass (in g) of inventory flow i, and

OP_i = grams of CFC-11 with the same ozone depletion potential as one gram of inventory flow i, as listed in Table 2.9.[41]

Table 2.9 BEES Ozone Depletion Potential Characterization Factors

***Flow** (i)*	***OP_i*** *(CFC-11 equivalents)*
Carbon Tetrachloride (CC_{l4})	1.10
CFC 12 (CCl_2F_2)	1.00
Halon 1301 (CF_3Br)	10.00
HCFC 22 (CHF_2Cl)	0.06
Methyl Bromide (CH_3Br)	0.60
Trichloroethane (1,1,1-CH_3CCl_3)	0.10

*Ecological Toxicity***.** The ecological toxicity impact measures the potential of a chemical released into the environment to harm terrestrial and aquatic ecosystems. An assessment method for this impact was developed for the TRACI set of U.S. impact assessment methods and adopted in BEES. The method involves measuring pollutant concentrations from industrial sources as well as the potential of these pollutants to harm ecosystems.

TRACI characterization factors for potential ecological toxicity use 2,4-dichlorophenoxy-acetic acid (2,4-D) as the reference substance. These factors permit computation of a single index for potential ecological toxicity (in grams of 2,4-D per functional unit of product), representing the quantity of 2,4-D with the same potential for ecological toxicity:

$$\text{ecological toxicity index} = \Sigma_i\, m_i \times EP_i, \text{ where}$$

m_i = mass (in grams) of inventory flow i, and

EP_i = grams of 2,4-D with the same ecological toxicity potential as one gram of inventory flow i.

There are more than 150 flows included in the BEES ecological toxicity assessment. A sampling of the most important of these flows and their characterization factors are reported in Table 2.10, sorted in descending order of 2,4-D equivalents.[42] Flows to air are preceded with the designation "(a)" and flows to water with the designation "(w)." To browse the entire list of ecological toxicity flows and factors, open the file EQUIV12.DBF under the File/Open menu item in the BEES software.

Table 2.10 Sampling of BEES Ecological Toxicity Potential Characterization Factors

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[41] *ibid.*

[42] *ibid.*

***Flow** (i)*	***EP_i*** *(2,4-D equivalents)*
(a) Dioxins (unspecified)	2 486 822.73
(a) Mercury (Hg)	118 758.09
(a) Benzo(g,h,i)perylene ($C_{22}H_{12}$)	4948.81
(a) Cadmium (Cd)	689.74
(a) Benzo(a)anthracene	412.83
(a) Chromium (Cr VI)	203.67
(w) Naphthalene ($C_{10}H_8$)	179.80
(a) Vanadium (V)	130.37
(a) Benzo(a)pyrene ($C_{20}H_{12}$)	109.99
(a) Beryllium (Be)	106.56
(a) Arsenic (As)	101.32
(a) Copper (Cu)	89.46
(w) Vanadium (V^{3+}, V^{5+})	81.82
(a) Nickel (Ni)	64.34
(w) Mercury (Hg^{+}, Hg^{++})	58.82
(a) Cobalt (Co)	49.45
(a) Selenium (Se)	35.07
(a) Fluoranthene	29.47
(w) Copper (Cu^{+}, Cu^{++})	26.93
(a) Chromium (Cr III, Cr VI)	24.54
(w) Cadmium (Cd^{++})	22.79
(w) Formaldehyde (CH_2O)	22.62
(a) Zinc (Zn)	18.89
(w) Beryllium (Be)	16.55
(a) Lead (Pb)	12.32

2.1.3.3 Normalizing Impacts in BEES

Once impacts have been characterized, the resulting impact category performance measures are expressed in noncommensurate units. Global warming is expressed in carbon dioxide equivalents, acidification in hydrogen ion equivalents, eutrophication in nitrogen equivalents, and so on. In order to assist in the next LCA step, interpretation, performance measures are often placed on the same scale through normalization.

The U.S. EPA Office of Research and Development has developed normalization data corresponding to its TRACI set of impact assessment methods.[43] These data are used in BEES to

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[43] J.C. Bare et al, "U.S. Normalization Database and Methodology for Use within Life Cycle Impact Assessment," submitted to the Journal of Industrial Ecology. Note that while a normalization value is not reported for the Indoor Air Quality impact, a figure for U.S. VOC emissions/year/capita is reported. To approximate the Indoor Air Quality normalization value, 30% of this reported value is taken, based on a U.S. EPA Fact Sheet citing that 30% of annual U.S. VOC emissions flow from consumer products such as surface coatings, personal care products, and household cleaning products (U.S. Environmental Protection Agency, Fact Sheet: Final Air Regulations for Consumer Products, 1998). Further note that an error in the original U.S. EPA-reported Human Health normalization value was corrected in 2007 by Greg Norris of Sylvatica, Inc., under contract to NIST, and incorporated in BEES 4.0.

place its impact assessment results on the same scale. The data, reported in Table 2.11, estimate for each impact its performance at the U.S. level. Specifically, inventory flows contributing to each impact have been quantified and characterized in terms of U.S. flows per year per capita.[44] Summing all characterized flows for each impact then yields, in effect, impact category performance measures for the United States. As such, they represent a "U.S. impact yardstick" against which to evaluate the *significance* of product-specific impacts. Normalization is accomplished by dividing BEES product-specific impact values by the fixed U.S.-scale impact values, yielding an impact category performance measure that has been placed in the context of all U.S. activity contributing to that impact. By placing each product-specific impact measure in the context of its associated U.S. impact measure, the measures are all reduced to the same scale, allowing comparison across impacts.

Table 2.11 BEES Normalization Values

Impact	***Normalization Value***
Global Warming	25 582 640.09 g CO_2 equivalents/year/capita
Acidification	7 800 200 000.00 millimoles H+ equivalents/year/capita
Eutrophication	19 214.20 g N equivalents/year/capita
Fossil Fuel Depletion	35 309.00 MJ surplus energy/year/capita
Indoor Air Quality	35 108.09 g TVOCs/year/capita
Habitat Alteration	0.00335 T&E count/acre/capita[a]
Water Intake	529 957.75 liters of water/year/capita
Criteria Air Pollutants	19 200.00 microDALYs/year/capita
Smog	151 500.03 g NO_X equivalents/year/capita
Ecological Toxicity	81 646.72 g 2,4-D equivalents/year/capita
Ozone Depletion	340.19 g CFC-11 equivalents/year/capita
Human Health	274 557 555.37 g C_7H_8 equivalents/year/capita

[a] One acre is equivalent to 0.40 hectares.

Normalized BEES impact scores have powerful implications. First, by evaluating a product's impacts with reference to their importance in a larger context, an impact to which a product contributes little will not appear important when, by comparison, competing products contribute even less to that impact.

Second, while *selecting* among building products continues to make sense only within the same building element, like floor covering, normalized impact scores can now be compared across building elements if they are first scaled to reflect the product quantities to be used in the building under analysis. Take the example of global warming scores for roof coverings and chairs. If these scores are each first multiplied by the quantity of their functional units to be used in a particular building (roof area to be covered and seating requirements, respectively), they may then be compared. Comparing across elements can provide insights into which building elements lead to the larger environmental impacts, and thus warrant the most attention.

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[44] Habitat alteration flows have been quantified and characterized in terms of U.S. flows per 0.40 hectares (per acre) per capita.

2.1.4 Interpretation

At the LCA interpretation step, the normalized impact assessment results are evaluated. Few products are likely to dominate competing products in all BEES impact categories. Rather, one product may out-perform the competition relative to fossil fuel depletion and habitat alteration, fall short relative to global warming and acidification, and fall somewhere in the middle relative to indoor air quality and eutrophication. To compare the overall environmental performance of competing products, the performance scores for all impact categories may be synthesized. Note that in BEES, synthesis of impact scores is optional.

Impact scores may be synthesized by weighting each impact category by its relative importance to overall environmental performance, then computing the weighted average impact score. In the BEES software, the set of importance weights is selected by the user. Several alternative weight sets are provided as guidance, and may be either used directly or as a starting point for developing user-defined weights. The alternative weights sets are based on an EPA Science Advisory Board study, a 2006 BEES Stakeholder Panel's structured judgments, and a set of equal weights, representing a spectrum of ways in which people value diverse aspects of the environment.

Refer to Appendix A for the BEES environmental performance computational algorithms and to Appendix B for a primer on interpreting BEES environmental performance scores.

2.1.4.1 EPA Science Advisory Board study

In 1990 and again in 2000, EPA's Science Advisory Board (SAB) developed lists of the relative importance of various environmental impacts to help EPA best allocate its resources.[45] The following criteria were used to develop the lists:

- The spatial scale of the impact
- The severity of the hazard
- The degree of exposure
- The penalty for being wrong

Ten of the twelve BEES impact categories were included in the SAB lists of relative importance:

- Highest-Risk Problems: global warming, habitat alteration
- High-Risk Problems: indoor air quality, ecological toxicity, human health
- Medium-Risk Problems: ozone depletion, smog, acidification, eutrophication, criteria air pollutants

The SAB did not explicitly consider fossil fuel depletion or water intake as impacts. For this exercise, fossil fuel depletion and water intake are assumed to be relatively medium-risk and low-risk problems, respectively, based on other relative importance lists.[46]

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[45] United States Environmental Protection Agency, Science Advisory Board, *Toward Integrated Environmental Decision-Making*, EPA-SAB-EC-00-011, Washington, D.C., August 2000 and United States Environmental Protection Agency, Science Advisory Board, *Reducing Risk: Setting Priorities and Strategies for Environmental Protection,* SAB-EC-90-021, Washington, D.C., September 1990, pp. 13-14.

Verbal importance rankings, such as "highest risk," may be translated into numerical importance weights by following ASTM standard guidance provided by a Multiattribute Decision Analysis method known as the Analytic Hierarchy Process (AHP).[47] The AHP methodology suggests the following numerical comparison scale:

1	Two impacts contribute equally to the objective (in this case environmental performance)
3	Experience and judgment slightly favor one impact over another
5	Experience and judgment strongly favor one impact over another
7	One impact is favored very strongly over another, its dominance demonstrated in practice
9	The evidence favoring one impact over another is of the highest possible order of affirmation
2,4,6,8	When compromise between values of 1, 3, 5, 7, and 9, is needed.

Through an AHP process known as pairwise comparison, numerical comparison values are assigned to each possible pair of environmental impacts. Relative importance weights can then be derived by computing the normalized eigenvector of the largest eigenvalue of the matrix of pairwise comparison values. Tables 2.12 and 2.13 list the pairwise comparison values assigned to the verbal importance rankings, and the resulting SAB importance weights computed for the BEES impacts, respectively. Note that the pairwise comparison values were assigned through an iterative process based on NIST's background and experience in applying the AHP technique.

Table 2.12 Pairwise Comparison Values for Deriving Impact Category Importance Weights

Verbal Importance Comparison	*Pairwise Comparison Value*
Highest vs. Low	6
Highest vs. Medium	3
Highest vs. High	1.5
High vs. Low	4
High vs. Medium	2
Medium vs. Low	2

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[46] See, for example, Hal Levin, "Best Sustainable Indoor Air Quality Practices in Commercial Buildings," *Third International Green Building Conference and Exposition--1996*, NIST Special Publication 908, Gaithersburg, MD, November 1996, p. 148.

[47] ASTM International, *Standard Practice for Applying the Analytic Hierarchy Process to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems,* ASTM Designation E1765-02, West Conshohocken, PA, 2002; and Thomas L. Saaty, *MultiCriteria Decision Making: The Analytic Hierarchy Process--Planning, Priority Setting, Resource Allocation*, University of Pittsburgh, 1988.

Table 2.13 Relative Importance Weights based on Science Advisory Board Study

Impact Category	***Relative Importance Weight (%)***
Global Warming	16
Acidification	5
Eutrophication	5
Fossil Fuel Depletion	5
Indoor Air Quality	11
Habitat Alteration	16
Water Intake	3
Criteria Air Pollutants	6
Smog	6
Ecological Toxicity	11
Ozone Depletion	5
Human Health	11

2.1.4.2 BEES Stakeholder Panel judgments

With version 4.0, BEES introduces a new optional weight set. While the derived, EPA SAB-based weight set is valuable and offers expert guidance,[48] several interpretations and assumptions were required in order to translate SAB findings into numerical weights for interpreting LCA-based analyses. A more direct approach to weight development would consider a closer match to the context of the application; that is, environmentally preferable purchasing in the United States based on life-cycle impact assessment results, as reported by the BEES software.

In order to develop such a weight set, NIST assembled a volunteer stakeholder panel that met at its facilities in Gaithersburg, Maryland, for a full day in May 2006. To convene the panel, invitations were sent to individuals representing one of three "voting interests:" producers (e.g., building product manufacturers), users (e.g., green building designers), and LCA experts. Nineteen individuals participated in the panel: seven producers, seven users, and five LCA experts. These "voting interests" were adapted from the groupings ASTM International employs for developing voluntary standards, in order to promote balance and support a consensus process.

The BEES Stakeholder Panel was led by Dr. Ernest Forman, founder of the premier AHP firm *Expert Choice Inc.* Dr. Forman facilitated panelists in weighting the BEES impact categories using the AHP pairwise comparison process. The panel weighted all impacts in the Short Term (0 years to 10 years), Medium Term (10 years to 100 years), and Long Term (>100 years). One year's worth of U.S. flows for each pair of impacts was compared, with respect to their contributions to environmental performance. For example, for an impact comparison over the

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[48] The 1992 Harvard University study-based weight set included in prior BEES versions has been abandoned because its data are out of date.

Long Term, the panel was evaluating the effect that this year's U.S. emissions would have more than 100 years hence.

Once the panel pairwise compared impacts for the three time horizons, its judgments were synthesized across these time horizons. Note that when synthesizing judgments across voting interests and time horizons, all panelists were assigned equal importance, while the short, medium, and long-term time horizons were assigned by the panel to carry 24 %, 31 %, and 45 % of the weight, respectively.

Prior versions of BEES combined TRACI-based measures of cancerous and noncancerous health effects into a single Human Health impact because deriving the EPA SAB weight set was only possible at the combined level. For the BEES Stakeholder Panel event, however, Cancerous and Noncancerous effects were judged separately to enable a more refined assessment of these two constituents of the Human Health impact. If the BEES 4.0 user chooses to interpret life-cycle impact assessment results using the BEES Stakeholder Panel weight set, then, impact-based results may be viewed separately for cancerous and noncancerous health effects. For compatibility with the other BEES 4.0 weighting schemes, however, these results are weighted and combined into a single Human Health impact for display of BEES Environmental Performance Scores.

The environmental impact importance weights developed through application of the AHP technique at the facilitated BEES Stakeholder Panel event are shown in Table 2.14. These weights reflect a synthesis of panelists' perspectives across all combinations of stakeholder voting interest and time horizon. The weight set draws on each panelist's personal and professional understanding of, and value attributed to, each impact category. While the synthesized weight set may not equally satisfy each panelist's view of impact importance, it does reflect contemporary values in applying LCA to real world decisions. This synthesized BEES Stakeholder Panel weight set is offered as an option in the BEES software.

Table 2.14 Relative Importance Weights based on BEES Stakeholder Panel Judgments

Impact Category		***Relative Importance Weight (%)***
Global Warming		29
Acidification		3
Eutrophication		6
Fossil Fuel Depletion		10
Indoor Air Quality		3
Habitat Alteration		6
Water Intake		8
Criteria Air Pollutants		9
Smog		4
Ecological Toxicity		7
Ozone Depletion		2
Human Health	Cancerous Effects	8
	Noncancerous Effects	5

The three figures below display in graphical form the BEES Stakeholder Panel weights. Figure 2.3 displays the synthesized weight set, Figure 2.4 the weights specific to panelist voting interest, and Figure 2.5 the weights specific to time horizon. The BEES user is free to interpret results using any of the weight sets displayed in Figures 2.4 and 2.5 by entering them as a user-defined weight set in the BEES software.

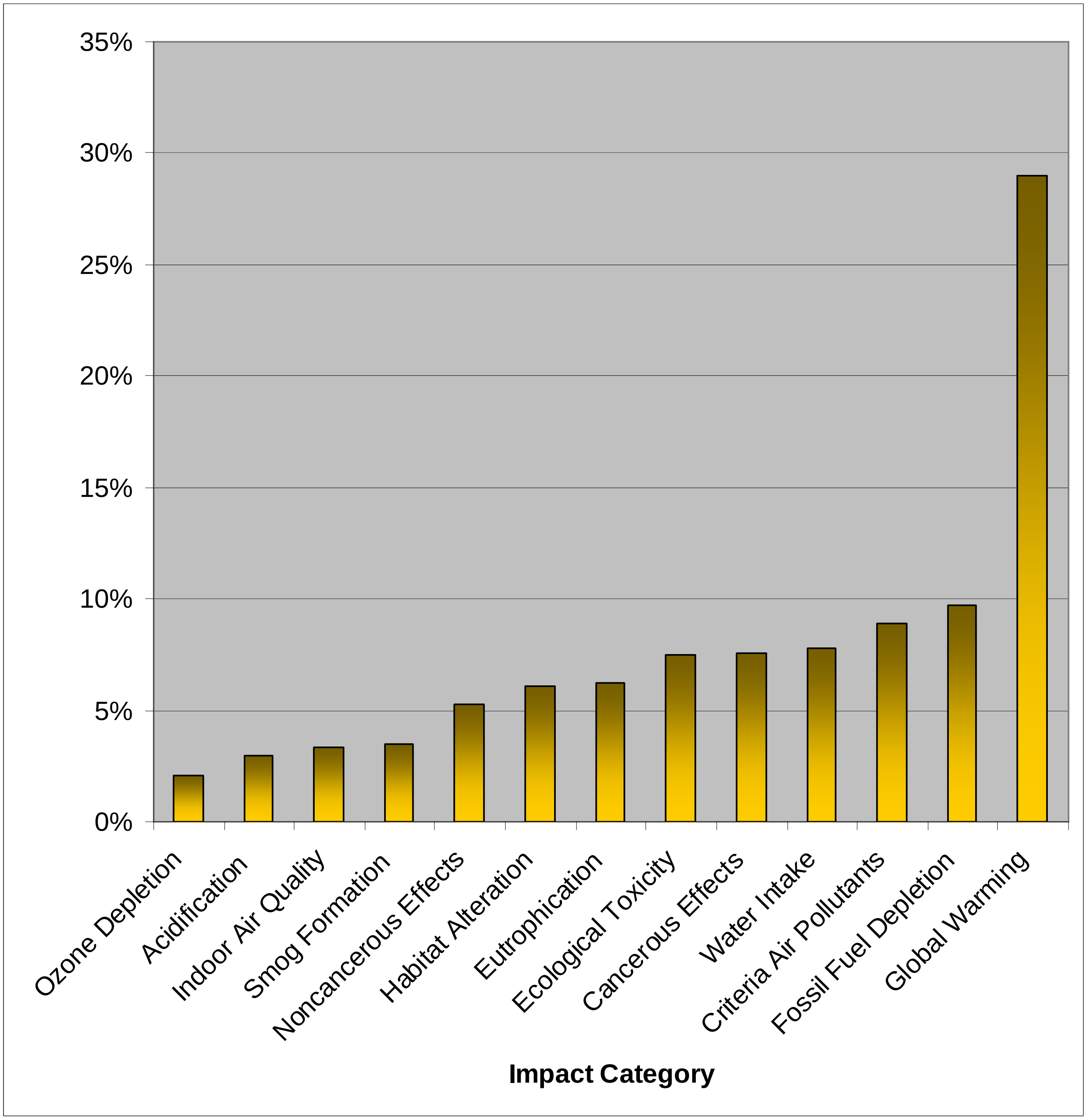

Figure 2.3 BEES Stakeholder Panel Importance Weights Synthesized across Voting Interest and Time Horizon

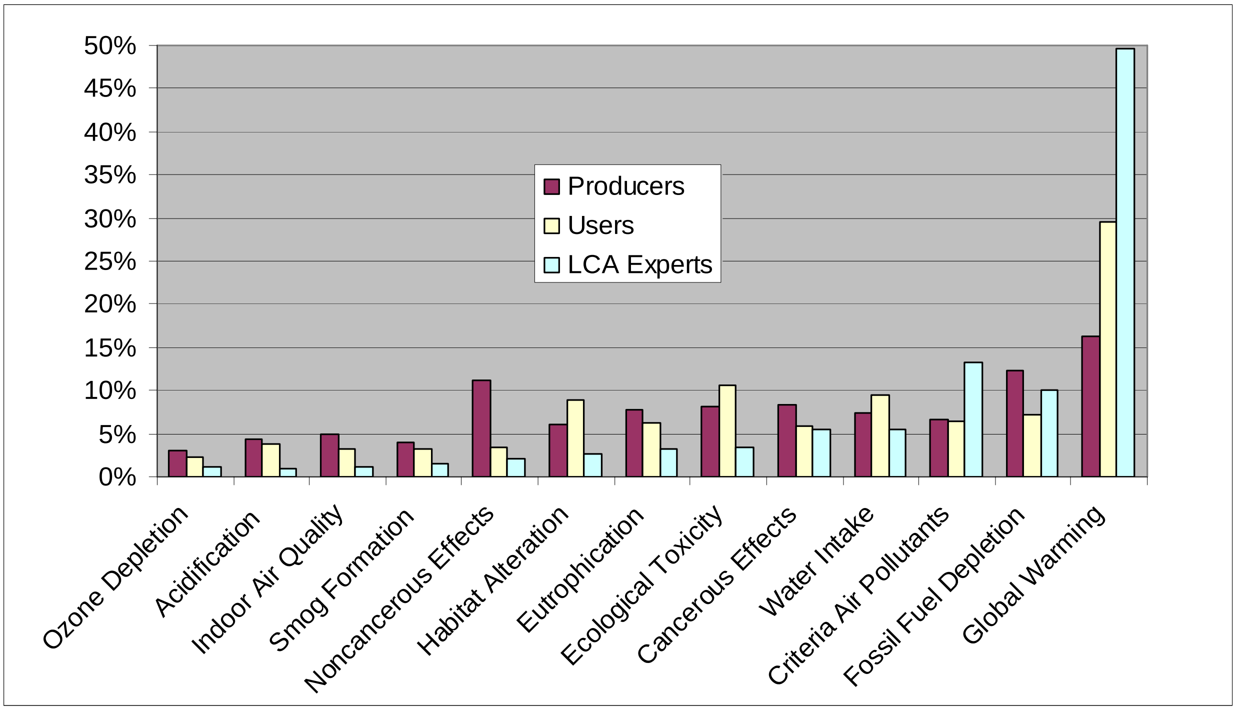

Figure 2.4 BEES Stakeholder Panel Importance Weights by Stakeholder Voting Interest

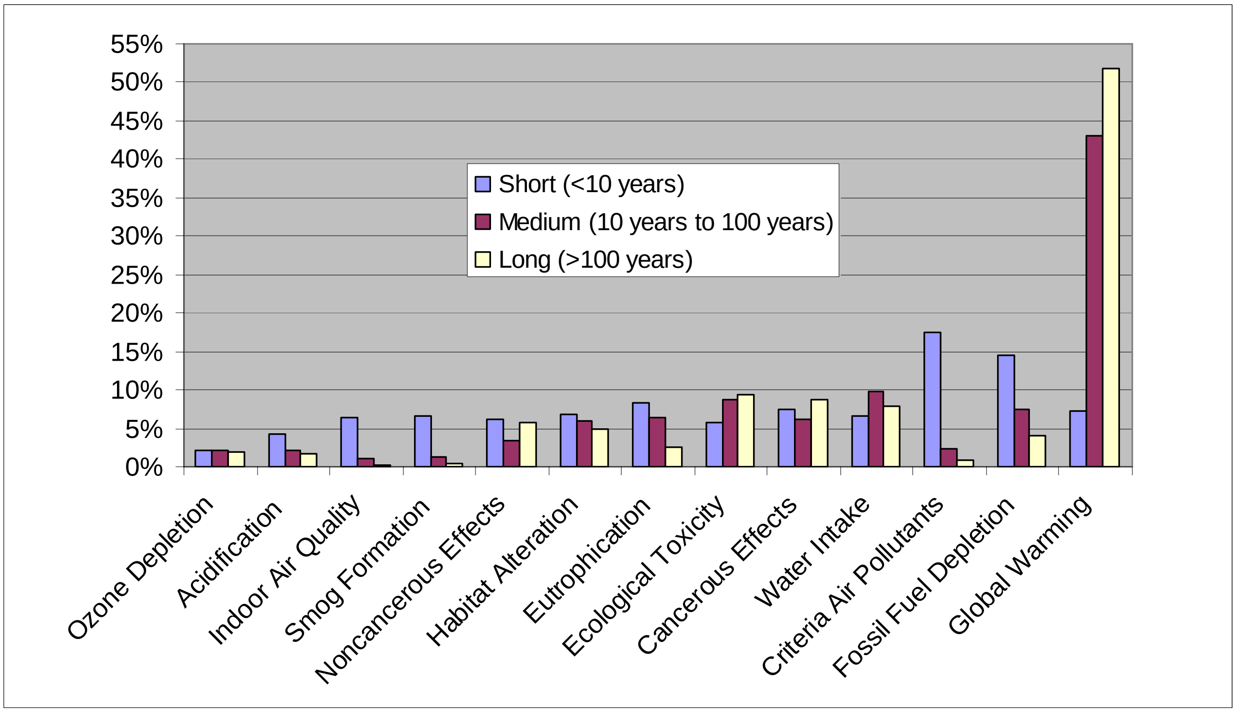

Figure 2.5 BEES Stakeholder Panel Importance Weights by Time Horizon

2.2 Economic Performance

Measuring the economic performance of building products is more straightforward than measuring environmental performance. Published economic performance data are readily available, and there are well-established ASTM standard methods for conducting economic performance evaluations. First cost data are collected from the R.S. Means publication, *2007 Building Construction Cost Data*, and industry interviews, while future cost data are based on data published by Whitestone Research in *The Whitestone Building Maintenance and Repair Cost Reference 2006-2007* and industry interviews. The most appropriate method for measuring the economic performance of building products is the life-cycle cost (LCC) method. BEES follows the ASTM standard method for life-cycle costing of building-related investments.[49]

It is important to distinguish between the time periods used to measure environmental performance and economic performance. These time periods are different. Recall that in environmental LCA, the time period begins with raw material acquisition and ends with product end-of-life. Economic performance, on the other hand, is evaluated over a fixed period (known as the study period) that begins with the purchase and installation of the product and ends at some point in the future that does not necessarily correspond with product end-of-life.

Economic performance is evaluated beginning at product purchase and installation because this is when out-of-pocket costs begin to be incurred, and investment decisions are made based upon out-of-pocket costs. The study period ends at a fixed date in the future. For a private investor, its length is set at the period of product or facility ownership. For society as a whole, the study period length is often set at the useful life of the longest-lived product alternative. However, when alternatives have very long lives, (e.g., more than 50 years), a shorter study period may be selected for three reasons:

- Technological obsolescence becomes an issue
- Data become too uncertain
- The farther in the future, the less important the costs

In the BEES model, economic performance is measured over a 50-year study period, as shown in Figure 2.6. This study period is selected to reflect a reasonable period of time over which to evaluate economic performance for society as a whole. The same 50-year period is used to evaluate all products, even if they have different useful lives. This is one of the strengths of the LCC method. It accounts for the fact that different products have different useful lives by evaluating them over the same study period.

For consistency, the BEES model evaluates the use stage of environmental performance over the same 50-year study period. Product replacements over this 50-year period are accounted for in

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[49] E917-05 Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems ASTM International, *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems,* ASTM Designation E917-05, West Conshohocken, PA, 2005.

the life cycle inventory analysis, and end-of-life inventory flows are prorated to year 50 for products with lives longer than the 50-year study period.

The LCC method sums over the study period all relevant costs associated with a product. Alternative products for the same function, say floor covering, can then be compared on the basis of their LCCs to determine which is the least cost means of fulfilling that function over the study period. Categories of cost typically include costs for purchase, installation, operation, maintenance, repair, and replacement. A negative cost item is the residual value. The residual value is the product value remaining at the end of the study period. In the BEES model, the residual value is computed by prorating the purchase and installation cost over the product life remaining beyond the 50-year period.[50]

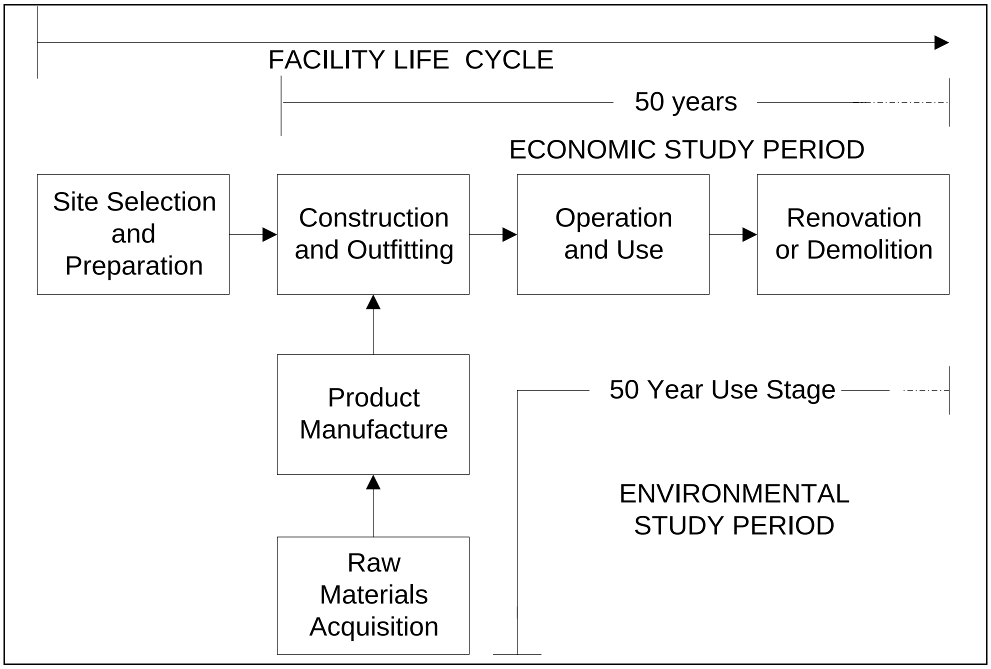

Figure 2.6 BEES Study Periods For Measuring Building Product Environmental And Economic Performance

The LCC method accounts for the time value of money by using a discount rate to convert all future costs to their equivalent present value. Refer to Appendix A for the BEES economic performance computational algorithm showing the discounting technique.

Future costs must be expressed in terms consistent with the discount rate used. There are two approaches. First, a *real* discount rate may be used with constant-dollar (e.g., 2006) costs. Real discount rates reflect that portion of the time value of money attributable to the real earning power of money over time and not to general price inflation. Even if all future costs are expressed in constant 2006 dollars, they must be discounted to reflect this portion of the time-value of money. Second, a *market* discount rate may be used with current-dollar amounts (e.g.,

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[50] For example, a product with a 40 year life that costs \$111/m^2 (\$10/ft^2) to install would have a residual value of \$7.50 in year 50, considering replacement in year 40.

actual future prices). Market discount rates reflect the time value of money stemming from both inflation and the real earning power of money over time. When applied properly, both approaches yield the same LCC results. The BEES model computes LCCs using constant 2006 dollars and a real discount rate.[51] As a default, the BEES tool offers a real rate of 3.0 %, the 2006 rate mandated by the U.S. Office of Management and Budget for most Federal projects.[52]

2.3 Overall Performance

The BEES overall performance measure synthesizes the environmental and economic results into a single score, as illustrated in Figure 2.7. Yet the environmental and economic performance scores are denominated in different units. How can these diverse measures of performance be combined into a meaningful measure of overall performance? The most appropriate technique is Multiattribute Decision Analysis (MADA). MADA problems are characterized by tradeoffs between apples and oranges, as is the case with the BEES environmental and economic performance results. The BEES system follows the ASTM standard for conducting MADA evaluations of building-related investments.[53]

Before combining the environmental and economic performance scores, each is placed on a common scale by dividing by the sum of corresponding scores across all alternatives under analysis. In effect, then, each performance score is rescaled in terms of its share of all scores, and is placed on the same, relative scale from 0 to 100. Then the two scores are combined into an overall score by weighting environmental and economic performance by their relative importance and taking a weighted average. The BEES user specifies the relative importance weights used to combine environmental and economic performance scores and should test the sensitivity of the overall scores to different sets of relative importance weights. Refer to Appendix A for the BEES overall performance computational algorithm.

2.4 Limitations

Properly interpreting the BEES scores requires placing them in perspective. There are inherent limits to applying U.S. average LCA and LCC results and in comparing building products outside the design context.

The BEES LCA and LCC approaches produce U.S. average performance results for generic and manufacturer-specific product alternatives. The BEES results do not apply to products sold in other countries where manufacturing and agricultural practices, fuel mixes, environmental

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[51] Any year 2002 costs were converted to year 2006 dollars using a 1.126 inflation factor developed from consumer price indices for housing reported in U.S. Department of Labor, *Consumer Price Index: All Urban Consumers*, Series CUUR0000SAH, Bureau of Labor Statistics, http://data.bls.gov, January 3, 2007.

[52] U.S. Office of Management and Budget (OMB) Circular A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, Washington, DC, October 27, 1992 and OMB Circular A-94, Appendix C, Washington, DC, January 2007.

[53] ASTM International, *Standard Practice for Applying the Analytic Hierarchy Process to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems,* ASTM Designation E1765-02, West Conshohocken, PA, 2002.

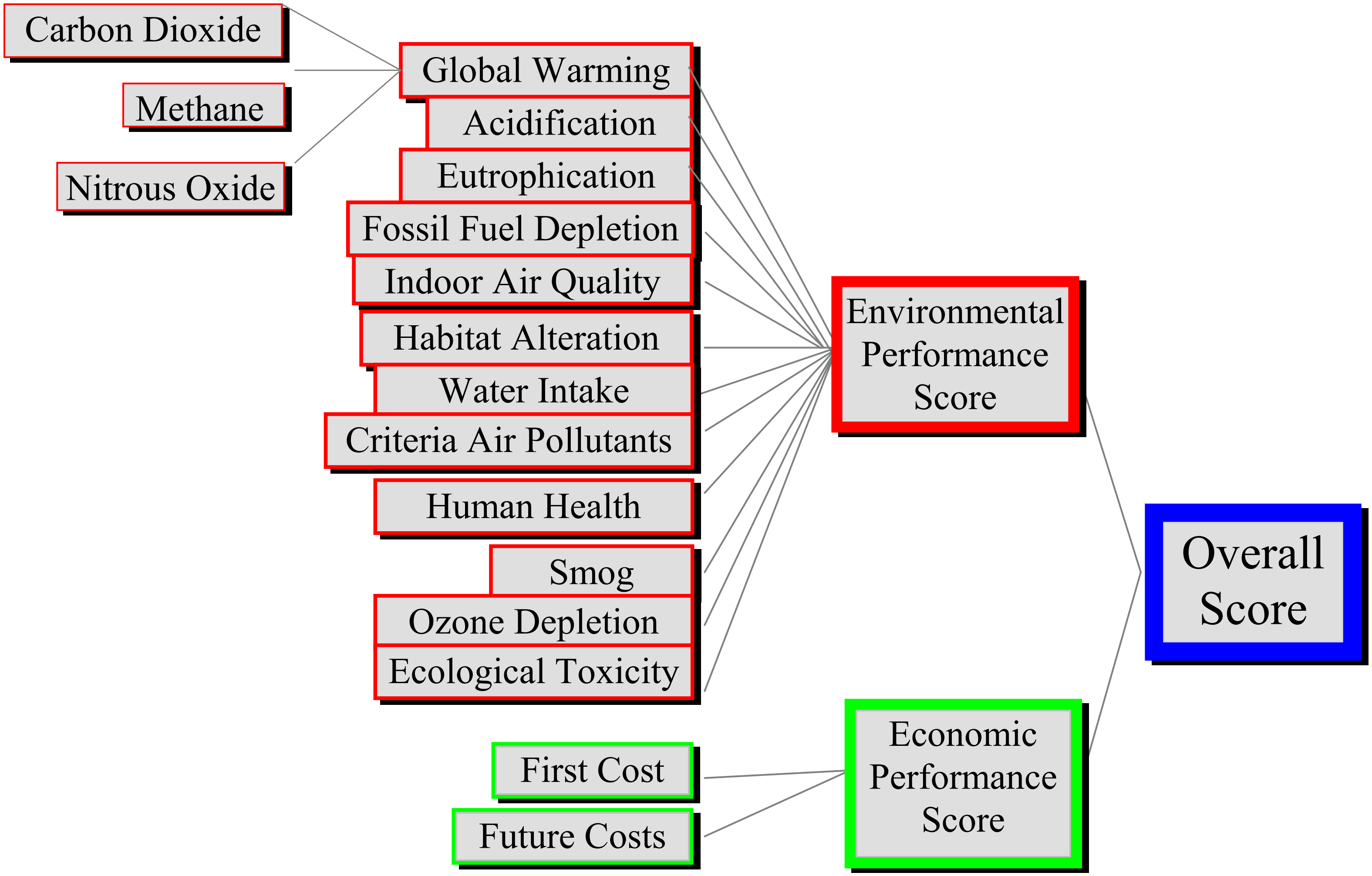

Figure 2.7 Deriving the BEES Overall Performance Score

regulations, transportation distances, and labor and material markets may differ.[54] Furthermore, all products in a generic product group, such as vinyl composition tile floor covering, are not created equal. Product composition, manufacturing methods, fuel mixes, transportation practices, useful lives, and cost can all vary for individual products in a generic product group. The BEES results for the generic product group do not necessarily represent the performance of an individual product.

The BEES LCAs use selected inventory flows converted to selected local, regional, and global environmental impacts to assess environmental performance. Those inventory flows which currently do not have scientifically proven or quantifiable impacts on the environment are excluded, such as mineral extraction and wood harvesting which are qualitatively thought to lead to loss of habitat and an accompanying loss of biodiversity. If the BEES user has important knowledge about these issues, it should be brought into the interpretation of the BEES results.

Life cycle impact assessment is a rapidly evolving science. Assessment methods unheard of several years ago have since been developed and are now being used routinely in LCAs. While BEES 4.0 incorporates state-of-the-art impact assessment methods, the science will continue to evolve and methods in use today—particularly those for habitat alteration, water intake, and indoor air quality—are likely to change and improve over time. Future versions of BEES will incorporate these improved methods as they become available.

During the interpretation step of the BEES LCAs, environmental impacts are optionally combined into a single environmental performance score using relative importance weights. These weights necessarily incorporate values and subjectivity. BEES users should routinely test the effects on the environmental performance scores of changes in the set of importance weights.

The BEES LCAs do not incorporate uncertainty analysis as required by ISO 14040.[55] At present, incorporating uncertainty analysis is problematic due to a lack of underlying uncertainty data. The BEES 2.0 Peer Review Team discussed this issue and advised NIST not to incorporate uncertainty analysis into BEES in the short run.[56] In the long run, however, one aspect of uncertainty may be addressed: the representativeness of generic products. That is, once BEES is extensively populated with manufacturer-specific data, the variation in manufacturer-specific products around their generic representations will become available.

The BEES overall performance scores do not represent *absolute* performance. Rather, they represent proportional differences in performance, or *relative* performance, among competing alternatives. Consequently, the overall performance score for a given product alternative can change if one or more competing alternatives are added to or removed from the set of alternatives under consideration. In rare instances, rank reversal, or a reordering of scores, is

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[54] BEES *does* apply to products manufactured in other countries and sold in the United States. These results, however, do not apply to those same products as sold in other countries because transport to the United States is built into their BEES life cycle inventory data.

[55] International Organization for Standardization (ISO), *Environmental Management – Life-Cycle Assessment – Principles and Framework,* International Standard 14040, 2006.

[56] Curran, M.A. et al., *BEES 2.0, Building for Environmental and Economic Sustainability: Peer Review Report*, NISTIR 6865, National Institute of Standards and Technology, Washington, DC, 2002.

possible. Finally, since they are relative performance scores, no conclusions may be drawn by comparing overall scores across building elements. For example, if exterior wall finish Product A has an overall performance score of 30, and roof covering Product D has an overall performance score of 20, Product D does not necessarily perform better than Product A (keeping in mind that lower performance scores are better). This limitation does *not* apply to comparing environmental performance scores across building elements, as discussed in section 2.1.3.3.

There are inherent limits to comparing product alternatives without reference to the whole building design context. Such comparisons may overlook important environmental and cost interactions among building elements. For example, the useful life of one building element (e.g., floor coverings), which influences both its environmental and economic performance scores, may depend on the selection of related building elements (e.g., subflooring). There is no substitute for good building design.

Environmental and economic performance are but two attributes of building product performance. The BEES model assumes that competing product alternatives all meet minimum technical performance requirements.[57] However, there may be significant differences in technical performance, such as acoustic or fire performance, which may outweigh environmental and economic considerations.

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[57] BEES environmental and economic performance results for wall insulation, roof coverings, and exterior wall finishes *do* consider one important technical performance difference. For these building elements, BEES accounts for differential heating and cooling energy consumption.

3. BEES Product Data

The BEES model uses the ASTM standard classification system, UNIFORMAT II,[58] to organize comparable building products into groups. The ASTM standard classifies building components into a four-level hierarchy: major group elements (e.g., substructure, shell, interiors), group elements (e.g., foundations, roofing, interior finishes), individual elements (e.g., slab on grade, roof coverings, floor finishes), and suggested sub-elements. Elements are defined such that each performs a given function, regardless of design specifications or materials used. The UNIFORMAT II classification system is well suited to the BEES environmental and economic performance methodologies, which define comparable products as those that fulfill the same basic function. The BEES model uses the UNIFORMAT II classification of individual elements, the third level of the hierarchy, as the point of departure for selecting functional applications for BEES product comparisons.

3.1 Concrete Slabs, Walls, Beams, and Columns

3.1.1 Generic Portland Cement Products

Portland cement concrete, typically referred to as "concrete," is a mixture of portland cement (a fine powder), water, fine aggregate such as sand or finely crushed rock, and coarse aggregate such as gravel or crushed rock. Ground granulated blast furnace slag (slag cement), fly ash, silica fume, or limestone may be substituted for a portion of the portland cement in the concrete mix.

Concrete mixes modeled in the BEES software include compressive strengths of 21 MPa, 28 MPa, and 34 MPa (3 000 lb/in2, 4 000 lb/in2, and 5 000 lb/in2). Concrete with 21 MPa strength is used in applications such as residential slabs and basement walls, while strengths of 28 MPa and 34 MPa are used in structural applications such as beams and columns.

Portland cement concrete products like beams and columns are modeled based on volume of concrete (e.g., a functional unit of 1 ft3), while basement walls and slabs are modeled on an area basis (e.g., a functional unit of 1 ft2). The amount of concrete required depends on the dimensions of the product (e.g., thickness of slab or wall and surface area). Above-grade walls are typically 15 cm (6 in) thick. Basement walls are 20 cm (8 in) thick, slabs 10 cm (4 in) thick, and a typical column size is 51 cm by 51 cm (20 in by 20 in).

Manufacturing data for concrete products are taken from the Portland Cement Association's LCA database, with extensive documentation provided by the Portland Cement Association for incorporating their LCA data into BEES.

The detailed environmental performance data for generic portland cement products may be viewed by opening the following files under the File/Open menu item in the BEES software:

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[58] ASTM International, *Standard Classification for Building Elements and Related Sitework--UNIFORMAT II,* ASTM Designation E1557-05, West Conshohocken, PA, 2005.

- A1030A.DBF—100 % Portland Cement for Slabs
- A1030B.DBF—15 % Fly Ash Cement for Slabs
- A1030C.DBF—20 % Fly Ash Cement for Slabs
- A1030D.DBF—20 % Slag Cement for Slabs
- A1030E.DBF—35 % Slag Cement for Slabs
- A1030F.DBF—50 % Slag Cement for Slabs
- A1030G.DBF—5 % Limestone Cement for Slabs
- A1030H.DBF—10 % Limestone Cement for Slabs
- A1030I.DBF—20 % Limestone Cement for Slabs
- A1030O.DBF—35 % Fly Ash Cement for Slabs
- A2020A.DBF—100 % Portland Cement for Basement Walls
- A2020B.DBF—15 % Fly Ash Cement for Basement Walls
- A2020C.DBF—20 % Fly Ash Cement for Basement Walls
- A2020D.DBF—20 % Slag Cement for Basement Walls
- A2020E.DBF—35 % Slag Cement for Basement Walls
- A2020F.DBF—50 % Slag Cement for Basement Walls
- A2020G.DBF—5 % Limestone Cement for Basement Walls
- A2020H.DBF—10 % Limestone Cement for Basement Walls
- A2020I.DBF—20 % Limestone Cement for Basement Walls
- B1011A.DBF—100 % Portland Cement 4KSI for Beams
- B1011B.DBF—15 % Fly Ash Cement 4KSI for Beams
- B1011C.DBF—20 % Fly Ash Cement 4KSI for Beams

- B1011D.DBF—20 % Slag Cement 4KSI for Beams
- B1011E.DBF—35 % Slag Cement 4KSI for Beams
- B1011F.DBF—50 % Slag Cement 4KSI for Beams
- B1011G.DBF—5 % Limestone Cement 4KSI for Beams
- B1011H.DBF—10 % Limestone Cement 4KSI for Beams
- B1011I.DBF—20 % Limestone Cement 4KSI for Beams
- B1011J.DBF—100 % Portland Cement 5KSI for Beams
- B1011K.DBF—15 % Fly Ash Cement 5KSI for Beams
- B1011L.DBF—20 % Fly Ash Cement 5KSI for Beams
- B1011M.DBF—20 % Slag Cement 5KSI for Beams
- B1011N.DBF—35 % Slag Cement 5KSI for Beams
- B1011O.DBF—50 % Slag Cement 5KSI for Beams
- B1011P.DBF—5 % Limestone Cement 5KSI for Beams
- B1011Q.DBF—10 % Limestone Cement 5KSI for Beams
- B1011R.DBF—20 % Limestone Cement 5KSI for Beams
- B1012A.DBF—100 % Portland Cement 4KSI for Columns
- B1012B.DBF—15 % Fly Ash Cement 4KSI for Columns
- B1012C.DBF—20 % Fly Ash Cement 4KSI for Columns
- B1012D.DBF—20 % Slag Cement 4KSI for Columns
- B1012E.DBF—35 % Slag Cement 4KSI for Columns
- B1012F.DBF—50 % Slag Cement 4KSI for Columns
- B1012G.DBF—5 % Limestone Cement 4KSI for Columns

- B1012H.DBF—10 % Limestone Cement 4KSI for Columns
- B1012I.DBF—20 % Limestone Cement 4KSI for Columns
- B10120J.DBF—100 % Portland Cement 5KSI for Columns
- B1012K.DBF—15 % Fly Ash Cement 5KSI for Columns
- B1012L.DBF—20 % Fly Ash Cement 5KSI for Columns
- B1012M.DBF—20 % Slag Cement 5KSI for Columns
- B1012N.DBF—35 % Slag Cement 5KSI for Columns
- B1012O.DBF—50 % Slag Cement 5KSI for Columns
- B1012P.DBF—5 % Limestone Cement 5KSI for Columns
- B1012Q.DBF—10 % Limestone Cement 5KSI for Columns
- B1012R.DBF—20 % Limestone Cement 5KSI for Columns

Flow Diagram

The flow diagrams below show the major elements of the production of portland cement concrete products with and without cement substitutes such as fly ash, slag, and limestone.

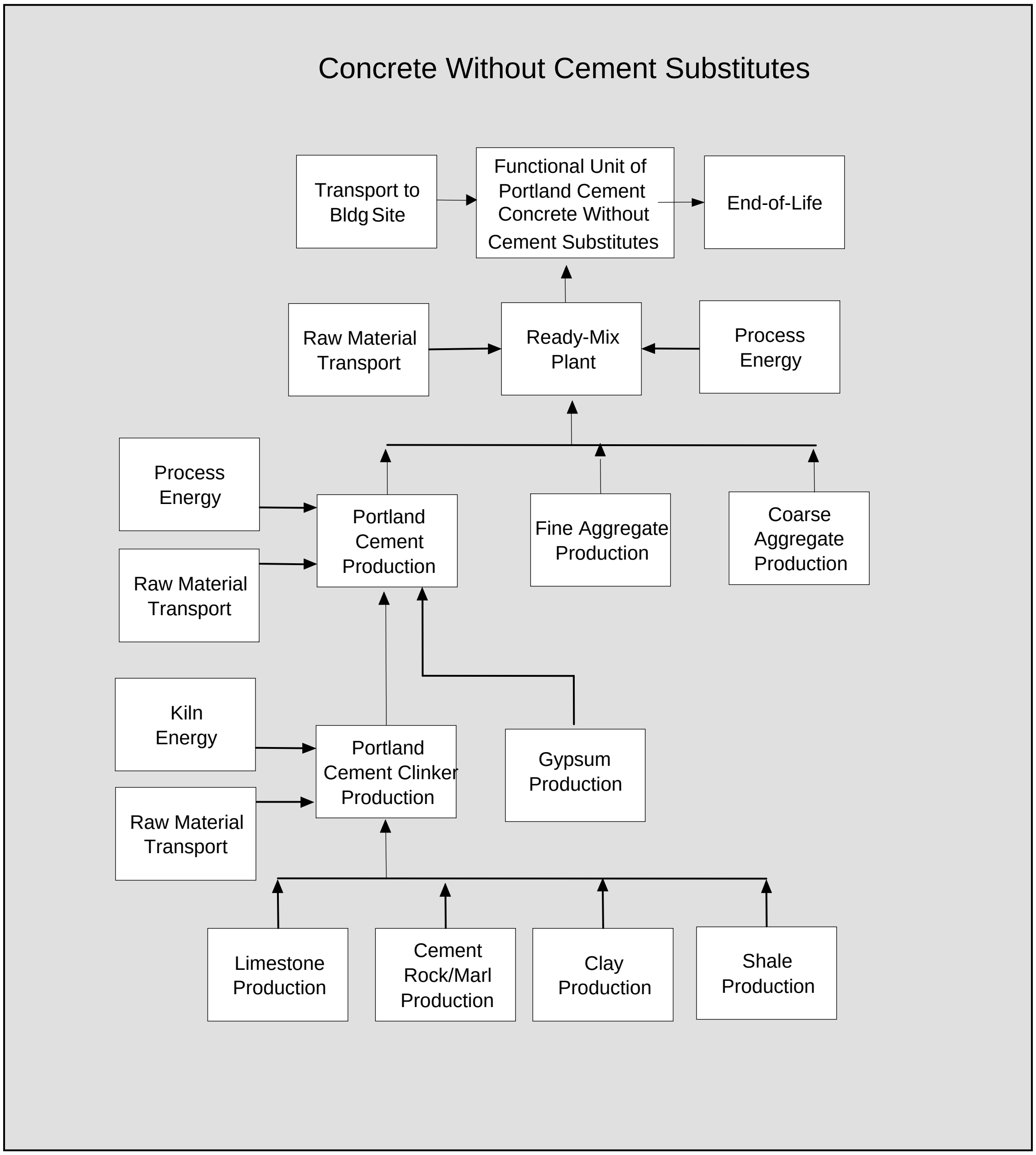

Figure 3.1: Concrete without Cement Substitutes System Boundaries

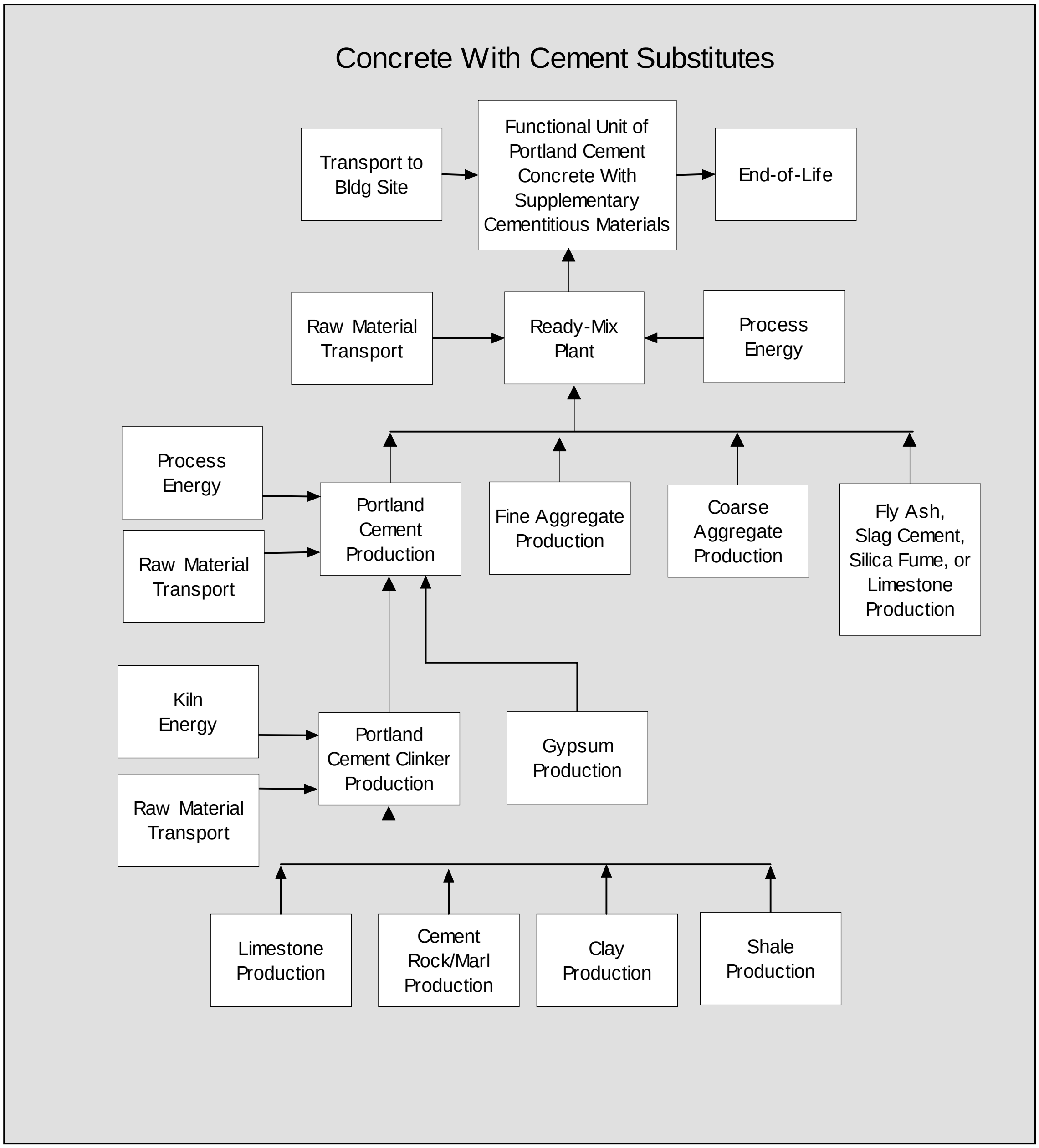

Figure 3.2: Concrete with Cement Substitutes System Boundaries

Raw Materials

As noted above, the constituents of portland cement concrete are portland cement (a fine powder), water, fine aggregate such as sand or finely crushed rock, and coarse aggregate such as gravel or crushed rock. Ground granulated blast furnace slag (slag cement), fly ash, silica fume, or limestone may be substituted for a portion of the portland cement in the concrete mix.

Typically, fly ash and slag are equal replacements by weight for cement. The same is true for a 5 % limestone blended cement, but at the 10 % and 20 % blend levels, more blended cement is needed in the concrete to achieve equivalent strength as mixes with no limestone replacements. Quantities of constituent materials used in an actual project will vary. Mix designs (that is, the constituent quantities) and strength will also vary depending on the aggregates and cement used.

The following Table shows quantities of concrete constituents for the three compressive strengths modeled. Other materials that are sometimes added, such as silica fume and chemical admixtures, are not considered.

Table 3.1: Concrete Constituent Quantities by Cement Blend and Compressive Strength of Concrete

Constituent	*Constituent Density in kg/m^3(lb/yd^3)*		
	21 MPa (3 000 lb/in^2)	*28 MPa (4 000 lb/in^2)*	*34 MPa (5 000 lb/in^2)*
Cement and Fly Ash, Slag, or 5 % Limestone	223 (376)	279 (470)	335 (564)
Coarse Aggregate	1 127 (1 900)	1 187 (2 000)	1 187 (2 000)
Fine Aggregate	831 (1 400)	771 (1 300)	712 (1 200)
Water	141 (237)	141 (237)	141 (237)
Cement and 10 % Limestone	236 (397)	294 (496)	353 (595)
Coarse Aggregate	1 127 (1 900)	1 187 (2 000)	1 187 (2 000)
Fine Aggregate	831 (1 400)	771 (1 300)	712 (1 200)
Water	148 (250)	147 (248)	148 (250)
Cement and 20 % Limestone	265 (447)	331 (558)	397 (670)
Coarse Aggregate	1 127 (1 900)	1 127 (1 900)	1 187 (2 000)
Fine Aggregate	831 (1 400)	771 (1 300)	653 (1 100)
Water	167 (281)	166 (279)	167 (281)

Portland Cement Production. Cement plants are located throughout North America at locations with adequate supplies of raw materials. Major raw materials for cement manufacture include limestone, cement rock/marl, shale, and clay. These raw materials contain various proportions of calcium oxide, silicon dioxide, aluminum oxide, and iron oxide, with oxide content varying widely across North America. Since portland cement must contain the appropriate proportion of these oxides, the mixture of the major raw materials and minor ingredients (as required) varies among cement plants.

BEES data for cement manufacture is based on the average raw material mix and oxide content for all U.S. cement plants for ASTM C150 Type I/II cement, the most commonly used cement in North America. The average raw materials for U.S. cement include limestone, cement rock/marl, shale, clay, bottom ash, fly ash, foundry sand, sand, and iron/iron ore. For the BEES model, the raw materials listed in the Table below are used.[59]

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[59] The weight of inputs is greater than the weight of portland cement output, as a significant percentage of the weight of limestone is released as CO_2.

Table 3.2: Portland Cement Constituents

Constituent	***Mass of inputs in kg***	***Mass Fraction***
Limestone	1.17	72.2 %
Cement rock, marl	0.21	12.8 %
Clay	0.06	3.7 %
Shale	0.05	3.2 %
Sand	0.04	2.5 %
Slag	0.02	1.2 %
Iron/iron ore	0.01	0.9 %
Fly ash	0.01	0.8 %
Bottom ash	0.01	0.6 %
Foundry sand	0.004	0.2 %
Slate	0.001	0.1 %

In the manufacturing process, major raw materials are blended with minor ingredients, as required, and processed at high temperatures in a cement kiln to form an intermediate material known as clinker. Gypsum is interground with clinker to form portland cement. Gypsum content is assumed to be added at 3.0 % (by mass fraction) of portland cement.

Portland cement is manufactured using one of four processes: wet, long dry, preheater, or precalciner. The wet process is the oldest and uses the most energy due to the energy required to evaporate the water. New cement manufacturing plants are being constructed, and older plants converted, to use the more energy efficient preheater and precalciner processes. The mix of production processes modeled is 16.5 % wet, 14.4 % dry, 15.8 % preheater, and 53.3 % precalciner.[60]

The following Table presents U.S. industry-average energy use by process and fuel type, and, for all processes combined, average energy use weighted by the process mix. The production of the different types of fuel is based on the U.S. LCI Database; however, production of “wastes” used as fuel is assumed to be free of any environmental burdens to portland cement production.

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[60] Portland Cement Association, *U.S. and Canadian Labor-Energy Input Survey 2002* (Skokie, IL: Portland Cement Association, 2005).

Table 3.3: Energy Requirements for Portland Cement Manufacturing

Energy Carrier	***Cement Manufacturing Process***[*]				
	Wet	***Long Dry***	***Preheater***	***Precalciner***	***Weighted Average***
Coal	50 %	50 %	70 %	63 %	60 %
Petroleum Coke	18 %	33 %	11 %	11 %	15 %
Electricity	8 %	10 %	12 %	12 %	11 %
Wastes	23 %	3 %	2 %	6 %	8 %
Natural Gas	1 %	4 %	3 %	7 %	5 %
Liquid Fuels[**]	1 %	1 %	1 %	1 %	1 %
All Fuels	100 %	100 %	100 %	100 %	100 %
Total Energy - kJ/kg of cement (Btu/lb)	6 400 (2 749)	5 591 (2 402)	4 357 (1 872)	4 220 (1 813)	4 798 (2 061)

* Cement constitutes 10 % to 15 % by mass fraction of the total mass of concrete.

** Liquid fuels include gasoline, middle distillated, residual oil, and light petroleum gas

Emissions for portland cement manufacturing are from the Portland Cement Association cement LCA database.[61] Emissions include particulate matter, carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxides (SO_X), nitrogen oxides (NO_X), total hydrocarbons, and hydrogen chloride (HCl). Emissions vary for the different combinations of compressive strength and blended cements.

The major waste material from cement manufacturing is cement kiln dust (CKD). There is no breakdown of CKD by process type. An industry average of 38.6 kg of CKD is generated per metric ton (93.9 lb/ton) of cement. Of this, 30.7 kg (74.6 lb) is landfilled and 7.9 kg (19.3 lb) is reused on-site or enters commerce as inputs to the agricultural, construction, and waste treatment industries.[62]

Aggregate Production. Aggregate is a general term that describes a filler material in concrete. Aggregate generally provides 60 % to 75 % of the concrete volume. Typically, aggregate consists of a mixture of coarse and fine rocks. Aggregate is either mined or manufactured. Sand and gravel are examples of mined aggregate. These materials are dug or dredged from a pit, river bottom, or lake bottom and require little or no processing. Crushed rock is an example of manufactured aggregate. Crushed rock is produced by crushing and screening quarry rock, boulders, or large-sized gravel. Approximately half of the coarse aggregate used in the United States is crushed rock.

Concrete contains 25 % coarse and fine aggregate from crushed rock and 75 % coarse and fine

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[61] Nisbet, M.A., Marceau, M.L., and VanGeem, M.G. "Life Cycle Inventory of Portland Cement Manufacture" (an appendix to Environmental Life Cycle Inventory of Portland Cement Concrete), *PCA R&D Serial No. 2095a* (Skokie, IL: Portland Cement Association, 2002).

[62] Bhatty, J., et al., *Innovations in Portland Cement Manufacturing* (Skokie, IL: Portland Cement Association, 2004).

aggregate from sand and gravel.[63] The energy to produce coarse and fine aggregate from crushed rock is 81 kJ/kg (35 Btu/lb), and the energy to produce coarse and fine aggregate from uncrushed aggregate is 17 kJ/kg (7.3 Btu/lb).[64] The energy for aggregate production is a 50:50 mix of diesel oil and electricity.

Fly Ash Production. Fly ash is a waste material that results from burning coal to produce electricity. In LCA terms, fly ash is an environmental outflow of coal combustion, and an environmental inflow of concrete production. This waste product is assumed to be an environmentally "free" input material.[65] However, transport of the fly ash to the ready mix plant is included.

Ground Granulated Blast Furnace Slag (Slag Cement) Production. Slag cement is a waste material that is a result of the production of steel. Similar to fly ash, slag is an environmental outflow of steel production and an environmental inflow of concrete production. Therefore, slag is considered to be an environmentally "free" input material. Unlike fly ash, slag must be processed prior to inclusion in concrete. Processing consists of quenching and granulating at the steel mill, transport to the grinding facility, and finish grinding. This production energy (an assumed 75:25 mix of electricity and natural gas) is assumed to be 722 kJ/kg of slag cement (311 Btu/lb). Transportation to the ready mix plant is included.

Limestone Production. While not common practice in the United States, limestone is used as a partial replacement for portland cement in most European countries. The concrete mix designs used in BEES are estimates based on available literature and have not been tested in the laboratory. Mixes at the higher limestone replacement levels are based on limited data. Energy burdens for limestone production are taken from the U.S. LCI Database.

Manufacturing

Energy Requirements and Emissions. Most portland cement concrete is produced at a central ready mix plant. Energy use in the batch plant includes electricity and fuel used for heating and mobile equipment.[66]

Table 3.4: Energy Requirements for Ready Mix Concrete Production

Energy Carrier	*MJ/m3 (MBtu/yd3)*	*MJ/kg (Btu/lb)*
Heavy Fuel Oil	124 (0.09)	0.05 (22)
Electricity	124 (0.09)	0.05 (22)
Total	**247 (0.179)**	**0.1 (43)**

Transportation. Round-trip distances for transport of concrete raw materials to the ready-mix plant are assumed to be 97 km (60 mi) for portland cement and fly ash, 216 km (134 mi) for slag, and 80 km (50 mi) for aggregate and limestone. The method of transport is truck. A small percentage of the above materials, assumed to be 10 %, may be transported more than 3 219 km

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[63] U.S. Geological Survey. *USGS Minerals Yearbook—2003, Volume I. Metals and Minerals* (Washington, DC: Interior Dept., Geological Survey, 2003)), pp 64.1-2; 71.1-3.

[64] Nisbet, M., et al. "Environmental Life Cycle Inventory of Portland Cement Concrete." *PCA R&D Serial No. 2137a*(Skokie, IL: Portland Cement Association, 2002).

[65] The environmental burdens associated with the production of waste materials are typically allocated to the intended product(s) of the process from which the waste results.

[66] Nisbet, M., et. al, "Environmental Life Cycle Inventory of Portland Cement Concrete."

(2 000 mi). When this is the case, transport is assumed to be by rail.

Transportation

Transportation of concrete products with portland cement by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

Installing each of the BEES concrete applications requires different quantities of plywood forms and steel reinforcement as shown in the Table below.[67]

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[67] R. S. Means Co., Inc., *2007 Building Construction Cost Data* (Kingston, MA: 2006), pp. 711-713.

Table 3.5: Concrete Form and Reinforcing Requirements

Building Element	*Compressive Strength MPa (lb/in^2)*	*Plywood Forms (SFCA/functional unit)*	*Steel Reinforcing (lb/ft^2 for slabs, lb/yd^3 for rest)*	*Comment*
Slabs	21 (3 000)	1.03	1.67	For 7.62 m (25 ft) span, 4 in thick.
Above grade walls, precast concrete	34 (5000)	0	135	Assume 6 in thick. Plywood wall forms are reused over 75 times; hence their environmental burdens are not taken into account.
Above grade walls, ICF	21 (3000)	0	135	Assume 6 in thick. The insulation board used as formwork becomes part of the wall; hence no forms are used.
Above grade walls, cast-in-place	28 (4000)	0	135	Assume 6 in thick. Plywood wall forms are reused over 75 times; hence they are not taken into account.
Basement Walls	21 (3 000)	0	44	For 0.20 m (8 in) thick, 2.44 m (8 ft) high walls. Plywood wall forms are reused over 75 times; hence they are not taken into account.
Columns	28 (4 000)	65	290	For 0.51 m x 0.51 m (20 in x 20 in) columns with a 7.62 m (25 ft) span. Approximately 65 ft^2 of plywood is required per cubic yard of concrete. Plywood forms are reused four times, each time with 10 % installation waste. Steel reinforcements are added to the concrete forms at 290 lb of steel per cubic yard of concrete. The steel value is twice the amount for beams.
Columns	34 (5 000)	65	290	Values for forms and reinforcement provided for 28 MPa (4 000 lb/in^2) columns are used for 34 MPa (5 000 lb/in^2) columns.
Beams	28 (4 000)	54	145	For 7.62 m (25 ft) span beams. Steel reinforcements are added to the concrete forms at 145 lb of steel per cubic yard of concrete (half of the amount required for columns). Plywood forms are reused four times, each time with 10 % installation waste. Values for forms and reinforcement provided for 28 MPa (4 000 lb/in^2) beams are used for
Beams	34 (5 000)	54	145	34 MPa (5 000 lb/in^2) beams.

Notes: 1. Plywood forms are 12.7 mm (0.5 in) thick and their surface density is 5.88 kg/m^2 (1.17 lb/ft^2). Plywood production impacts are the same as those reported for the BEES Plywood Wall Sheathing

product.
2. SFCA=0.09 m^2 (1 ft^2) contact area.
3. Steel reinforcing is made from 100 % recycled steel.

The industry average for steel reinforcement is 5 lb of steel reinforcement/ft^3 of concrete (135 lb steel/yd^3 concrete). Installation materials are assumed to be transported by truck 161 km (100 mi) to the point of installation.

Use

With general maintenance, quality concrete in buildings will generally last more than 100 years. This is a performance-based lifetime.

Interior concrete not exposed to weather (such as beams, columns, foundations, and footings) generally does not require maintenance. For exterior concrete, maintenance will vary depending on weather conditions, but usually consists of minimal repairs that can be done by hand. Maintenance is not included within the system boundaries of the BEES model.

End of Life

The majority of concrete in the U.S. is used in urban areas where concrete is not accepted at landfills. Concrete is recycled as fill and road base, and steel used in concrete reinforcement is recycled. Plywood forms are assumed to be disposed of in a landfill at end of life.

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Industry Contacts

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3.1.2 Lafarge North America Products

Lafarge North America, part of the Lafarge Group, is a large, diversified supplier of cement, aggregates and concrete as well as other materials for residential, commercial, institutional, and public works construction in the United States and Canada. Four Lafarge products are included in BEES:

- Silica Fume Cement (SFC). A mixture of portland cement (90 %) and silica fume (10 %).
- NewCem Slag Cement. Ground granulated blast furnace slag used as a partial replacement for portland cement.
- BlockSet. A blend of cement kiln dust, fly ash, and cement used to make concrete blocks for basement walls.
- Portland Type I Cement.

BEES data for SFC and BlockSet products come from the Lafarge plant in Paulding, Ohio, with an annual production of 436 810 metric tons (481 500 short tons) of SFC, Type I cement, and masonry cement.[68] The Lafarge South Chicago location manufactures a total of 816 466 metric tons (900 000 short tons) of slag products. Data for the Portland Type I Cement product come from the Lafarge plant in Alpena, Michigan, with an annual production of 2 059 310 metric tons (2 270 000 short tons). The portland cement manufactured in Alpena is shipped by lake vessels to terminals around the Great Lakes. These cementitious products are incorporated in different concrete products in BEES as shown in the Table below.

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[68] Annual production data is based largely on 2001 production. Other Lafarge plant data ranges in time from the late 1990s to 2001.

Table 3.6: Lafarge North America Concrete Products

BEES Building Element	*Lafarge Product*	*Specifications*
Concrete for Slabs, Basement Walls, Beams and Columns	Silica Fume Cement (SFC)	1 kg (2.2 lb) of SFC is equivalent to 1 kg (2.2 lb) of generic portland cement. Fully 100 % of the portland cement is replaced by SFC.
	Slag Cement	1 kg (2.2 lb) of slag cement is equivalent to 1 kg (2.2 lb) of generic portland cement. The following substitution ratios of slag cement for portland cement are used: 20 %, 35 %, and 50 %.
	Alpena Portland Type I	1 kg (2.2 lb) of Alpena Portland Type I cement is equivalent to 1 kg (2.2 lb) of generic portland cement
Concrete for Basement Walls	BlockSet	1 kg (2.2 lb) of BlockSet is equivalent to 1 kg (2.2 lb) of generic portland cement. Forty percent (40 %) of the portland cement is replaced by BlockSet.
Parking Lot Paving	Alpena Portland Type I	1 kg (2.2 lb) of Alpena Portland Type I cement is equivalent to 1 kg (2.2 lb) of generic portland cement used in the concrete layer of paving.

The detailed environmental performance data for these product may be viewed by opening the following files under the File/Open menu item in the BEES software:

- A1030J.DBF—Silica Fume Cement for Slabs
- A1030L.DBF—NewCem Slag Cement (20 %) for Slabs
- A1030M.DBF—NewCem Slag Cement (35 %) for Slabs
- A1030N.DBF—NewCem Slag Cement (50 %) for Slabs
- A1030P.DBF—Portland Type I Cement for Slabs
- A2020J.DBF—Silica Fume Cement for Basement Walls
- A2020L.DBF—NewCem Slag Cement (20 %) for Basement Walls
- A2020M.DBF—NewCem Slag Cement (35 %) for Basement Walls

- A2020N.DBF—NewCem Slag Cement (50 %) for Basement Walls
- A2020O.DBF—BlockSet for Basement Walls
- A2020P.DBF—Portland Type I Cement for Basement Walls
- B1011S.DBF—Silica Fume Cement (4KSI) for Beams
- B1011U.DBF—NewCem Slag Cement 4KSI (20 %) for Beams
- B1011V.DBF—NewCem Slag Cement 4KSI (35 %) for Beams
- B1011W.DBF—NewCem Slag Cement 4KSI (50 %) for Beams
- B1011X.DBF—Silica Fume Cement (5KSI) for Beams
- B1011Z.DBF—NewCem Slag Cement 5KSI (20 %) for Beams
- B1011AA.DBF—NewCem Slag Cement 5KSI (35 %) for Beams
- B1011BB.DBF—NewCem Slag Cement 5KSI (50 %) for Beams
- B1011CC.DBF—Portland Type I Cement 4KSI for Beams
- B1011DD.DBF—Portland Type I Cement 5KSI for Beams
- B1012S.DBF—Silica Fume Cement (4KSI) for Columns
- B1012U.DBF—NewCem Slag Cement 4KSI (20 %) for Columns
- B1012V.DBF—NewCem Slag Cement 4KSI (35 %) for Columns
- B1012W.DBF—NewCem Slag Cement 4KSI (50 %) for Columns
- B1012X.DBF—Silica Fume Cement (5KSI) for Columns
- B1012Z.DBF—NewCem Slag Cement 5KSI (20 %) for Columns
- B1012AA.DBF—NewCem Slag Cement 5KSI (35 %) for Columns
- B1012BB.DBF—NewCem Slag Cement 5KSI (50 %) for Columns
- B1012CC.DBF—Portland Type I Cement 4KSI for Columns
- B1012DD.DBF—Portland Type I Cement 5KSI for Columns

- G2022G.DBF—Alpena Type I Cement for Parking Lot Paving

Flow Diagram
The flow diagram below shows the major elements of the production of this product as it is currently modeled for BEES.

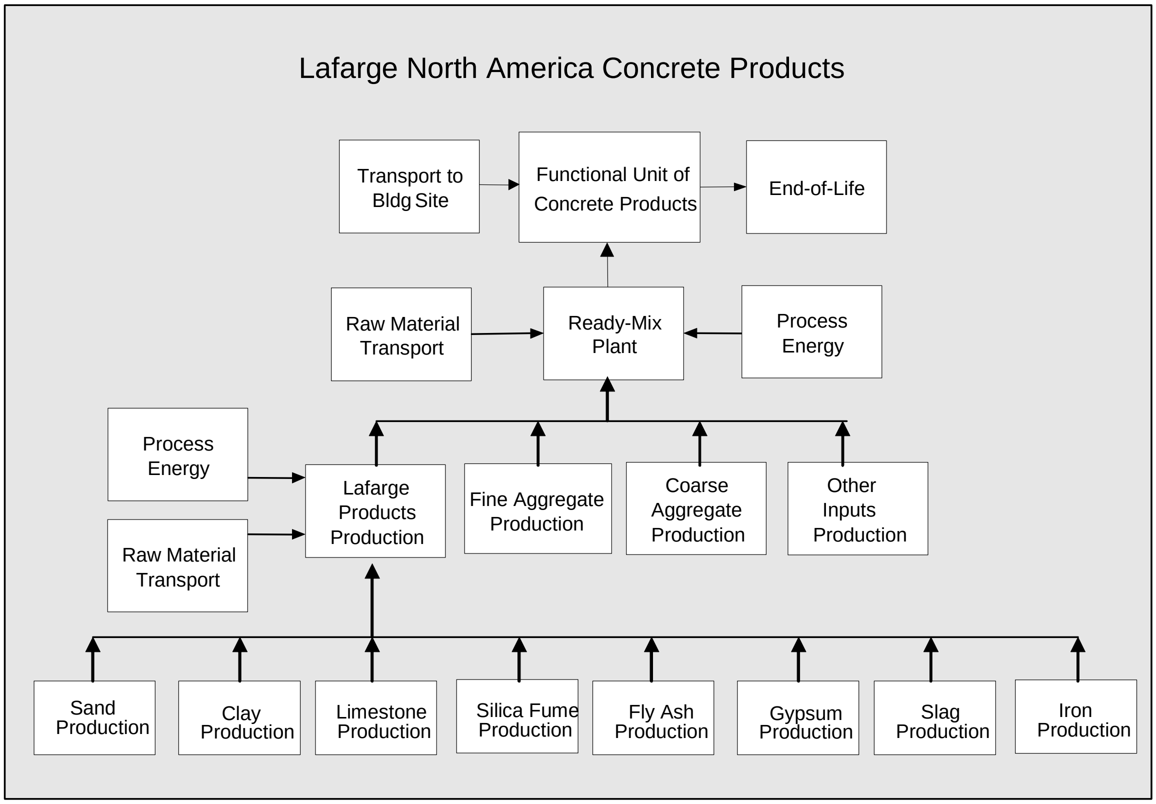

Figure 3.3: Lafarge North America Concrete Products System Boundaries

Raw Materials
The Lafarge products are comprised of the raw materials given in the Table below.

Table 3.7: Lafarge North America Cement Constituents

Constituent	***Silica Fume Cement***	***Slag Cement***	***BlockSet***	***Alpena Portland Type I***
Limestone	72 %	--	76 %	91 %
Clay	16 %	--	16 %	--
Silica Fume	5 %	--	--	--
Sand	3 %	--	3 %	3 %
Gypsum	3 %	--	3 %	--
Slag	--	100 %	--	--
Fly Ash	<0.01 %	--	<0.01 %	5 %
Iron source/scrap	1 %	--	1 %	1 %

Clay and limestone. Energy consumption and air emissions data for clay and limestone production were provided by Construction Technology Laboratories, Inc. as part of the overall cement plant data collected for Lafarge's Alpena site, and take into account fuel combustion, quarry operations, and haul roads.

Silica fume. Silica fume is a by-product of the metallurgical processes used in the production of silicon metals. It is called "fume" because it is an extremely fine smoke-like particulate material. Because it is both pozzolanic and extremely fine (about 100 times finer than cement particles), silica fume may be used to considerable advantage as a supplementary cementitious material in portland cement concrete. Silica fume has been used in the North American cement and concrete industry for over 25 years and can be used in concretes to withstand aggressive exposure conditions. Transportation of the silica fume to the electric furnace is accounted for in the model.

Sand and gypsum. Sand production takes into account energy combustion, waste production, and air emissions from fuel combustion and quarry operations. Gypsum production takes into account electricity and diesel fuel consumption used in surface mining and processing, as well as air emissions and waste production. Data for both of these materials are based on the SimaPro database.

Slag. Slag is a waste material from the blast furnace during the production of pig iron. Blast furnaces, which produce iron from iron ore in the presence of limestone or dolomite fluxes, produce a molten slag. This slag is tapped off the furnace separately from the iron.

Fly ash. Fly ash comes from coal-fired, electricity-generating power plants. These power plants grind coal to a fine powder before it is burned. Fly ash – the mineral residue produced by burning coal – is captured from the power plant's exhaust gases and collected for use. Fly ash particles are nearly spherical in shape, allowing them to flow and blend freely in mixtures, one of the properties making fly ash a desirable admixture for concrete. In LCA terms, this waste byproduct from coal combustion is assumed to be an environmentally "free" input material. However, transport of the fly ash from the production site is included.

Iron. The iron source for the Paulding site is mill scale, a by-product from hot rolling steel. It is treated as scrap iron with no upstream burdens since it is a byproduct, but transportation of the material is accounted for.

Manufacturing

Energy requirements and emissions. The Paulding site uses electricity, petroleum coke, diesel oil, and fuel-quality waste (primarily solvents) as energy sources to produce silica fume cement, BlockSet, and cement dust. Fuel-quality waste is the largest source of energy for the plant. Its upstream production is modeled as being "free," but its combustion emissions are accounted for (using the U.S. LCI Database's fuel oil combustion data). The Alpena site uses electricity, coke, coal, diesel oil, fuel oil, and gasoline as energy sources to produce Portland Type I cement.

To prepare the slag for use in concrete, slag is quenched with water and is ground. Since the water evaporates, there is no effluent run off. Water, electricity, and natural gas consumption associated with this process are taken into account. All energy and electricity data are based on the U.S. LCI Database.

Transportation. Transportation distances for the raw materials to the manufacturing site were provided by Lafarge. Clay and limestone are hauled 1.61 km (1 mi) to the Paulding cement plant and 3.22 km (2 mi) to the Alpena site. Silica fume is transported to the Paulding plant 241 km (150 mi). Sand is transported to the Paulding and Alpena plants 80 km (50 mi) and 16 km (10 mi), respectively. Gypsum is transported to the Paulding plant 97 km (60 mi). Slag and iron are transported 32 km (20 mi). Fly ash is transported by rail 322 km (200 mi). With the exception of fly ash, materials are transported by diesel truck. Both diesel truck and rail transport are modeled based on the U.S. LCI Database.

Transportation

Transportation of finished products to the building site is evaluated based on the same parameters given for the generic counterparts to Lafarge products. All products are shipped by diesel truck as modeled in the U.S. LCI Database. Emissions from transportation allocated to each product depend on the overall weight of the product.

Installation and Use

Installing each of the BEES concrete applications requires plywood forms and steel reinforcement. Refer to the documentation on generic portland cement concrete products for a full description of the modeling of these installation materials.

End of Life

Beams, columns, basement walls, and slabs are all assumed to have 100-year lifetimes. Concrete parking lot paving is assumed to last 30 years. Since the BEES model for parking lot paving accounts for a 50-year use period, two concrete installations are made.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants, *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Industry Reference

Oscar Tavares, Lafarge North America (2002)

3.2 Roof and Wall Sheathing

3.2.1 Generic Oriented Strand Board Sheathing

Oriented strand board (OSB) is made from strands of low density hardwoods and softwoods. OSB sheathing is a structural building material used for residential and commercial construction. The OSB panels must be grade-stamped to meet building code. Each panel has a third party certification and a grade stamp that provides such information as the grading agency, the manufacturer, the product type (in this case, sheathing), wood species, adhesive type, the allowable roof and floor spans, and panel thickness. A wax, primarily a petroleum-based wax, is used as an additive to OSB to provide temporary water holdout. Phenol-formaldehyde and methylene–diphenyl-isocyanate (MDI) resins are used as binder materials to hold the strands together.

For residential construction, the building code requirement is typically for a rated sheathing panel of either OSB or plywood of 0.95 cm (3/8 in) thickness when sheathing is required, such as for shear wall sections; however, common practice is to use sheathing thicknesses greater than specified by code, which is referred to as "code plus." The most common sheathing thickness for OSB is 1.1 cm (7/16 in).

For the BEES system, 0.09 m^2 (1 ft^2) of OSB measuring 1.1-cm (7/16-in) thick is studied. BEES performance data are provided for both roof and wall sheathing; life-cycle costs and environmental performance data are essentially the same for the two applications. The detailed environmental performance data for this product may be viewed by opening the file B1020A.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

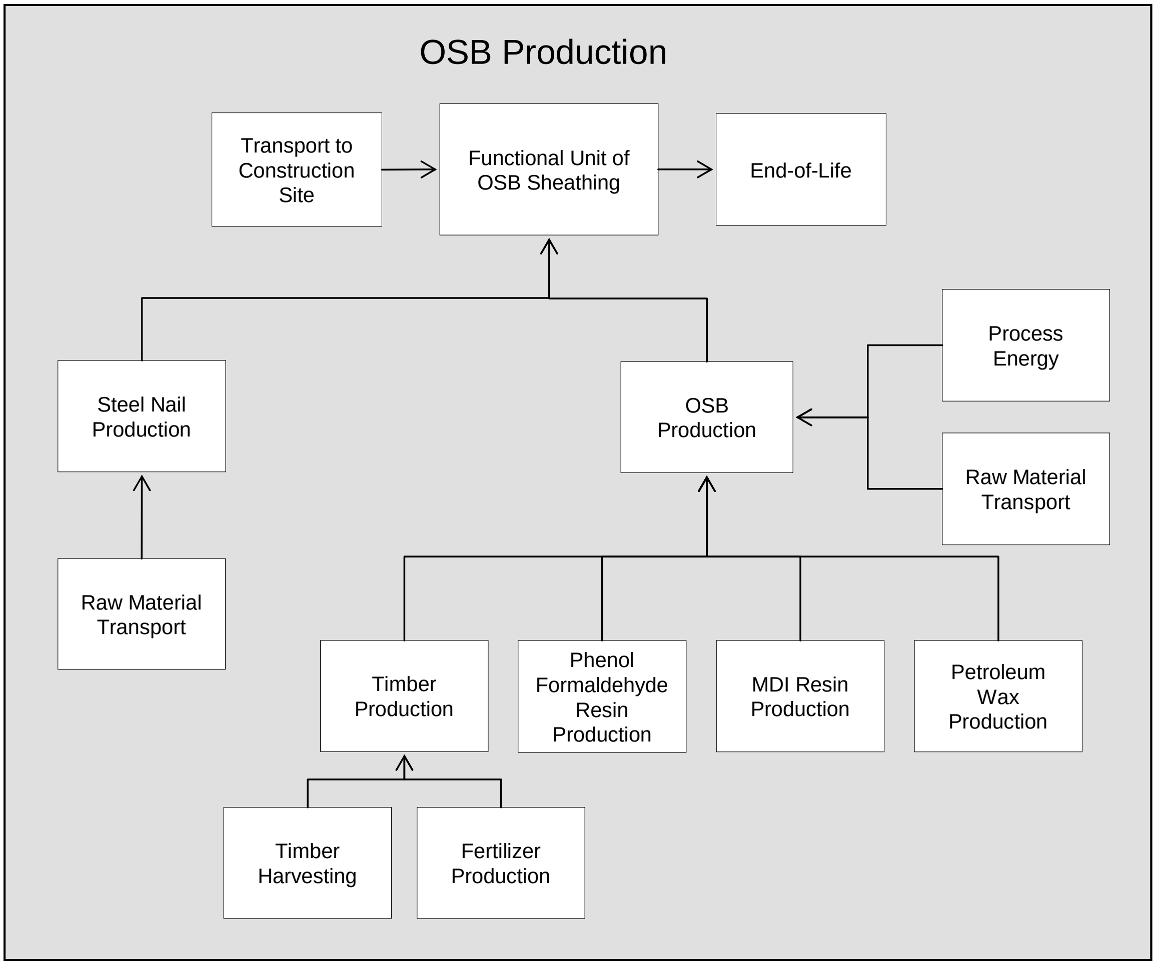

Figure 3.4: OSB Sheathing System Boundaries

Raw Materials

The OSB data for BEES are based on a study performed by CORRIM.[69] The following Table shows the constituents of 0.09 m^2 (1 ft^2) of 1.1 cm (7/16 in) thick OSB sheathing, in terms of percentage of final product.

Table 3.8: OSB Constituents

Constituent	*Mass* kg/m^2 *(*lb/ft^2*)*	*Mass Fraction (%)*
Wood	6.76 (1.38)	94.5
PF resin	0.237 (0.049)	3.34
MDI resin	0.043 (0.009)	0.66
Wax	0.108 (0.022)	1.5
Totals	7.15 (1.46)	100

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[69] Kline, D.E. "Southeastern oriented strandboard production," Module A, Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction (Seattle, WA: Consortium for Research on Renewable Industrial Materials-CORRIM, Inc)/University of Washington, 2004). Found at: http://www.corrim.org/reports.

The BEES model includes timber production, which includes raising seedlings, planting, fertilizer, and harvesting. Energy use and life cycle data on timber production are based on a study by CORRIM of tree production and harvesting in the Southeastern United States for southern pine.[70] The growing and harvesting of wood is modeled as a composite comprised of a mix of low-, medium-, and high-intensity managed timber. Energy use includes electricity for greenhouses to grow seedlings, gasoline for chain saws, diesel fuel for the harvesting mechanical equipment, and a small amount of fertilizer. Fertilizer production data is adapted from European data in the U.S. LCI Database. Emissions from tractors and those associated with production of diesel fuel as well as production and delivery of electricity are included and taken from the U.S. LCI Database. Electricity use for greenhouse operation is based on the grids for the regions where the seedlings are grown. The mix of wood resources for the OSB mills is southern pine softwood (75 %) and several different southern hardwoods (25 %). The average density of this mix, on an oven-dry basis, is 558 kg/m^3 (34.82 lb/ft^3).

BEES modeling accounts for the absorption of carbon dioxide by trees as they grow; the carbon becomes part of the wood, and the oxygen is released to the atmosphere. The “uptake” of carbon dioxide from the atmosphere during the growth of timber is about 1.84 kg (4.06 lb) of carbon dioxide per kilogram of harvested wood (oven-dry weight).

Data representing the production of the phenol formaldehyde (PF) resin and MDI are derived from American Chemistry Council 2006 data developed for submission to the U.S. LCI Database, The ATHENA Institute, and the SimaPro database. The wax used in the production of OSB is assumed to be petroleum wax. Production of the petroleum wax is based on the SimaPro database and includes the extraction, transportation, and refining of crude oil into petroleum wax. Electricity for greenhouse operation is regional for the Southeastern United States, whereas electricity for fertilizer production and other inputs is a U.S. average based on fuel source breakdown values.

Manufacturing

Energy Requirements. The energy for the OSB manufacturing process comes from burning the wood waste, which was generated during processing, and use of natural gas. Other fuels used include propane, diesel, fuel oil, and gasoline to operate mechanical equipment, as well as purchased electricity. The site energy and electricity used are shown in the Table below.

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[70] Bowyer, J., et al., *Phase I Final Report: Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction*. (Seattle, WA: Consortium for Research on Renewable Industrial Materials--CORRIM, Inc./University of Washington, 2004). Found at http://www.corrim.org/reports. 600+ pp.; data also submitted to US LCI Database.

Table 3.9: OSB Production Energy

Energy Carrier	*Units*	*Quantity, 0.95 cm (3/8 in) basis*
Electricity - Southeast Grid	MJ/m^2 (kWh/ft^2)	7.360 (190)
Natural Gas	MJ/m^2 (ft^3/ft^2)	8.743 (747)
Diesel fuel	L/m^2 (gal/ft^2)	0.19 (0.01)
Distillate Fuel Oil	L/m^2 (gal/ft^2)	7.74 (0.19)
LPG	L/m^2 (gal/ft^2)	0.030 (0.71)
Gasoline	MJ/m^2 (gal/ft^2)	0.004 (0.03)
Hogfuel/Biomass (50 % moisture)	kg/m^2 (lb/ft^2)	4 078 (836)

Emissions. The process emissions from the OSB manufacturing process (e.g., volatile organic compound (VOC) emissions from drying the OSB) are based on CORRIM data, as reported in the Table below and in the U.S. LCI Database. With the exception of wood residue combustion, emissions from energy combustion at the plant are included upstream.

Table 3.10: OSB Manufacturing Site Emissions

Air Emission	*Quantity in kg/m^2(lb/ ft^2), 0.95 cm (3/8 in) basis*
Particulates (unspecified)	3.03E-03 (0.62)
VOC (unspecified)	1.06E-02 (2.18)
Carbon Dioxide (biomass)	1.17E-01 (24)
Acetaldehyde	6.34E-04 (0.13)
Acrolein	2.29E-04 (0.047)
Methanol	1.95E-03 (0.4)
Phenol	1.17E-04 (0.024)
Formaldehyde	5.37E-04 (0.11)

Transportation. For transportation of raw materials to the manufacturing plant, BEES assumes truck transportation of 143 km (89 mi) for wood timber, 932 km (579 mi) for PF resin, 1328 km (825 mi) for MDI resin, and 1149 km (714 mi) for the wax, based on CORRIM survey data. The tailpipe emissions from the trucks and the emissions from producing the fuel used in the trucks are taken into account and are based on the U.S. LCI Database. The delivery distances are one-way with an empty backhaul. For shipping weights to the OSB mill, the moisture content of the logs is taken into account. The PF resin is shipped at 50 % solids (50 % water) on a wet basis. MDI resin and wax are transported as their stated weight.

Waste. There is essentially no solid waste from the OSB manufacturing process. All the input resin (mainly PF resin with some MDI resin) and the wax can be assumed to go into the final product and the excess wood material is assumed to be burned on site for fuel.

Transportation

Transportation of OSB by heavy-duty truck to the building site is modeled as a variable of the BEES system. To determine the shipping weight of OSB, the model assumes the product has a 5 % moisture content.

Installation

During installation, 1.5 % of the mass of the product is assumed to be lost as waste, which is sent to the landfill. For walls and roofs, OSB is installed using nails. Approximately 0.0024 kg (0.0053 lb) of steel nails are used per ft^2 of OSB. Steel h-clips are used in addition to nails for roof sheathing, although only a small number of clips are required per panel. H-clip production is not included within the boundary of the model.

Use

Based on U.S. Census data, the mid-service life of OSB in the United States is over 85 years. As a conservative estimate, CORRIM—and BEES—use a product life of 75 years.

There is no routine maintenance for sheathing over its lifetime. Roofing material and siding over the sheathing should be replaced as needed. Sheathing would only be replaced when the framing is replaced, so no replacement is assumed.

End of Life

All of the OSB is assumed to be landfilled at end of life.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Kline, D.E. "Southeastern oriented strandboard production," Module A*, Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction* (Seattle, WA: Consortium for Research on Renewable Industrial Materials. (CORRIM, Inc.)/University of Washington, 2004): Found at http://www.corrim.org/reports.

Bowyer, J., et. al., *Phase I Final Report: Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction.* (Seattle, WA: Consortium for Research on Renewable Industrial Materials. (CORRIM, Inc.)/University of Washington, 2004) Found at http://www.corrim.org/reports.

Industry Contacts

Jim Wilson, Oregon State University/CORRIM, Inc. (August 2005-Jan 2006)

3.2.2 Generic Plywood Sheathing

Plywood sheathing is a structural building material used for residential and commercial construction. The panels must be grade-stamped to meet building code. Each panel has a third party certification, a grade stamp that provides such information as the grading agency, the manufacturer, the product type (in this case, sheathing), wood species, adhesive type, the allowable roof and floor spans, and panel thickness.

Plywood sheathing is made from lower density softwoods. Phenol formaldehyde (PF) is used as an adhesive in the manufacturing process. The flow diagram below shows the major elements of plywood sheathing production.

For residential construction, the building code requirement typically is for a rated sheathing panel of either OSB or plywood of 0.95 cm (3/8 in) thickness when sheathing is required, as for shear wall sections; however, the common practice is to use sheathing thicknesses greater than code, which is referred to as “code plus.” The most common sheathing thicknesses are 1.2 cm (15/32 in) for plywood and 1.1 cm (7/16 in) for OSB.

For the BEES system, 0.09 m^2 (1 ft^2) of 1.2 cm (15/32 in) thick plywood panel is studied. BEES performance data are provided for both roof and wall sheathing. Life-cycle costs and environmental performance data are essentially the same for both products. The detailed environmental performance data for this product may be viewed by opening the file B1020B.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

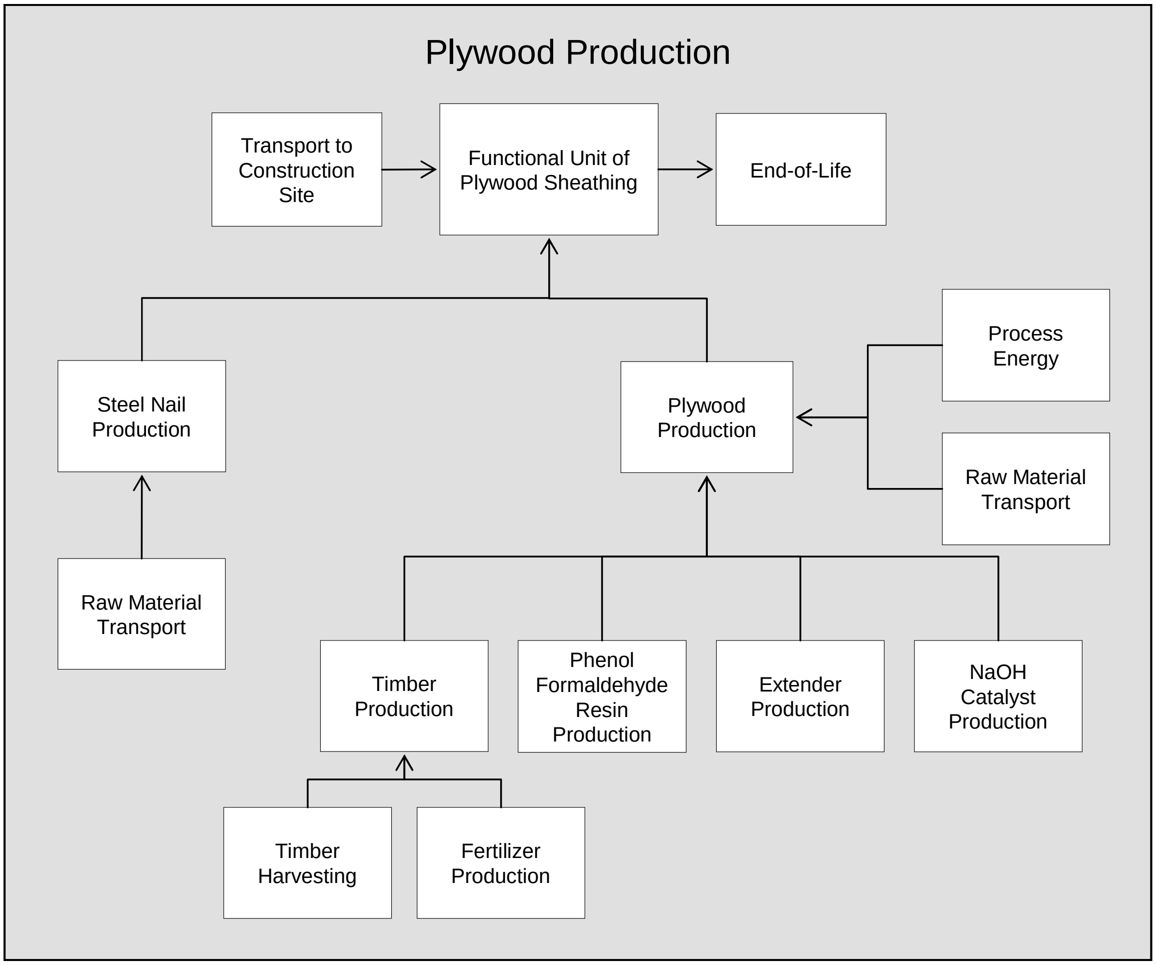

Figure 3.5: Plywood Sheathing System Boundaries

Raw Materials

The plywood data for BEES are based on two CORRIM resources.[71,72] The dry weight of plywood is assumed to be 521 kg/m^3 (32.5 lb/ft^3). The Table below shows the constituents of 0.09 m^2 (1 ft^2) of 1.2 cm (15/32 in) thick plywood in terms of their final product percentages.

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[71] Bowyer, J., et al., Phase I Final Report: Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction. (Seattle, WA: Consortium for Research on Renewable Industrial Materials--CORRIM, Inc./University of Washington, 2004). Found at: http://www.corrim.org/reports; data also submitted to US LCI Database.

[72] www.corrim.org

Table 3.11: Plywood Sheathing Constituents

Constituent	*Mass* *kg/m^2(lb/ft^2)*	*Mass Fraction (%)*
Wood	5.96 (1.22)	97
PF Resin	0.108 (0.022)	1.8
Extender	0.065 (0.013)	1.1
Catalyst (NaOH)	0.014 (0.003)	0.1
Total	6.15 (1.23)	100

Softwood plywood sheathing is primarily produced in the Pacific Northwest and the Southeastern United States. For the Pacific Northwest the species of wood used are Douglas Fir and Western Hemlock, while for the Southeast the wood species is Southern Yellow Pine, which is actually a group of six different softwood species.

The data for growing and harvesting softwood logs for a composite forest management scenario of the Pacific Northwest (PNW) and Southeastern United States (SE) is found in the CORRIM studies. The growing and harvesting of wood is comprised of a mix of low-, medium-, and high-intensity managed timber. Energy use for wood production includes electricity for greenhouses to grow seedlings, gasoline for chain saws, diesel fuel for harvesting mechanical equipment, and a small amount of fertilizer. Emissions associated with production and combustion of gasoline and diesel fuel and those for the production and delivery of electricity are based on the U.S. LCI Database. Fertilizer production data is adapted from European data in the U.S. LCI Database. Electricity use for greenhouse operation is based on the grids for the regions where the seedlings are grown, while the U.S. average electricity grid is used for fertilizer production. CORRIM equally weights production in PNW and SE

BEES modeling accounts for the absorption of carbon dioxide by trees as they grow; the carbon becomes part of the wood, and the oxygen is released to the atmosphere. The “uptake” of carbon dioxide from the atmosphere during the growth of timber is about 1.84 kg (4.06 lb) of carbon dioxide per kilogram of harvested wood (oven-dry weight).

The glue used in bonding plywood consists of PF resin in liquid form combined with extender (which can be a dry agrifiber such as walnut shells or corn husks) and an alkaline catalyst. Data for the production of PF resin comes from the U.S. LCI Database. Weights of resin, extender and catalyst are given on a 100 % solids basis (moisture content not considered).

Manufacturing

Energy Requirements. Manufacturing to produce oven-dry plywood includes several process steps including debarking, log conditioning, production of green veneer, production of dry veneer, pressing and lay-up, and trimming and sawing.

The energy for the plywood manufacturing process is generated from burning wood waste and a small amount of natural gas, and from purchased electricity. Electricity production emissions are based on an average of regional electricity grids for PNW and SE. A small amount of fuel is used for log haulers and forklifts at the plywood mill, and consists of liquid petroleum gas (propane) and diesel. The allocated site energy and electricity use are broken down in the following Table for SE and PNW plywood production. The BEES model uses an equally-weighted average for the final product--1.2 cm (15/32 in) thick plywood:

Table 3.12: Plywood Production Energy

Energy Carrier	***Units***	***Plywood from SE***	***Plywood from PNW***
Electricity - Regional Grid	MJ/m^2 (kWh/ft^2)	4.26 (0.11)	4.26 (0.11)
Natural Gas	MJ/m^2 (ft^3/ft^2)	3.04 (0.26)	1.64 (0.14)
Diesel Fuel	L/m^2 (gal/ft^2)	0.041 (0.001)	0.041 (0.001)
LPG	L/m^2 (gal/ft^2)	0.015 (0.0004)	0.011 (0.0003)
Hogfuel/Biomass (oven-dry)	kg/m^2 (lb/ft^2)	1.41 (0.29)	0.88 (0.18)

Emissions. The allocated air emissions from the plywood manufacturing process are based on the CORRIM study and reported in the Table below. Allocation is based on mass and a multi-unit process analysis to correctly assign burdens. The VOC emissions are from the drying of wood veneer.

Table 3.13: Plywood Production Emissions

Air Emission	***Plywood from SE kg/MJ (lb/ft^2)***	***Plywood from PNW kg/MJ (lb/ft^2)***
Particulates (unspecified)	3.12E-03 (6.40E-04)	2.00E-03 (4.10E-04)
VOC (unspecified)	1.32E-03 (2.70E-04)	3.95E-03 (8.10E-04)
Acetaldehyde	2.39E-05 (4.90E-06)	6.83E-05 (1.40E-05)
Acrolein	--	2.78E-03 (5.70E-04)
Methanol	7.32E-04 (1.50E-04)	8.30E-04 (1.70E-04)
Phenol	8.78E-06 (1.80E-06)	1.85E-05 (3.80E-06)
Formaldehyde	1.17E-05 (2.40E-06)	1.37E-04 (2.80E-05)
Acetone	3.42E-05 (7.00E-06)	3.03E-05 (6.20E-06)
Alpha-pinene	4.88E-04 (1.00E-04)	4.54E-04 (9.30E-05)
Beta-pinene	1.95E-04 (4.00E-05)	1.76E-04 (3.60E-05)
Limonene	5.37E-05 (1.10E-05)	4.88E-05 (1.00E-05)
Methyl-ethyl ketone	3.46E-06 (7.10E-07)	7.32E-06 (1.50E-06)

Transportation. For transportation of raw materials to the plywood manufacturing plant, CORRIM surveys report truck transportation of 126 km (78 mi) for harvested wood and truck transportation of 177 km (110 mi) for the resin. The weights of materials shipped to the plywood mill reflect the actual moisture content rather than the oven-dry weight in the plywood product.

Both the logs and the PF resin are shipped with 50 % moisture content on a wet basis (50 % water). The delivery distances are one-way with an empty backhaul.

Waste. There is no solid waste from the plywood manufacturing process. The PF resin is assumed to go into the final product and all the wood is assumed to go into plywood or co-products. Co-products include materials such as peeler core, veneer clippings, panel trim, and sawdust, as well as wood fuels in the form of bark and wood waste that are burned on site.

Transportation

Transportation of the plywood by heavy-duty truck to the building site is modeled as a variable of the BEES system

Installation

During installation, 1.5 % of the mass of the product is assumed to be lost as waste which is sent to the landfill – although wood construction materials are increasingly being recycled into other products. For walls and roofs, plywood is installed using nails. Approximately 0.0024 kg (0.0053 lb) of steel nails are used per ft^2 of plywood. Steel h-clips are used in addition to nails for roof sheathing, although only a small number of clips are required per panel. H-clip production is not included within the boundary of the model.

Use

Based on U.S. Census data, the mid-service life of plywood sheathing in the United States is over 85 years. As a conservative estimate, CORRIM uses a product life of 75 years.

There is no routine maintenance required for sheathing over its lifetime. Roofing material and siding over the sheathing should be replaced as needed. Sheathing would only be replaced when the framing is replaced; no replacement is assumed.

End of Life

All of the plywood is assumed to be disposed of in a landfill at end of life.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Bowyer, J., et. al., *Phase I Final Report: Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction*. (Seattle, WA: Consortium for Research on Renewable Industrial Materials. (CORRIM, Inc.)/University of Washington, 2004). Found at: http://www.corrim.org/reports.

Industry Contacts

Jim Wilson, Oregon State University/CORRIM, Inc. (August 2005-Jan 2006)

3.3 Exterior Wall Systems

3.3.1 CENTRIA Formawall Insulated Composite Panel

Based in Moon Township, Pennsylvania, near Pittsburgh, CENTRIA is an international company specializing in the manufacture of metal building products and systems for nonresidential walls, roofs, and electrical cellular floors. CENTRIA's Formawall Insulated Composite Panel is a factory foam-installed metal panel system with a rigid insulating, CFC-free, foam core. Its one-piece design permits a complete, thermally efficient exterior wall that can be installed quickly. Its design provides air, water, and vapor barriers. CENTRIA Formawall Insulated Panels are available in a selection of finishes and thicknesses and come in a range of profile options for new and retrofit buildings. CENTRIA Formawall Insulated Panels provide an interior wall, vapor barrier, thermal insulation, and exterior metal substrate. Besides stainless steel fasteners, no additional materials, such as sheathing or more insulation, typically are required. For this reason, CENTRIA Formawall is considered an exterior wall system as opposed to a wall finish.

The detailed environmental performance data for this product may be viewed by opening the file B2010A.DBF under the File/Open menu item in the BEES software.

Flow Diagram
The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

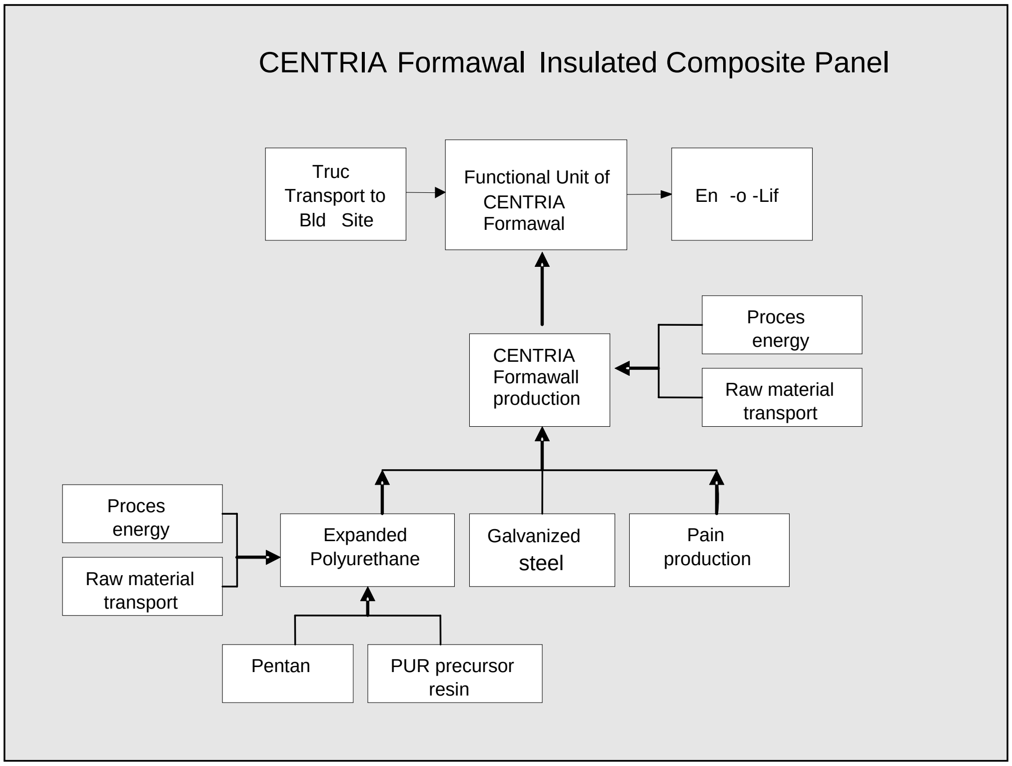

Figure 3.6: CENTRIA Formawall Insulated Composite Panel System Boundaries

Raw Materials

For BEES, a typical finish made of painted galvanized steel skin encases a CFC-free expanded polyurethane (PUR) foam insulation layer. The following Table presents the major constituents of a CENTRIA Formawall Insulated Panel, in terms of their mass per ft^2.

Table 3.14: CENTRIA Formawall Insulated Composite Panel Constituents

Constituent	***Mass, kg/m^2 (lb/ft^2)***	***Mass Fraction (%)***
Galvanized steel	11.9 (2.43)	79.7
Expanded PUR foam	3.0 (0.61)	20
Solvent-based paint	0.05 (0.01)	0.3

The rigid PUR foam, blown with pentane, is produced with 59 % diphenylmethane diisocyanate (MDI) resin and 41 % rigid polyether polyol resin. The amount of pentane used for PUR blowing is 0.024 kg (0.054 lb) per lb of foam. Data for pentane comes from APME[73] and data for the resins from American Chemistry Council 2006 data developed for submission to the U.S. LCI Database.

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[73] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005), Tables 1-9.

Galvanized steel comes from an LCI study by the International Iron and Steel Institute using worldwide facility (primary) data from 1999 and 2000.[74] Data on production of components in the solvent paint comes from elements of the SimaPro database.

Manufacturing

Energy Requirements and Emissions. Manufacturing energy is used for painting the steel, producing the foam, and assembling the components into the CENTRIA Formawall Insulated Panel. The following Table presents the manufacturing energy per 0.09 m^2 (1 ft^2) of CENTRIA Formawall Insulated Panel:

Table 3.15: Energy Requirements for CENTRIA Formawall Insulated Panel Production

Energy source	***Unit/ft^2***
Electricity	0.9 kWh
Natural gas	180 ft^3

All energy production and consumption data come from the U.S. LCI Database. The emissions associated with the production process are provided in the Table below, and result mainly from PUR foam blowing and painting.

Table 3.16: Air Emissions from CENTRIA Formawall Insulated Panel Production

Emission	***kg/m^2 (lb/ft^2)***
Methylene Chloride	1.3 E-2 (2.7 E-3)
Pentane	1.1 E-2 (2.3 E-3)
Toluene	1.4 E-5 (2.8 E-6)
Naphthalene	1.5 E-7 (3.0 E-8)
Formaldehyde	2.0 E-7 (4.0 E-8)
Acetone	1.7 E-6 (3.5 E-7)
Methyl Ethyl Ketone (MEK)	4.3 E-5 (8.9 E-6)
Dimethyl phthalate	8.8 E-6 (1.8 E-6)
Glycol Ethers	2.8 E-5 (5.8 E-6)
Methyl isobutyl ketone	2.3 E-6 (4.7 E-7)
Xylene (mixed isomers)	1.7 E-5 (3.4 E-6)
Isophorone	5.4 E-5 (1.1 E-5)
Ethyl benzene	1.6 E-6 (3.2 E-7)

A small amount of manufacturing waste is produced: 0.002 kg (0.004 lb) per ft^2 of CENTRIA Formawall Insulated Composite Panel.

Transportation. The steel is transported approximately 80 km (50 mi) to a facility where it is painted, and then it is transported approximately 1 449 km (900 mi) to the CENTRIA facility in

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[74] International Iron and Steel Institute (IISI) LCI data sheets provided by an industry contact at Steel Recycling Institute. Data are from worldwide production of steel products, with use of 1999-2000 plant data.

Arkansas. The polyether polyol and MDI resin are transported approximately 1 288 km (800 mi) and 725 km (450 mi), respectively, to CENTRIA. These are all transported by diesel truck, with burdens modeled using the U.S. LCI Database.

Transportation

CENTRIA Formawall Insulated Panels are transported an average of 805 km (500 mi) by diesel truck to the building site.

Installation

Installation of CENTRIA Formawall Insulated Composite Panels entails attaching the panel directly onto the building framing with Type 305 stainless steel, #14 x 1-3/4 fasteners. Eight fasteners are used per 9 m^2 (100 ft^2). At 0.01 kg (0.02 lb) each, 0.07 kg (0.16 lb) of fasteners are used per 9 m^2 (100 ft^2), or 0.0016 lb/ ft^2. The electricity used during installation is 0.00021 kWh/ ft^2. The fasteners are transported an average of 160 km (100 mi) to the installation site.

Because CENTRIA Formawall panels are built according to pre-designed building specifications, they arrive at the site fully measured and ready for installation, and only rarely is there a need to trim the product to fit for correct installation. Because any waste would be such a small percentage of total material use, no installation waste is modeled for BEES.

Use

The product is assumed to have a useful life of 60 years. A building using CENTRIA Formawall Insulated Panels typically needs no additional insulation,

End of Life

It is assumed that CENTRIA Formawall Insulated Panels are waste at end of life and are sent to a landfill. CENTRIA has begun to look at possibilities of a steel recovery process for the CENTRIA Formawall panel at the end of its life. In any event, CENTRIA Formawall panels have not been in existence long enough for CENTRIA to assess if this recovery will occur during decommissioning.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 7.0 LCA Software*. 2005. The Netherlands.

Boustead, I., Eco-profiles of the European Plastics Industry: Pentane (Association of Plastics Manufacturers of Europe, March 2005), Tables 1-9.

International Iron and Steel Institute (IISI), LCI data sheets provided by an industry contact at Steel Recycling Institute.

Industry Contacts

Mark A. Thimons, CENTRIA (September 2006)

3.4 Exterior Wall Finishes

3.4.1 Generic Brick & Mortar

Brick is a masonry unit of clay or shale, formed into a rectangular shape while plastic, cored, and then burned or fired in a kiln. Mortar is used to bond the bricks into a single unit. Facing brick is used on exterior walls.

The BEES model for brick in mortar evaluates fired clay facing brick. The brick is cored prior to being fired, which removes about 25 % to 30 % of the clay material. The actual dimensions of the brick are 9.2 cm x 5.7 cm x 19.4 cm (3.6 in x 2.2 in x 7.62 in). A cored and fired brick of this size weighs 1.86 kg (4.10 lb). The nominal dimensions of the brick including the mortar joint are 9.2 cm x 6.8 cm x 20 cm (3.6 in x $2^2/_3$ in x 8 in). The brick is assumed to be installed with Type N mortar, which has a density of 1840 kg/m^3 (115 lb/ft^3), with an air content of at least 20 %. Masonry is typically measured on the basis of wall area (m^2 or ft^2). A brick wall is assumed to be 80 % brick and 20 % mortar by surface area.

While buildings with brick and mortar finishes require insulation, the finish does provide a thermal resistance value of about R-2. The BEES user has the option of accounting for the resulting energy saved, relative to other exterior wall finishes, over the 50-year use period. This is explained in more detail under Use.

The detailed environmental performance data for this product may be viewed by opening the file B2011A.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

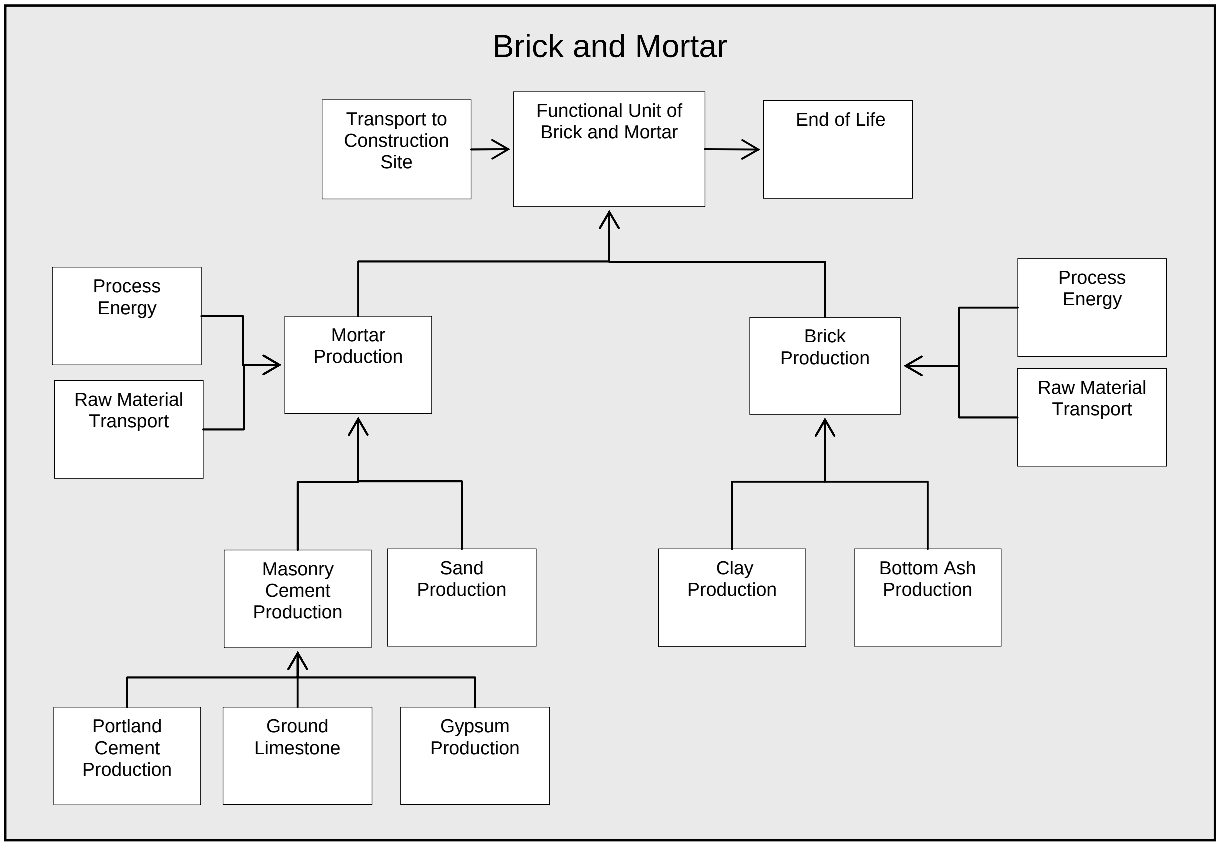

Figure 3.7: Brick and Mortar System Boundaries

Raw Materials

Brick uses virtually 100 % mined clay or shale. Bottom ash, a post-industrial recycled material, is the most widely used recycled material that is added to the clay during brick production. Typical replacement of clay or shale inputs is 0.8 % bottom ash by mass.

Table 3.17: Fired Brick Constituents

Constituent	*Mass Fraction (%)*
Clay	99.2
Bottom Ash	0.8

All material removed in the manufacturing process is returned to the manufacturing stream. Fired product that is scrapped is used as grog[75] in brick manufacturing or for other uses such as landscape chips and roadbed.

Type N mortar consists of 1 part masonry cement (by volume fraction), 3 parts sand,[76] and 6.3 L

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[75] Grog is previously-fired ceramic material, typically from ground brick. It is included in the brick body to reduce drying shrinkage or provide a more open texture to the fired brick.

[76] Based on ASTM Specification C270-96.

(1.7 gal) of water. The raw material use for masonry cement is based on Type N masonry cement, and its constituents are shown below.

Table 3.18: Masonry Cement Constituents

Constituent	***Mass Fraction (%)***
Portland Cement Clinker	50.0
Limestone	47.5
Gypsum	2.5

The flow diagram for brick and mortar shows only the solid components of mortar. Some water in mortar is chemically bound, so there is some net consumption of water—based on 25 % by weight for hydration, approximately 230 kg/m^3 (14 lb/ft^3) of water is used. Production of the raw materials for brick and mortar are based on the SimaPro LCA database and the U.S. LCI Database.

Manufacturing

Energy Requirements and Emissions. The energy requirements for brick production are listed in the Table below. These figures include the drying and firing production steps only, based on the latest Brick Industry Association survey stating that these are the most important steps in terms of energy use. Environmental flows resulting from the production of the different types of fuel are based on the U.S. LCI Database.

Table 3.19: Energy Requirements for Brick Manufacturing

Energy Carrier	***Quantity per Lb***
Natural Gas	0.028 m^3 (0.987 ft^3)
Grid Electricity	0.0810 MJ (0.0225 kWh)

Brick production is distributed across U.S. Census Regions as given below.

Table 3.19a: U.S. Brick Production by Census Region

Census Region	***Brick Production***
Pacific	2.8 %
Mountain	3.5 %
West South Central	17.8 %
East South Central	17.9 %
South Atlantic	39.6 %
West North Central	4.1 %
East North Central	8.1 %
Middle Atlantic	5.4 %
New England	0.8 %

A blend of grid electricity sources are used to represent this distribution of manufacturing facilities.

Emissions for brick firing and drying are based on AP-42 data for emissions from brick manufacturing for each manufacturing technology and type of fuel burned.[77,78]

Water Consumption. Water is used in the manufacturing process to impart plasticity to the raw materials, which allows the brick to be formed. On average, approximately 20.5 % water by weight is used and returned to the atmosphere in drying.

Transportation. Brick raw materials are typically transported less than 80 km (50 mi) by truck to the brick plant.[79]

Waste. The manufacturing process generates no waste materials as all materials are reused in the plant.

Transportation

Transportation of brick to the building site is modeled as a variable of the BEES system. Bricks are assumed to be transported by truck and rail (84.7 % and 15.3 %, respectively) to the building site.[80]

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[77] United States Environmental Protection Agency, "Brick and Structural Clay Product Manufacturing," Volume I: Section 11.3, AP-42: Compilation of Air Pollutant Emission Factors(Washington, DC: US Environmental Protection Agency, August 1997). Found at: http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s03.pdf.

[78] According to the Brick Industry Association (BIA), AP-42 emissions data are likely to be overstated, as at least 30 brick plants have added emission control devices in the past five years, and all new plants (including at least 5 new plants completed in the past 5 years) include these emission control devices. However, no alternate emissions data were made available by BIA.

[79] An additional note regarding the production of bricks: according to BIA, brick companies have been cited for their reclamation of spent clay pits. Examples include golf courses, wetlands, and land fills.

[80] United States Environmental Protection Agency, "Brick and Structural Clay Product Manufacturing," Volume I: Section 11.3, AP-42: Compilation of Air Pollutant Emission Factors(Washington, DC: US Environmental Protection Agency, August 1997). Found at: http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s03.pdf.

Installation

Installation of brick and mortar primarily consists of manual labor; no energy use is modeled for the installation phase. Losses during the installation phase are estimated to be 5 % of total materials per ft^2. Waste from the installation process is typically landfilled.

While sheathing, weather resistive barriers, and other ancillary materials may be required to complete the exterior wall system, these materials are not included in the system boundaries for BEES exterior wall finishes.

Use

Brick walls are often in service for more than 100 years. Older buildings are adapted to new uses, with the existing brick walls included as a design feature. A useful life of 200 years is assumed. Most brick walls have little maintenance. Repointing of mortar joints on portions of the wall may be required after 25 years, but this minor maintenance step was not included within the system boundary of the model.

It is important to consider thermal performance differences when assessing environmental and economic performance for exterior wall finish product alternatives. Thermal performance affects building heating and cooling loads, which in turn affect energy-related LCA inventory flows and building energy costs over the BEES 50-year use stage.

For exterior wall finishes, thermal performance differences are optionally assessed for 14 U.S. cities spread across a wide range of climate and fuel cost zones, and for electricity, distillate oil, and natural gas heating fuel types (electricity is assumed for all cooling). When selecting wall finish alternatives for analysis, if the BEES user chooses to account for thermal performance, he or she selects the U.S. city closest to the building location and the building heating fuel type, so that thermal performance differences may be customized to these important contributors to building energy use.

Three BEES exterior wall finish products affect thermal performance: generic brick and mortar, Dryvit Outsulation, and Dryvit Outsulation Plus. Assuming a thermal resistance value of R-13 is required by code for exterior walls, then R-13 insulation on a brick and mortar wall will increase its thermal performance to about R-15, and on a Dryvit Outsulation or Dryvit Outsulation Plus wall, to about R-19. If the BEES user chooses to account for thermal performance, use energy savings for these three products, over and above that provided by R-13 insulation, are accounted for in the BEES results.[81]

End of Life

Demolition of brick walls at end of life typically is not done very carefully. The walls are knocked down using equipment such as a wrecking ball or explosives, resulting in some loss of brick. It is estimated that 75 % of the brick is recovered in usable form. The mortar is removed by hand labor using chisels and hammers, typically at the demolition site. The cleaned brick is sold for new construction, and the mortar and broken brick are taken to landfills.

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[81] Note that if generic brick and mortar and/or the two Dryvit products are the *only* alternatives being compared, use energy savings are computed relative to the selected alternative with the lowest R-value.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

United States Environmental Protection Agency, "Brick and Structural Clay Product Manufacturing," Volume I: Section 11.3, *AP-42: Compilation of Air Pollutant Emission Factors*, (Washington, DC: U.S. Environmental Protection Agency, August 1997). Found at: http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s03.pdf.

ASTM International, *C270-06 Standard Specification for Mortar for Unit Masonry*, (West Conshohocken, PA, 2005).

Industry Contacts

J. Gregg Borchelt, P.E., Brick Industry Association (August-November 2005)

3.4.2 Generic Stucco

Stucco is cement plaster that can be used to cover exterior wall surfaces. Both portland cement and masonry cement are used for the base and finish coats of stucco exterior walls. The densities of the different types of stucco coats for portland cement (for a base coat Type C plaster, finish coat Type F plaster) and masonry cement (for a base coat Type MS plaster, finish coat Type FMS plaster) are shown in the Table below. Since no data on relative market shares of portland cement and masonry cement stucco were available, life cycle data for the two stucco types were averaged for use in the BEES model. Thus, each generic stucco coat (base or finish) is represented by an average of the corresponding portland cement and masonry cement coats.

Table 3.20: Density of Stucco by Type

Type of Stucco	***Density kg/m^3 (lb/ ft^3)***
Portland Cement Base Coat C	1 830 (114.18)
Portland Cement Finish Coat F	1 971 (122.97)
Masonry Cement Base Coat MS	1 907 (118.98)
Masonry Cement Finish Coat FMS	2 175 (135.69)

The BEES model assumes a functional unit of 1 ft^2 of stucco applied to a frame construction (stucco applied over metal lath). This generally requires a 3-coat covering totaling 2.22 cm (7/8 in) in thickness. Coats 1 and 2 are each 0.95 cm (3/8 in) thick and the finish coat is 0.32 cm (1/8 in) thick.

The detailed environmental performance data for this product may be viewed by opening the file B2011B.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagrams that follow show the major elements of the production of portland cement stucco and masonry cement stucco exteriors.

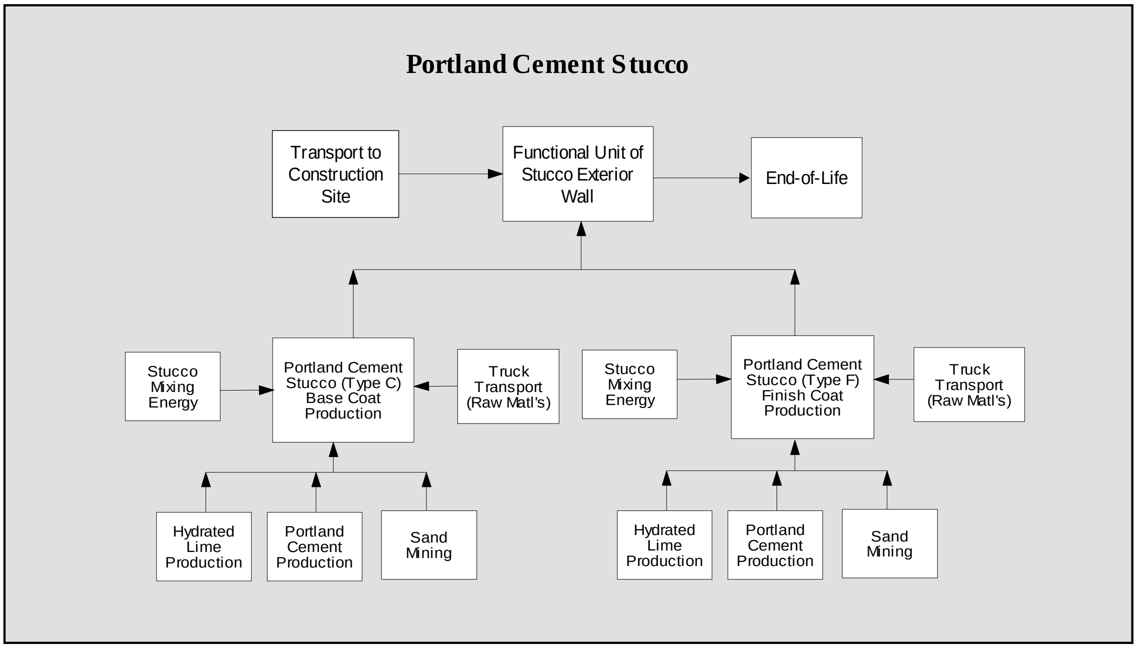

Figure 3.8: Portland Cement Stucco System Boundaries

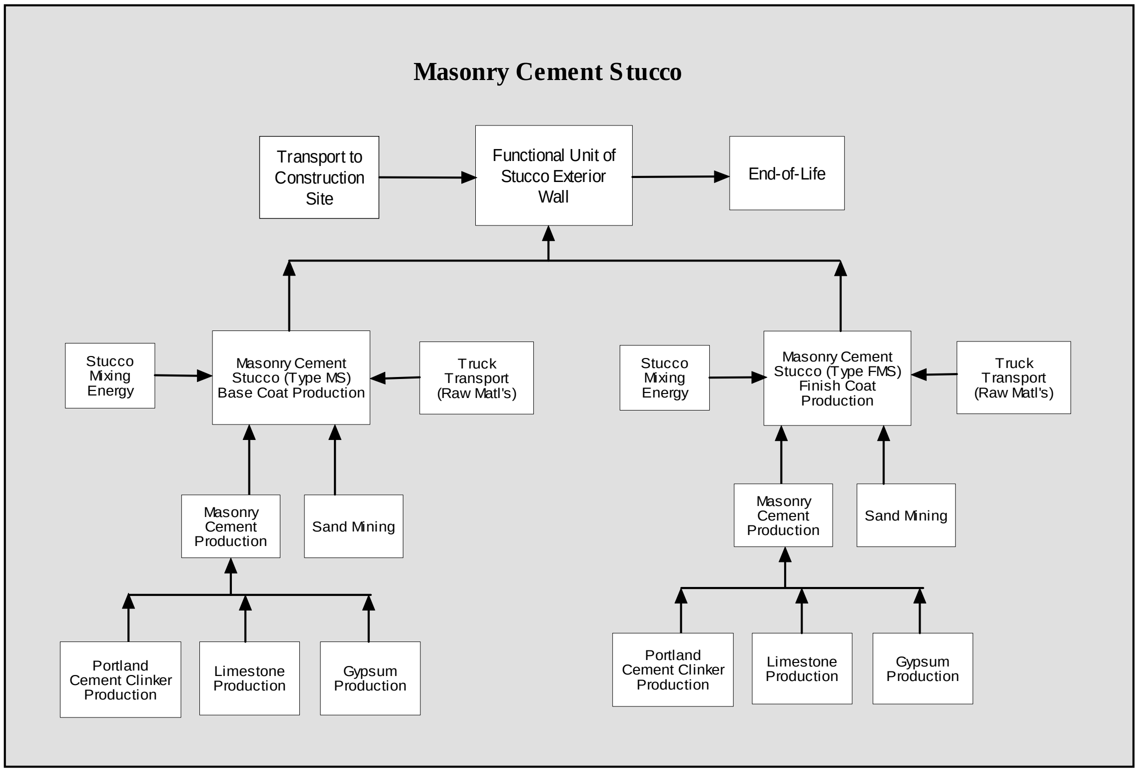

Figure 3.9: Masonry Cement Stucco System Boundaries

Raw Materials

The material composition of portland cement and masonry cement base coat and finish coat stuccos is shown in the following Table.[82]

Table 3.21: Stucco Constituents

Constituent	Cementitious Materials (volume fraction)			Sand (volume fraction of cementitious material)
	Portland Cement	Masonry Cement	Lime	
Base Coat C	1		1.125	3.25
Finish Coat F	1		1.125	3
Base Coat MS		1		3.25
Finish Coat FMS		1		3

Masonry Cement Production. The raw material use for masonry cement is based on Type N masonry cement, and its constituents are shown below.

Table 3.22: Masonry Cement Constituents

Constituent	Mass Fraction (%)
Portland Cement Clinker	50.0
Limestone	47.5
Gypsum	2.5

Production of raw material inputs for masonry cement (limestone and gypsum) and stucco (sand and lime) are based on data from the U.S. LCI Database and the SimaPro database. The energy requirements for masonry cement production are based on the energy required to grind and mix the masonry cement constituents, as follows.

Table 3.23: Energy Requirements for Masonry Cement Manufacturing

Fuel Use	Manufacturing Energy
Electricity	0.196 MJ/kg (409.55 Btu/lb)

The only emissions from masonry cement production, aside from those due to the production of the portland cement, are CO_2 emissions from the additional lime used to make the masonry cement. According to the U.S. Greenhouse Gas Inventory:[83]

"During the cement production process, calcium carbonate ($CaCO_3$) is heated in a cement kiln at a

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[82] Based on ASTM Specification C926-94.

[83] U.S. Environmental Protection Agency, "Cement Manufacture (IPCC Source Category 2A1)," Chapter 4.2, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*. (Washington, DC: U.S. Environmental Protection Agency, April 2006). pp. 4-8 to 4-9.

> temperature of about 1 300 °C (2 400 °F) to form lime (i.e., calcium oxide or CaO) and CO_2. This process is known as calcination or calcining. Next, the lime is combined with silica-containing materials to produce clinker (an intermediate product), with the earlier by-product CO_2 being released to the atmosphere. The clinker is then allowed to cool, mixed with a small amount of gypsum, and used to make portland cement. The production of masonry cement from portland cement requires additional lime and, thus, results in additional CO_2 emissions. Masonry cement requires additional lime over and above the lime used in clinker production. In particular, nonplasticizer additives such as lime, slag, and shale are added to the cement, increasing its weight by approximately five percent."

In the BEES model, lime accounts for approximately 47.5 % percent of the added weight. An emission factor for this added lime can then be calculated by multiplying this value by the emission factor for lime calcining, resulting in a factor of 0.44 kg (0.97 lb) CO_2 per kg lime. The following Table reports the final CO_2 emission factor in terms of emissions per kg masonry cement produced.

Table 3.24: Emissions from Masonry Cement Manufacturing

Air Emission	*Emission Factor per kg Masonry Cement*
Carbon Dioxide (CO2)	0.0209 kg (0.0461 lb)

Portland Cement Production. BEES documentation on the production of portland cement can be found under Generic Portland Cement Concrete Products.

Transportation. A small percentage of the above raw materials, assumed to be 10 %, may be transported more than 3 219 km (2 000 mi). When this is the case, transport is assumed to be by rail. Otherwise, transport is assumed to be an average of 322 km (200 mi), by truck.

Manufacturing

Stucco is "manufactured" at the point of use of the material. See the section below on "Installation."

Transportation

The stucco raw materials are transported to the building site via diesel truck. The distance transported is a variable in the BEES model.

Installation

Stucco is assumed to be mixed in a 5.9 kW (8 hp), gasoline powered mixer with a stucco flow rate of 0.25 m^3/h (9 ft^3/h), running for 5 min. The stucco is applied manually to the building, so no energy or environmental impacts are assumed at this installation step. A small amount of waste, approximately 1 %, is assumed to be generated during the installation process.

A lath made of 100 % recycled steel may be used as a surface for the applied stucco. The amount of steel used per surface area of stucco applied varies according to application. Lath is used on wood and metal frame walls; typically 0.15 kg (1/3 lb) is used per ft^2 of wall area.

While sheathing, weather resistive barriers, and other ancillary materials may be required to complete the exterior wall system, these materials are not included in the system boundaries for BEES exterior wall finishes.

Use

With general maintenance, a properly installed stucco exterior will have a useful life of 100 years. Maintenance will vary greatly with weather conditions, but is usually minimal. Crack repairs are done manually. Maintenance is not included within the boundaries of the BEES model.

It is important to consider thermal performance differences when assessing environmental and economic performance for exterior wall finish product alternatives. Thermal performance affects building heating and cooling loads, which in turn affect energy-related LCA inventory flows and building energy costs over the BEES 50-year use stage.

For exterior wall finishes, thermal performance differences are optionally assessed for 14 U.S. cities spread across a wide range of climate and fuel cost zones, and for electricity, distillate oil, and natural gas heating fuel types (electricity is assumed for all cooling). When selecting wall finish alternatives for analysis, if the BEES user chooses to account for thermal performance, he or she selects the U.S. city closest to the building location and the building heating fuel type, so that thermal performance differences may be customized to these important contributors to building energy use.

Three BEES exterior wall finish products affect thermal performance: generic brick and mortar, Dryvit Outsulation, and Dryvit Outsulation Plus. Assuming a thermal resistance value of R-13 is required by code for exterior walls, then R-13 insulation on a brick and mortar wall will increase its thermal performance to about R-15, and on a Dryvit Outsulation or Dryvit Outsulation Plus wall, to about R-19. If the BEES user chooses to account for thermal performance, use energy savings for these three products, over and above that provided by R-13 insulation, are accounted for in the BEES results.[84]

End of Life

Approximately one-third of U.S. stucco production is used in commercial projects, typically over masonry or steel studs. At end of life, it is assumed that stucco and lath installed on commercial buildings in urban areas are recycled. No data are available on recycling of stucco or lath from residential applications; it is assumed that none of this residential material is recycled.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

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[84] Note that if generic brick and mortar and/or the two Dryvit products are the *only* alternatives being compared, use energy savings are computed relative to the selected alternative with the lowest R-value.

U.S. Environmental Protection Agency, "Cement Manufacture (IPCC Source Category 2A1)," Chapter 4.2, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*. (Washington, DC: U.S. Environmental Protection Agency, April 2006). pp. 4-8 to 4-9

Industry Contacts

Martha VanGeem, P.E. Construction Technology Laboratory, Inc., on behalf of the Portland Cement Association (August-October 2005)

Medgar Marceau, P.E., Construction Technology Laboratory, Inc., on behalf of the Portland Cement Association (August-October 2005)

3.4.3 Generic Aluminum Siding

Aluminum siding is a commonly-used exterior wall cladding that is known for its light weight and durability. Aluminum siding typically has an exterior coating to provide color and durability. Popular coatings include acrylic, polyester, and vinyl.

For the BEES system, the functional unit is one ft^2 of exterior wall area covered with horizontal aluminum siding in a thickness of 0.061 cm (0.024 in) and a width of 20 cm (8 in). The aluminum siding is assumed to be fastened with aluminum nails 41 cm (16 in) on center, requiring approximately 0.000374 kg (0.000825 lb) of aluminum nails per ft^2 The detailed environmental performance data for this product may be viewed by opening the file B2011C.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

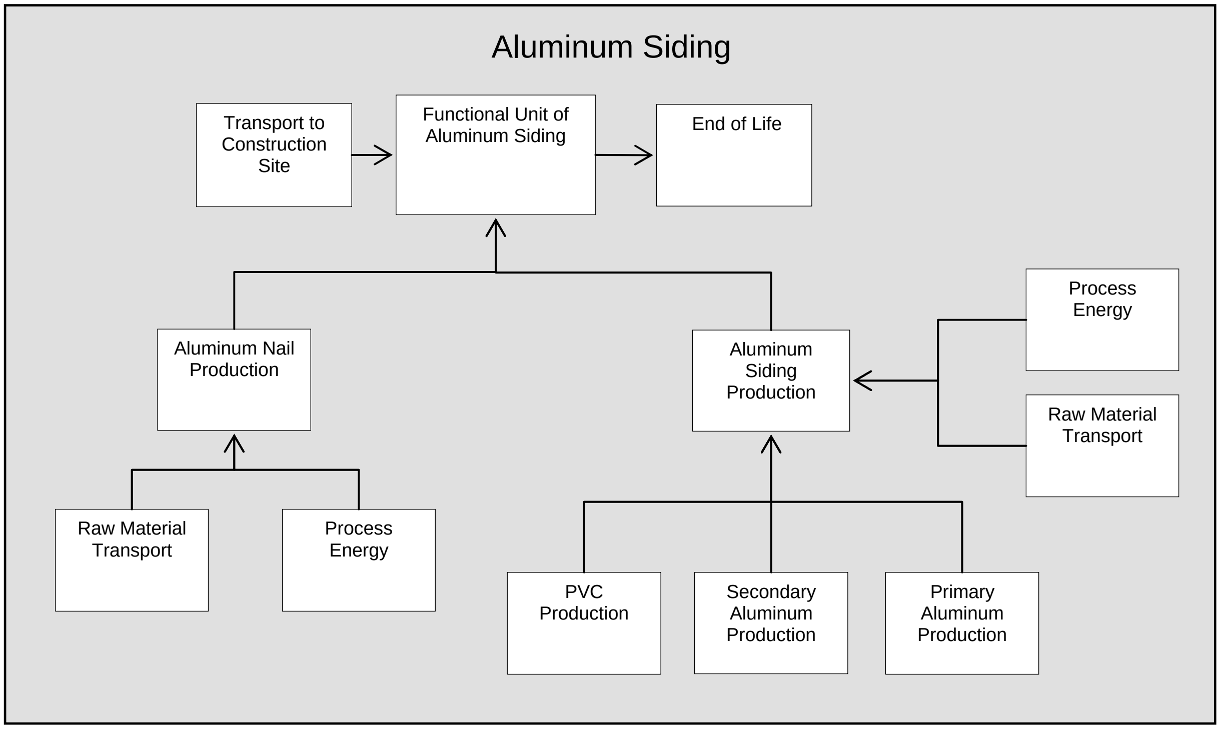

Figure 3.10: Aluminum Siding System Boundaries

Raw Materials

There are a number of aluminum siding products on the market, most of which are manufactured using different combinations of aluminum alloys and coating materials. Coating formulations are generally proprietary; the product studied for the BEES system is manufactured as an aluminum sheet with a polyvinyl chloride (PVC) thermoset topcoat.

The following Table presents the major constituents of aluminum siding. Life cycle data for the production of these raw materials comes from the U.S. LCI Database.

Table 3.25: Aluminum Siding Constituents

Constituent	*Mass* *kg/m^2 (lb/ft^2)*	*Mass Fraction (%)*
Aluminum Alloy Sheet	1.631 (0.3340)	99
PVC Topcoat	0.0161 (0.0033)	1

The aluminum sheet is manufactured from aluminum ingots. Since aluminum recycling is considered to be a closed loop process and aluminum siding is generally recycled at the end of the life of the building (see End of Life below), the environmental burdens from aluminum production are determined by the end-of-life recovery rate and the yield of metal from the aluminum recycling process. According to The Aluminum Association, 30 % of all aluminum used in construction is from secondary sources. Therefore, the BEES model assumes a mix of 30 % secondary and 70 % primary aluminum.

The vinyl topcoat is 0.08 mm to 0.09 mm (3.3 mils to 3.7 mils) thick; environmental burdens from the production of PVC come from the SimaPro database.

According to The Aluminum Association, the following aluminum alloys account for over 90 percent of aluminum used in siding: 3005, Alclad 3004, 3003, 1100, and 3105. Their composition is given in the Table below.

Table 3.26: Alloy Composition[85]

Alloy	**Al**	**Co**	**Fe**	**Pb**	**Mn**	**Mo**	**S**	**Ti**	**Zn**	**Total**
1100	99.0	-	0.1	-	-	0.1	1.0	-	0.0	100.1
3003	97.3	-	0.1	0.7	-	1.2	0.6	-	0.1	100.0
3004	96.2	-	0.3	0.7	1.0	1.2	0.3	-	0.3	99.9
3005	96.3	0.1	0.3	0.7	0.4	1.2	0.6	0.1	0.3	100.0
3105	96.6	0.2	0.3	0.7	0.5	0.6	0.6	0.1	0.4	100.0
Average	97.1	0.1	0.2	0.6	0.4	0.9	0.6	0.0	0.2	100.0
3000 series only	96.6	0.1	0.2	0.7	0.5	1.1	0.5	0.1	0.3	100.0
6061 (nails)	96.7	0.2	0.3	0.7	1.0	0.2	0.6	0.2	0.3	100.0

In all, alloys only account for 2.9 % to 3.3 % of the mass of the aluminum product. The life cycle environmental data for the alloying metals is not included in the model due to lack of available data; as a result the model assumes that the alloy is in fact made of 100 % aluminum.

Manufacturing

Energy Requirements and Emissions. Energy requirements and emissions for production of the individual siding components (rolled aluminum alloy and PVC resin) are included in the BEES data for the raw material acquisition life-cycle stage. The model, however, does not include the energy demands or emissions associated with application of PVC topcoat to the aluminum siding.

In the U.S., approximately half of rolled aluminum products are either hot or cold rolled.[86] The energy requirements for the average of the hot and cold rolling processes are presented in the Table below.

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[85] Alloy composition data from http://www.capitolcamco.com/MSDS/MSDS_I_Aluminum.htm.

[86] BCS, Inc., *U.S. Requirements for Aluminum Production: Historical Prospective, Theoretical Limits, and New Opportunities* (Washington, DC: Prepared for the U.S. Department of Energy, Energy Efficiency and Renewable Energy, February 2003).

Table 3.27: Energy Requirements for Aluminum Rolling

Energy Carrier	*MJ/kg (Btu/lb)*
Diesel	0.00148 (0.636)
Kerosene	0.000131 (0.0565)
Gasoline	0.0372 (16.0)
Natural Gas	1.11 (479)
Propane	0.00345 (1.48)
Electricity	1.11 (475)
Total	**2.26 (972)**

Transportation. Transportation of rolled aluminum and PVC resin to aluminum siding mills is assumed to be 402 km (250 mi) by truck.

Waste. Before rolled aluminum sheet is coiled and shipped, edge trimming knives remove damaged material from the edge of the sheet. The average edge trim loss for hot and cold rolling is 17 % of unrolled aluminum.[87] Edge trim waste is returned to the cast shop for remelting.

Transportation

Transportation of manufactured aluminum siding by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

Aluminum siding installation is predominately a manual process--a small amount of energy may be required to operate compressors to power air guns, but this is assumed to be very small and is not included in the analysis. Installation waste with a mass fraction of 5 % is assumed, and all waste is assumed to go to landfill.

Nails are assumed to be placed 41 cm (16 in) on center; however, as it is increasingly common to find buildings with studs 61 cm (24 in) on center, manufacturers are typically providing instructions for nail spacing of 61 cm (24 in) in order for the fasteners to penetrate this framing configuration. For installation on 41 cm (16 in) centers, 0.00085 lb of aluminum nails are used per ft^2 of siding. The overall installation average is still probably close to 41 cm (16 in), but a slight reduction in the mass of the nails, taken conservatively to be 3 %, is modeled to account for some installation on 61 cm (24 in) framing.

While sheathing, weather resistive barriers, and other ancillary materials may be required to complete the exterior wall system, these materials are not included in the system boundaries for BEES exterior wall finishes.

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[87] BCS, Inc. *U.S. Requirements for Aluminum Production: Historical Prospective, Theoretical Limits, and New Opportunities.*

Use

The product is assumed to have a useful life of 80 years. In some instances, siding without significant corrosion damage can be found after 100 years. However, owners may replace siding for reasons other than corrosion (e.g., to update the home's exterior appearance or change the color). It is assumed for the model that the siding remains in place over the 50- year use period.

Buildings with aluminum siding are periodically cleaned, usually for aesthetic reasons. Information on typical cleaning practices (e.g., frequency of cleaning, types and quantities of cleaning solutions used) is not available; no use phase impacts from cleaning are included.

It is important to consider thermal performance differences when assessing environmental and economic performance for exterior wall finish product alternatives. Thermal performance affects building heating and cooling loads, which in turn affect energy-related LCA inventory flows and building energy costs over the BEES 50-year use stage.

For exterior wall finishes, thermal performance differences are optionally assessed for 14 U.S. cities spread across a wide range of climate and fuel cost zones, and for electricity, distillate oil, and natural gas heating fuel types (electricity is assumed for all cooling). When selecting wall finish alternatives for analysis, if the BEES user chooses to account for thermal performance, he or she selects the U.S. city closest to the building location and the building heating fuel type, so that thermal performance differences may be customized to these important contributors to building energy use.

Three BEES exterior wall finish products affect thermal performance: generic brick and mortar, Dryvit Outsulation, and Dryvit Outsulation Plus. Assuming a thermal resistance value of R-13 is required by code for exterior walls, then R-13 insulation on a brick and mortar wall will increase its thermal performance to about R-15, and on a Dryvit Outsulation or Dryvit Outsulation Plus wall, to about R-19. If the BEES user chooses to account for thermal performance, use energy savings for these three products, over and above that provided by R-13 insulation, are accounted for in the BEES results.[88]

End of Life

Aluminum scrap has a significant economic value – the market price of clean, thick-walled scrap is close to the market price of primary materials. There is therefore a financial incentive to recover aluminum siding from a building at the end of its useful life.

An EPA report, *Characterization of Building-Related Construction and Demolition Debris in the United States,* confirms that the materials most frequently recovered and recycled from construction and demolition (C&D) debris are concrete, asphalt, metals, and wood. The EPA study also estimates that from 1 % to 5 % of C&D waste consists of metals. Therefore, the model assumes that all of the aluminum siding is recovered at the end of its useful life and returned to a secondary aluminum smelter for recovery.

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[88] Note that if generic brick and mortar and/or the two Dryvit products are the *only* alternatives being compared, use energy savings are computed relative to the selected alternative with the lowest R-value.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Aluminum Association, *Life Cycle Inventory Report for the North American Aluminum Industry* (Washington, DC: Aluminum Association November 1998).

Franklin Associates, " Management of Construction and Demolition Debris in the United States", Chapter 8, *EPA530-R-98-010 - Characterization of Building-Related Construction and Demolition Debris in the United States* (Washington, DC: U.S. Environmental Protection Agency, June 1998) Found at: http://www.epa.gov/epaoswer/hazwaste/sqg/c&d-rpt.pdf.

BCS, Inc., *U.S. Requirements for Aluminum Production: Historical Prospective, Theoretical Limits, and New Opportunities* (Washington, DC: Prepared for the U.S. Department of Energy, Energy Efficiency and Renewable Energy, February 2003) http://www.eere.energy.gov/industry/aluminum/pdfs/al_theoretical.pdf.

Industry Contacts

Paola Kistler, Director Environment, EHS FIRST, Alcan Inc. (September 2005)
Michael Skillingberg, The Aluminum Association, Inc. (January 2006)

3.4.4 Generic Cedar Siding

Cedar wood is used for exterior siding because it is a lightweight, low-density, aesthetically-pleasing material that provides adequate weatherproofing. As with most wood products, cedar siding production consists of three major steps. First, roundwood is harvested from logging camps. Second, logs are sent to sawmills and planing mills where the logs are washed, debarked, and sawed into planks. The planks are edged, trimmed, and dried in a kiln. The dried planks are then planed and the lumber sent to a final trimming operation. Finally, the lumber from the sawmill is shaped into fabricated, milled wood products.

For the BEES system, beveled cedar siding 1.3 cm (½ in) thick and 15 cm (6 in) wide is studied. Cedar siding is assumed to be installed with galvanized nails 41 cm (16 in) on center and finished with one coat of primer and two coats of stain. Stain is reapplied every 10 years.

The detailed environmental performance data for this product may be viewed by opening the file B2011D.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

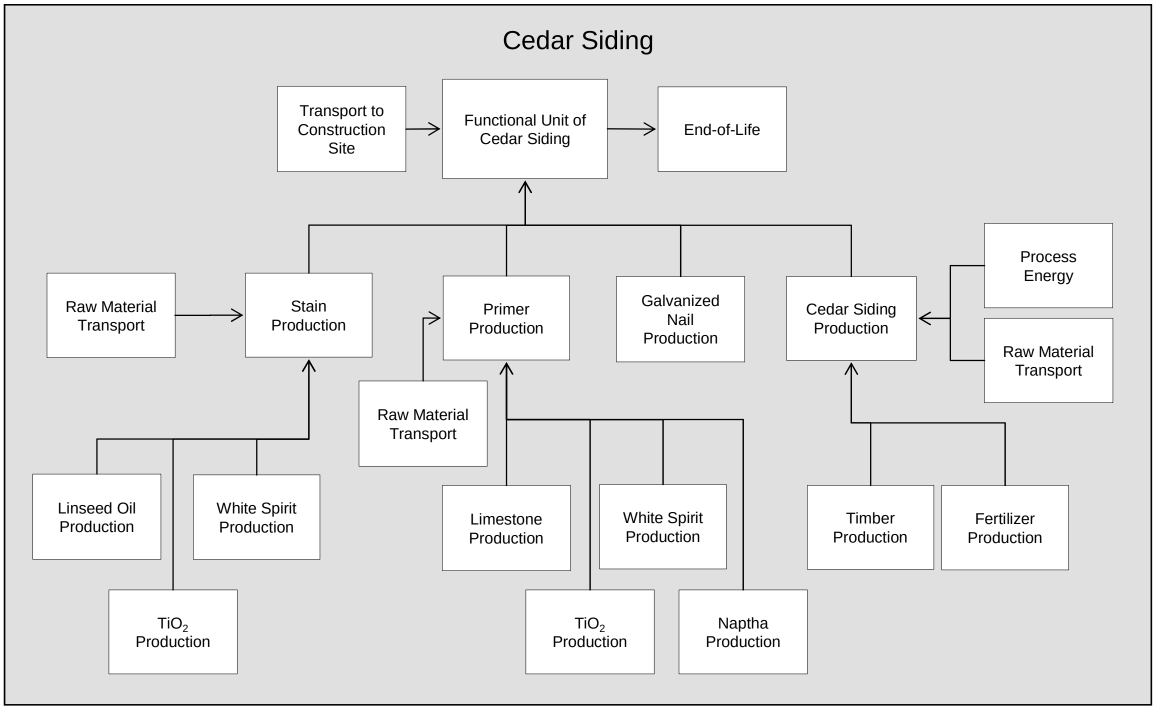

Figure 3.11: Cedar Siding System Boundaries

Raw Materials

CORRIM lumber production data was used to model cedar wood production. This dataset includes environmental burdens from growing and harvesting softwood logs for forest management in the Pacific Northwest.[89]

The growing and harvesting of wood is modeled as a composite comprised of a mix of low-, medium-, and high-intensity managed timber. Energy use for wood production includes electricity for greenhouses to grow seedlings, gasoline for chain saws, diesel fuel for harvesting mechanical equipment, and a small amount of fertilizer. Emissions associated with production and combustion of gasoline and diesel fuel and those from the production and delivery of electricity are based on the U.S. LCI Database. Fertilizer production data is adapted from European data in the U.S. LCI Database. Electricity use for greenhouse operation is based on the grids for the region where the seedlings are grown, while the U.S. average electricity grid is used for fertilizer production. The weight of wood harvested for lumber is based on an average oven-dry density of 509.77 kg/m^3 (31.824 lb/ft^3).

BEES modeling accounts for the absorption of carbon dioxide by trees as they grow; the carbon becomes part of the wood, and the oxygen is released to the atmosphere. The “uptake” of carbon dioxide from the atmosphere during the growth of timber is about 1.84 kg (4.06 lb) of carbon dioxide per kilogram of harvested wood (oven-dry weight).

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[89] Bowyer, J., et. al., *Phase I Final Report: Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction*. (Seattle, WA: Consortium for Research on Renewable Industrial Materials--CORRIM, Inc./University of Washington, 2004). Found at: http://www.corrim.org/reports600+ pp.; data also submitted to US LCI Database.

Manufacturing

Energy Requirements and Emissions. The energy requirements allocated to the production of softwood lumber for cedar siding are listed in the Table below. These requirements are based on average manufacturing conditions in the U.S. Pacific Northwest (PNW). The energy comes primarily from burning wood and bark waste generated in the sawmill process. Other fuel sources include natural gas for boilers, and propane and diesel for forklifts and log haulers at the sawmill. The production and combustion of the different types of fuel are based on the U.S. LCI Database.

Table 3.28: Cedar Siding Production Energy

Energy Carrier	***Quantity per lb Cedar Siding***
Electricity - PNW Grid	4.68E+05 J (0.13 kWh)
Natural Gas	4.53E-03 m^3 (0.16 ft^3)
Diesel fuel	2.01E-03 L (5.3E-04 gal)
LPG	1.21E-03 L (3.2E-04 gal)
Hogfuel/Biomass	1.90E-01 kg (0.42 lb)

Allocated process-specific air emissions from lumber production are based on the CORRIM study, as reported in the Table below. Allocation is based on mass and a multi-unit process analysis to correctly assign burdens. Note: In the BEES model, CO_2 generated by combustion of biofuel (hogged wood fuel) and fossil fuel are tracked separately since CO_2 from biomass is considered environmentally impact-neutral by the U.S. EPA, and as such is not considered when determining the Global Warming Potential impact.

Table 3.29: Cedar Siding Production Process-Related Emissions

Air Emission	***Emissions per lb Cedar Siding***
Particulates (unspecified)	1.36E-05 kg (3.0E-05 lb)
VOC (unspecified)	8.62E-05 kg (1.9E-04 lb)

Transportation. Since sawmills are typically located close to the forested area, transportation of raw materials to the sawmill is not taken into account. Transport of primer and stain to the manufacturing plant is included.

Transportation

Transportation of cedar siding by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

Cedar siding installation is predominately a manual process--a relatively tiny amount of energy may be required to operate compressors to power air guns, but this amount is assumed to be too small to warrant inclusion in the analysis. Installation waste with a mass fraction of 5 % is assumed, and all waste is assumed to go to landfill.

Cedar siding panels are attached using galvanized nails. Three nails are required per 0.09 m^2 (per ft^2) of siding. Assuming standard 6d 5 cm (2 in) nails, installation requires 0.0054 kg (0.0119 lb) of nails per ft^2 of siding. No installation waste is assumed for the nails.

After installation, the siding is primed and stained. The primer is modeled as a standard primer with coverage of 46.4 m^2 (500 ft^2) per gal; the stain is assumed to have coverage of 32.5 m^2 (350 ft^2) per gal. One coat of primer and two coats of stain are applied to the siding.

While sheathing, weather resistive barriers, and other ancillary materials may be required to complete the exterior wall system, these materials are not included in the system boundaries for BEES exterior wall finishes.

Use

The density of cedar siding at 12 % moisture content is assumed to be 449 kg/m^3 (28 lb/ft^3). The product is assumed to have a useful life of 40 years. To prolong the lifetime and maintain the appearance of the siding, two coats of stain are assumed to applied every 10 years. Information on typical cleaning practices (e.g., frequency of cleaning, types and quantities of cleaning solutions used) is not available; cleaning is not included in the system boundaries.

It is important to consider thermal performance differences when assessing environmental and economic performance for exterior wall finish product alternatives. Thermal performance affects building heating and cooling loads, which in turn affect energy-related LCA inventory flows and building energy costs over the BEES 50-year use stage.

For exterior wall finishes, thermal performance differences are optionally assessed for 14 U.S. cities spread across a wide range of climate and fuel cost zones, and for electricity, distillate oil, and natural gas heating fuel types (electricity is assumed for all cooling). When selecting wall finish alternatives for analysis, if the BEES user chooses to account for thermal performance, he or she selects the U.S. city closest to the building location and the building heating fuel type, so that thermal performance differences may be customized to these important contributors to building energy use.

Three BEES exterior wall finish products affect thermal performance: generic brick and mortar, Dryvit Outsulation, and Dryvit Outsulation Plus. Assuming a thermal resistance value of R-13 is required by code for exterior walls, then R-13 insulation on a brick and mortar wall will increase its thermal performance to about R-15, and on a Dryvit Outsulation or Dryvit Outsulation Plus wall, to about R-19. If the BEES user chooses to account for thermal performance, use energy savings for these three products, over and above that provided by R-13 insulation, are accounted for in the BEES results.[90]

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[90] Note that if generic brick and mortar and/or the two Dryvit products are the *only* alternatives being compared, use energy savings are computed relative to the selected alternative with the lowest R-value.

End of Life

All of the cedar siding is assumed to be disposed of in landfill at end of life. The practice of recycling wood building materials is increasing, but data is not available to quantify this practice.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Bowyer, J., et. al., *Phase I Final Report: Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction*. (Seattle, WA: Consortium for Research on Renewable Industrial Materials. (CORRIM, Inc.)/University of Washington, 2004). Found at: http://www.corrim.org/reports.

Industry Contacts

No industry contacts were identified to provide further insight on this product.

3.4.5 Generic Vinyl Siding

Vinyl siding is used as an exterior wall finish on new and renovated construction. Since its introduction in the 1960s, vinyl siding has become the most popular wall finish for new construction.

The product is manufactured in a wide variety of profiles, colors, and thicknesses to meet different market applications. Vinyl siding is commonly produced as double units that have the appearance of two overlapping or adjoining 10 cm or 13 cm wide (4 in or 5 in wide) boards. Double 4 and double 5 are the most common profiles and are about equally popular. The weight of vinyl siding is about 24 kg (52 lb) per 9.29 m^2 (100 ft^2), for a typical 0.107 cm to 0.112 cm (0.042 in to 0.044 in) thickness. For the BEES system, 0.107 cm (0.042 in) thick, 23 cm (9 in) wide horizontal vinyl siding installed with galvanized nail fasteners is studied. The nails are assumed to be placed 41 cm (16 in) on center.

The detailed environmental performance data for this product may be viewed by opening the file B2011E.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram that follows shows the major elements of the production of this product, as it is currently modeled for BEES.

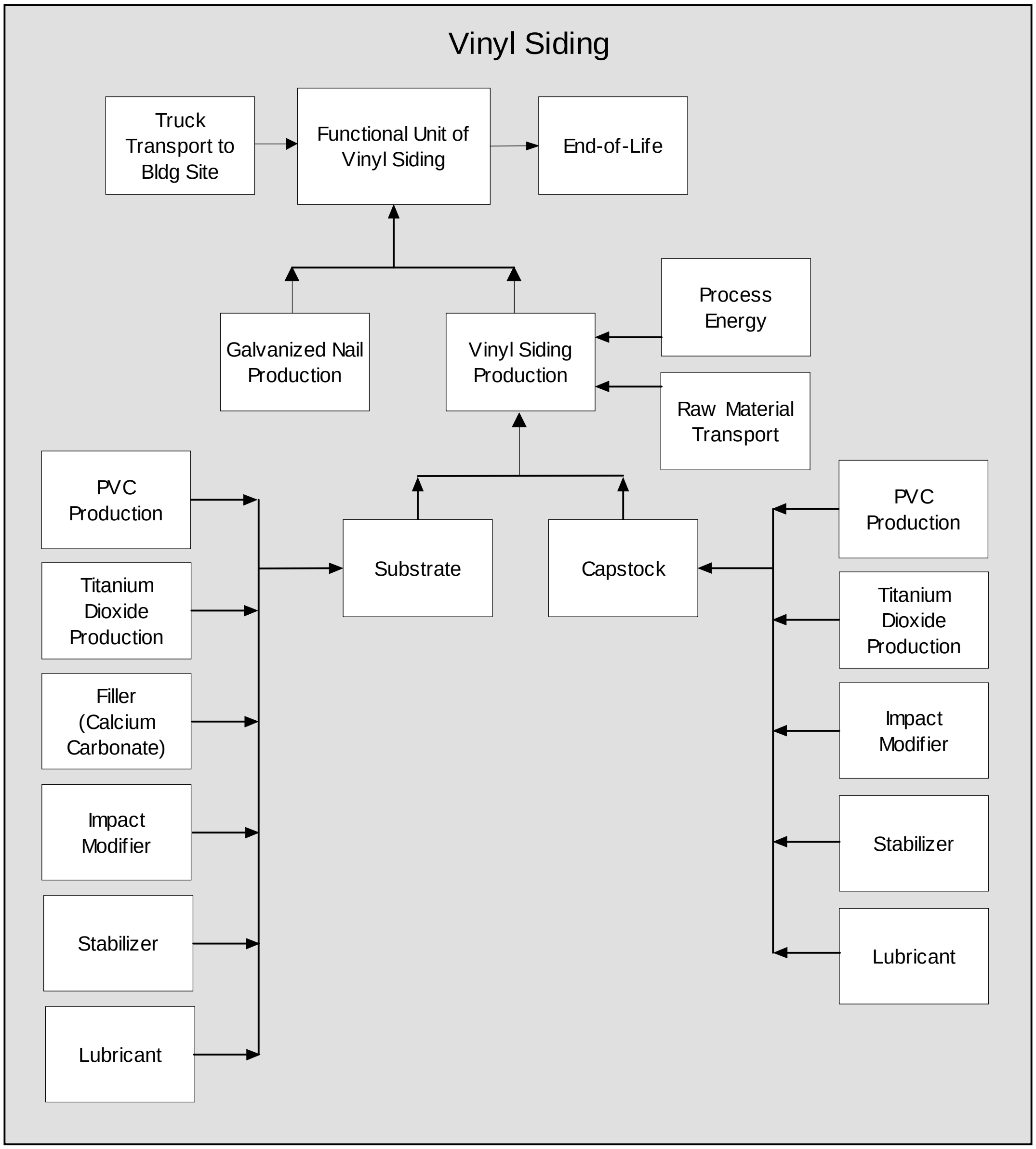

Figure 3.12: Vinyl Siding System Boundaries

Raw Materials

Most siding is composed of two layers: a substrate and a capstock. The capstock, which accounts for about 15 % by weight of the full panel, is the surface that is exposed to the outside and thus is formulated to be more weather resistant.

Polyvinyl chloride (PVC) is the main component in the manufacture of vinyl siding. A significant percentage of the final product is composed of post-industrial PVC waste (i.e., PVC cuttings and scraps collected from the manufacturing process and recycled into future batches). A typical percentage of the final product is 15 % recycled post-industrial material. Calcium carbonate is used as a filler material in vinyl siding. Titanium dioxide (TiO_2) is a chemical additive that is used in the siding as a pigment and stabilizer; less than 10 % of it is produced from ore mined in the United States. The ore is produced in diverse locations including Canada, Africa, and Australia. All other components are typically supplied from within 3 219 km (2 000 mi) of the siding manufacturing facility.

The Table below presents the proportions of constituent materials in the siding studied. Data representing the production of raw materials for vinyl siding are based on the SimaPro LCA database, the U.S. LCI Database, and American Chemistry Council 2006 data developed for submission to the U.S. LCI Database.

Table 3.30: Vinyl Siding Constituents

Constituent	*Percent in Substrate*	*Percent in Capstock*	*Overall Percent*
PVC	82 %	85.5 %	82.5 %
Filler (typically, calcium carbonate)	10 %	--	8.5 %
Titanium dioxide	≤1.5 %	8.5 %	2.5 %
Impact modifier (typically, acrylic or chlorinated polyethylene)	≤4 %	3 %	4 %
Stabilizer (typically, organo-tin mercaptide)	1 %	1.5 %	1 %
Lubricant (typically, paraffin/calcium stearate blend)	1.5 %	1.5 %	1.5 %

Manufacturing

Most manufacturers of vinyl siding in North America are located east of the Mississippi, the exceptions being manufacturers in Missouri and Texas. Most vinyl siding is extruded, although a small percentage of specialty panels are injection molded or thermoformed. For a general characterization of vinyl siding, extrusion is most appropriate.

Energy Requirements. Energy requirements for production of the individual siding components are included in the data for the raw material acquisition life-cycle stage. No information was available from manufacturers on energy and emissions for the vinyl siding production process.

Transportation. Transportation of siding raw materials from producers to the siding manufacturing plant is taken into account. An assumed average transport distance of 402 km (250 mi) is applied to each raw material.

Waste. As noted in the raw materials description for this product, scrap from siding production processes is typically collected at the plant and recycled back into the manufacturing process.

Transportation

Transportation of the manufactured siding and nails to the building site by heavy-duty truck is modeled as a variable of the BEES software.

Installation

Installation of siding is done primarily by manual labor. Nails or screws can be used to install the siding; nails are more common and would typically be the type installed with a gun. The energy required to operate compressors to power air guns is assumed to be very small and not included in the analysis. Installation waste with a mass fraction of 5 % is assumed, and this waste is assumed to go to a landfill.

Nails are placed 41 cm (16 in) on center; however, as it is increasingly common to find buildings with studs 61 cm (24 in) on center, manufacturers are typically providing instructions for nail spacing of 61 cm (24 in) in order for the fasteners to penetrate this framing configuration. Such installations represent a small but growing subset of vinyl siding applications. For installation on 41 cm (16 in) centers, nail use is 0.0024 kg (0.0053 lb) per 0.09 m^2 (per ft^2) of siding. The overall installation average is still probably close to 41 cm (16 in), but a slight reduction in the number of nails per ft^2 is modeled to account for the small proportion installed on 61 cm (24 in) framing.

While sheathing, weather resistive barriers, and other ancillary materials may be required to complete the exterior wall system, these materials are not included in the system boundaries for BEES exterior wall finishes.

Use

The product is assumed to have a useful life of 40 years. Many manufacturers provide warranties of 50 years or longer. No routine maintenance is required to prolong the lifetime of the product, although cleaning is recommended to maintain appearance. Cleaning would normally be done with water and household cleaners. Information on typical cleaning practices (e.g., frequency of cleaning, types and quantities of cleaning solutions used) was not available; maintenance was not included in the system boundaries.

It is important to consider thermal performance differences when assessing environmental and economic performance for exterior wall finish product alternatives. Thermal performance affects building heating and cooling loads, which in turn affect energy-related LCA inventory flows and building energy costs over the BEES 50-year use stage.

For exterior wall finishes, thermal performance differences are optionally assessed for 14 U.S. cities spread across a wide range of climate and fuel cost zones, and for electricity, distillate oil, and natural gas heating fuel types (electricity is assumed for all cooling). When selecting wall finish alternatives for analysis, if the BEES user chooses to account for thermal performance, he or she selects the U.S. city closest to the building location and the building heating fuel type, so that thermal performance differences may be customized to these important contributors to building energy use.

Three BEES exterior wall finish products affect thermal performance: generic brick and mortar, Dryvit Outsulation, and Dryvit Outsulation Plus. Assuming a thermal resistance value of R-13 is required by code for exterior walls, then R-13 insulation on a brick and mortar wall will increase its thermal performance to about R-15, and on a Dryvit Outsulation or Dryvit Outsulation Plus wall, to about R-19. If the BEES user chooses to account for thermal performance, use energy

savings for these three products, over and above that provided by R-13 insulation, are accounted for in the BEES results.[91]

End of Life

Vinyl siding at end of life is assumed to be disposed of in a landfill. End-of-life quantities of vinyl siding have not been large enough to warrant establishment of a recycling infrastructure. Vinyl siding is not among the top 36 building-related construction and demolition categories reported in the U.S. Environmental Protection Agency (EPA) benchmark report on construction and demolition waste.[92]

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Franklin Associates, " Management of Construction and Demolition Debris in the United States", Chapter 8, *EPA530-R-98-010 - Characterization of Building-Related Construction and Demolition Debris in the United States* (Washington, DC: U.S. Environmental Protection Agency, June 1998) Found at: http://www.epa.gov/epaoswer/hazwaste/sqg/c&d-rpt.pdf.

Industry Contacts

David Johnston, Technical Director, Vinyl Siding Institute (September-October 2005)

3.4.6 Trespa Meteon Panel

See documentation on all Trespa composite panels under Fabricated Toilet Partitions.

3.4.7 Headwaters Stucco Finish Application

Headquartered in Salt Lake City, Utah, Headwaters, Inc. is a supplier of materials to products as diverse as ready-mix concrete, precast concrete, roofing, carpeting, mortar, and stucco. Three Headwaters products are included in BEES

- Masonry Cement Type S. Meets ASTM C91 Type S standard for masonry cement.
- Scratch & Brown Stucco Cement. Meets ASTM C1328 Type S standard for plastic (stucco) cement. Used as a replacement for job-site-mixed stuccos (usually portland and lime or portland and masonry cement) under ASTM C926.
- FRS. Produced and sold under ICBO Evaluation Report No. 4776 and ICC Legacy Evaluation Report 459. At this time there are no ASTM standards for this class of products.

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[91] Note that if generic brick and mortar and/or the two Dryvit products are the *only* alternatives being compared, use energy savings are computed relative to the selected alternative with the lowest R-value.

[92] Franklin Associates, " Management of Construction and Demolition Debris in the United States", Chapter 8, *EPA530-R-98-010 - Characterization of Building-Related Construction and Demolition Debris in the United States* (Washington, DC: US Environmental Protection Agency, June 1998) Found at: http://www.epa.gov/epaoswer/hazwaste/sqg/c&d-rpt.pdf.

BEES data for these products are based on 2005 data from the manufacturer's San Antonio, Texas plant, with an annual production of 27 945 metric tons (30 804 short tons). These cementitious products are incorporated in different stucco finishes in BEES as shown in the Table below:

Table 3.31: Headwaters Cement Products

BEES Exterior Wall Finish Alternative	***Headwaters Product***	***Specifications***
Headwaters Masonry Cement Type S-based Stucco	Masonry Cement Type S	1 kg (2.2 lb) of Masonry Cement Type S produced by Headwaters replaces 1 kg (2.2 lb) of traditional Masonry Cement Type S used in generic stucco. Fully 100 % of the traditional cement is replaced by Headwaters' Masonry Cement.
Headwaters Scratch & Brown Stucco Cement Type S	Scratch & Brown Stucco Cement Type S	1 kg (2.2 lb) of Scratch & Brown Stucco Cement Type S produced by Headwaters replaces 1 kg (2.2 lb) of traditional Masonry Cement Type S used in generic stucco. Fully 100 % of the traditional cement is replaced by Headwaters' Scratch and Brown Stucco Cement.
Headwaters FRS-based Stucco	FRS	1 kg (2.2 lb) of FRS produced by Headwaters replaces 2 kg (4.4 lb) of traditional Masonry Cement. Fully 100 % of the traditional cement is replaced by Headwaters' FRS. The metallic lath weighs either 0.95 kg/m^2 (1.75 lb/yd^2) or 1.36 kg/m^2 (2.50 lb/yd^2). The lighter-weight lath is used in 60 % of the applications.

The detailed environmental performance data for these products may be viewed by opening the following files under the File/Open menu item in the BEES software:

- B2011H.DBF—Headwaters Scratch & Brown Stucco Cement Type S
- B2011I.DBF—Headwaters FRS-based Stucco
- B2011K.DBF—Headwaters Masonry Cement Type S-based Stucco

Flow Diagram

The flow diagram shown below shows the major elements of the production of this product, as it is currently modeled for BEES.

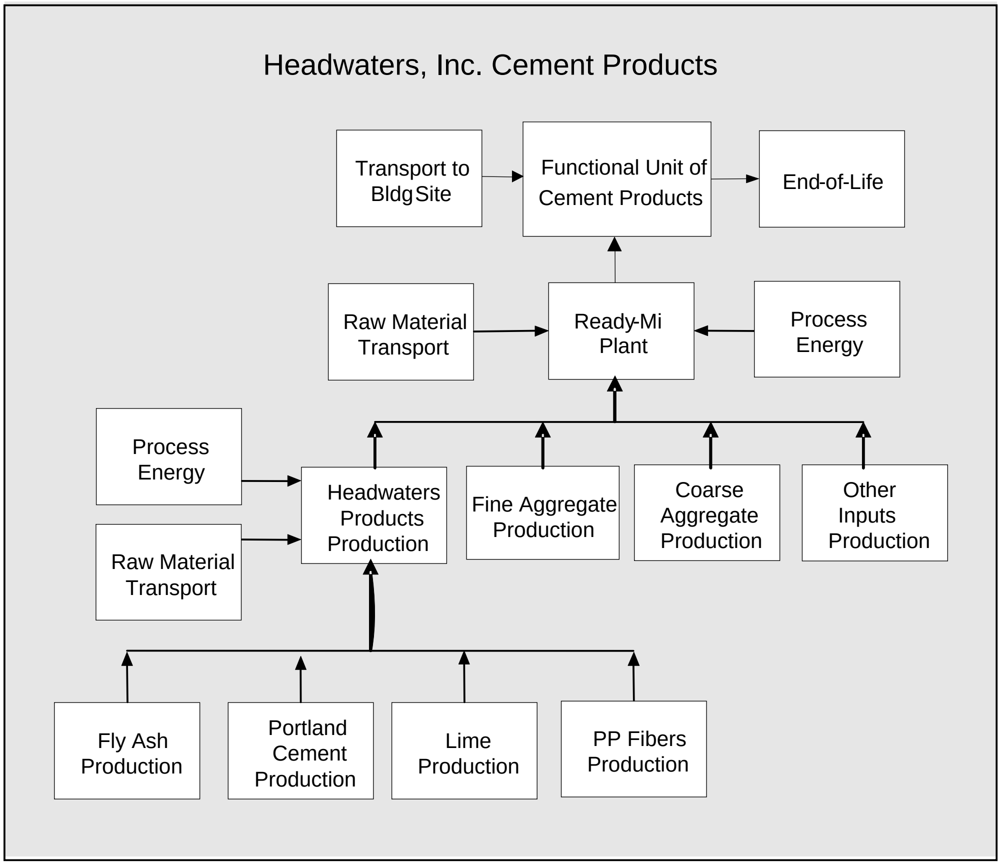

Figure 3.13: Headwaters Cement Products System Boundaries

Raw Materials

The three Headwaters products are comprised of the raw materials given in the Table below.

Table 3.32: Headwaters Cement Constituents

Constituent	*Masonry Cement Type S*	*Scratch & Brown Stucco Cement*	*FRS*
Fly Ash (class F)	Yes	Yes	Yes
Portland Cement (gray, type I)	Yes	Yes	Yes
Hydrated Lime (type S)	Yes	Yes	Yes
Polypropylene Fibers	No	No	Yes

Portland cement. The BEES generic portland cement data are used for the portland cement constituent, and comes from the Portland Cement Association LCA database, which is documented under Generic Portland Cement Concrete Products.

Fly Ash. Fly ash comes from coal-fired, electricity-generating power plants. These power plants grind coal to a fine powder before it is burned. Fly ash – the mineral residue produced by burning coal – is captured from the power plant's exhaust gases and collected for use. Fly ash particles are nearly spherical in shape, allowing them to flow and blend freely in mixtures, one of the properties making fly ash a desirable admixture for concrete. In LCA terms, this waste byproduct from coal combustion is assumed to be an environmentally "free" input material.[93] Transport of the fly ash from the production site is included in the product modeling.

Lime and Polypropylene. Data for hydrated lime production takes into account limestone extraction, crushing and calcination, and quick lime hydration, and comes from the U.S. LCI Database. Data for polypropylene production comes from the U.S. LCI Database.

Manufacturing

Energy Requirements and Emissions. Raw materials are brought to the cement plant in 18-wheel tankers and blown into silos. Material drops from the silos to a weigh-batcher, a blender, and a bagger. Only one product is produced at a time for at least a full day. Since all gray (fly ash-containing) products are related, changing products consists of tapping the system down and bagging the last of the product in the system. Allocation of the resources is based on the number of bags of each product produced. Energy consumed on site is mostly electricity (87 %) and diesel fuel oil. The site produces solid waste (1 % of production) and emits particulates. All energy and electricity data is based on the U.S. LCI Database.

Transportation. The transportation distance of raw materials from the supplier to the manufacturer was provided by Headwaters and ranges from 16 km (10 mi) for the polypropylene fibers, to 48 km (30 mi) for the portland cement and lime, to 660 km (410 mi) for the fly ash. Materials are transported by diesel truck, with burdens modeled using the U.S. LCI Database.

Transportation

Transportation of finished products to the building site is evaluated based on the same parameters given for the generic counterparts to Headwaters' products, and all products are shipped by diesel truck. Emissions from transportation allocated to each product depend on the overall weight of the product. Diesel truck transportation is based on the U.S. LCI Database.

Installation and Use

While sheathing, weather resistive barriers, and other ancillary materials may be required to complete the exterior wall system, these materials are not included in the system boundaries for BEES exterior wall finishes. Maintenance for Headwaters' exterior stucco products will vary depending on weather conditions, but usually consists of minimal repairs that can be done by hand. Maintenance is not included in the system boundaries for this product.

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[93] The environmental burdens associated with the production of waste materials are typically allocated to the intended product(s) of the process from which the waste results.

It is important to consider thermal performance differences when assessing environmental and economic performance for exterior wall finish product alternatives. Thermal performance affects building heating and cooling loads, which in turn affect energy-related LCA inventory flows and building energy costs over the BEES 50-year use stage.

For exterior wall finishes, thermal performance differences are optionally assessed for 14 U.S. cities spread across a wide range of climate and fuel cost zones, and for electricity, distillate oil, and natural gas heating fuel types (electricity is assumed for all cooling). When selecting wall finish alternatives for analysis, if the BEES user chooses to account for thermal performance, he or she selects the U.S. city closest to the building location and the building heating fuel type, so that thermal performance differences may be customized to these important contributors to building energy use.

Three BEES exterior wall finish products affect thermal performance: generic brick and mortar, Dryvit Outsulation, and Dryvit Outsulation Plus. Assuming a thermal resistance value of R-13 is required by code for exterior walls, then R-13 insulation on a brick and mortar wall will increase its thermal performance to about R-15, and on a Dryvit Outsulation or Dryvit Outsulation Plus wall, to about R-19. If the BEES user chooses to account for thermal performance, use energy savings for these three products, over and above that provided by R-13 insulation, are accounted for in the BEES results.[94]

End of Life
With general maintenance, exterior stucco wall finishes will generally last more than 100 years. This is a performance-based lifetime.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Industry Reference

Herb Nordmeyer, Headwaters, Inc. (2006)

3.4.8 Dryvit EIFS Cladding Outsulation

In 1969, Dryvit Systems, Inc., currently owned by RPM International Inc. in Medina, OH, introduced North America to its exterior wall cladding system with insulation installed as part of the outside wall. Since that time, Dryvit's Exterior Insulation and Finish Systems (EIFS) have been used on commercial and residential buildings in the United States.

The two most widely used EIFS cladding, Outsulation and Outsulation Plus, are evaluated in

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[94] Note that if generic brick and mortar and/or the two Dryvit products are the *only* alternatives being compared, use energy savings are computed relative to the selected alternative with the lowest R-value.

BEES. These are comprised of an expanded polystyrene (EPS) insulation board, a fiberglass mesh which is used for reinforcement, a polymer modified cement-based adhesive/basecoat and a polymer-based textured finish used as a top coat to enhance aesthetic appeal. Outsulation Plus is a next generation cladding that has an added layer of air and moisture barrier which not only protects the wall from accidental moisture but provides better insulation by stopping air infiltration. Both of these cladding systems can be installed in new and existing buildings.

Dryvit operates four manufacturing plants in the United States, including one at its headquarters in West Warwick, RI, and has subsidiary operations in Canada, Poland, and China. The data for the BEES evaluation is based on the West Warwick, RI facility.

Both Outsulation and Outsulation Plus are installed onto sheathing. While they are thermally efficient, the building still requires insulation. According to the manufacturer, both products provide a thermal resistance value of about R-6. The BEES user has the option of accounting for the energy saved, relative to other exterior wall finishes, over the 50-year use period. This is explained in more detail under Use.

The detailed environmental performance data for this product may be viewed by opening the files B2011L.DBF, for Dryvit Outsulation, and B2011M.DBF, for Dryvit Outsulation Plus, under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagrams below shows the major elements of the production of these products as they are currently modeled for BEES.

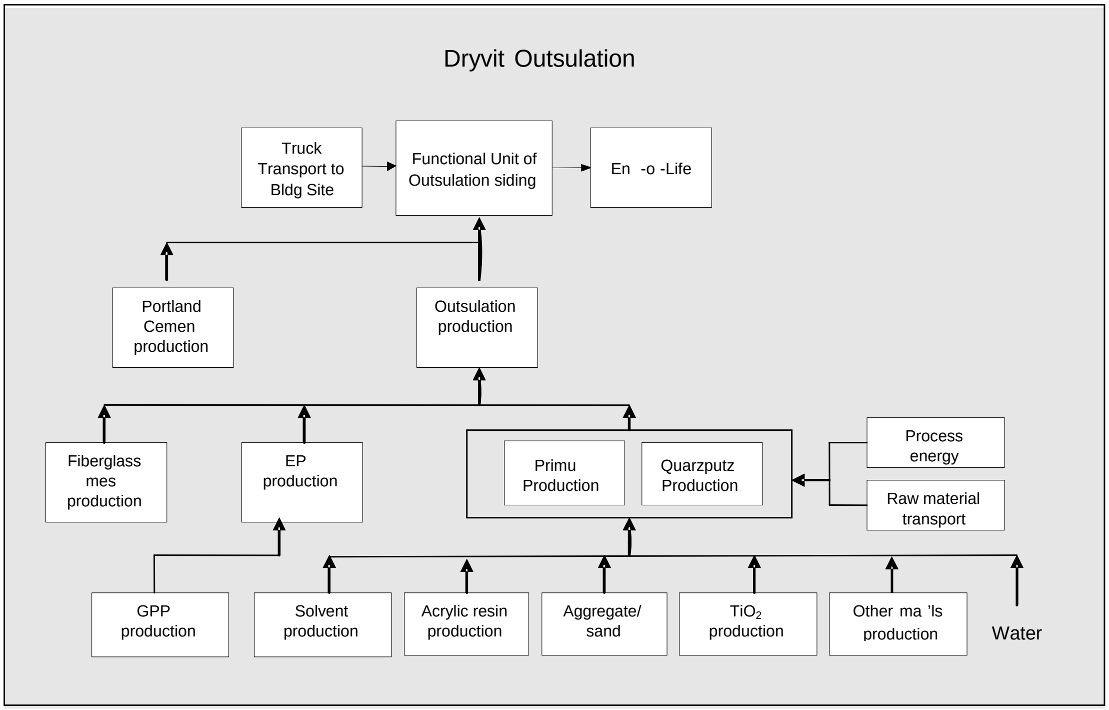

Figure 3.14: Dryvit Outsulation System Boundaries

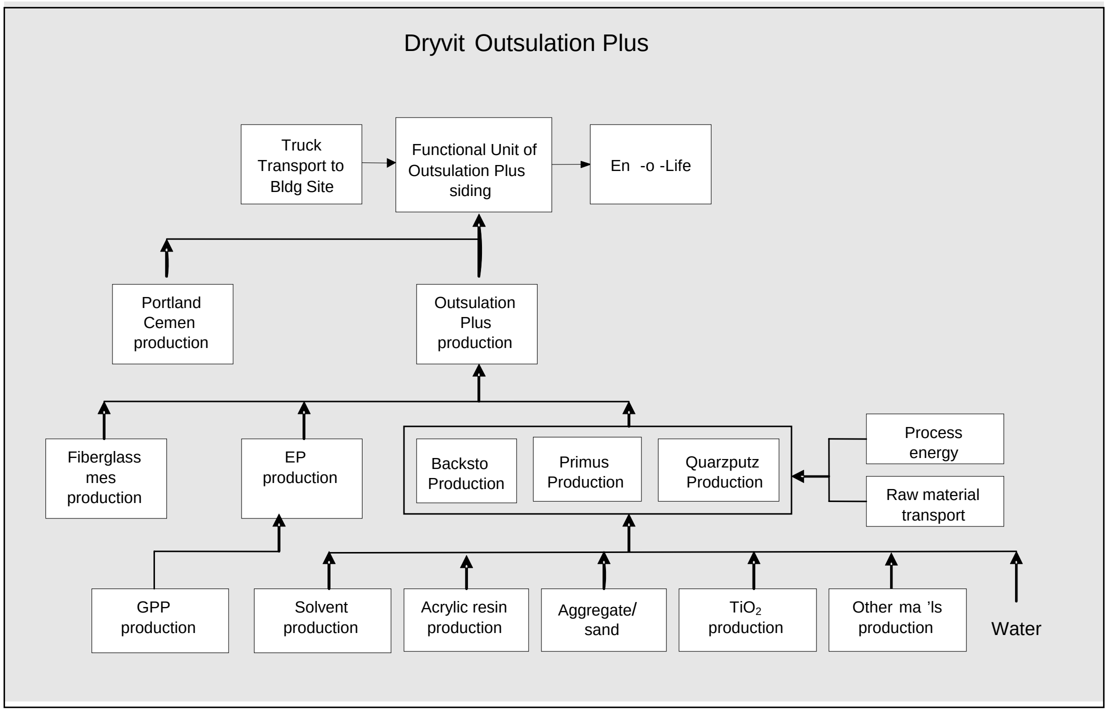

Figure 3.15: Dryvit Outsulation Plus System Boundaries

Raw Materials

Outsulation's basecoat, the textured finish top coat, and the barrier layer offered as part of Outsulation Plus are mixed and packaged at Dryvit's facility. These products and their constituent materials are presented in the Table below.

Table 3.33: Dryvit Product Constituents

Constituent	*Adhesive/Basecoat (Primus)*	*Topcoat (Quarzputz)*	*Barrier (Backstop NT)*
Solvent	yes	yes	yes
Resins	yes	yes	yes
Aggregate	yes	yes	yes
Fine filler		yes	yes
Titanium dioxide slurry		yes	yes
Other materials	yes	yes	yes
Water	yes	yes	yes

The solvent, considered to be mineral spirits, is modeled as naphtha, whose data comes from the refining model in a U.S. Department of Agriculture and U.S. Department of Energy study on biodiesel and petroleum diesel fuels.[95] The fine filler is modeled as lime, which is based on the U.S. LCI Database. The resin is modeled as an acrylic-based resin. Data for this resin, plus the aggregate and titanium dioxide (TiO_2) slurry, are based on elements of the SimaPro database, which is comprised of a mix of U.S. and European data. Water makes up over 23 % of Quarzputz and Backstop NT and almost 30 % of Primus.

Primus is just one of Dryvit's products that can be used as a basecoat and adhesive in Outsulation. Dryvit's other wet and dry basecoats include Genesis, Primus DM, and Genesis DM. Dryvit also produces a variety of textured finishes. The most popular are Quarzputz, Sandblast, Sandpebble and Sandpebble Fine. These are available in three bases (Mid base, Pastel base, and Accent base) depending upon the amount of TiO_2 present. The bases can be tinted to the desired color either in the factory or at distributor locations.

The packaging of these products (5 gal polypropylene pails) is included in the model, with the polypropylene data coming from American Chemistry Council 2006 data developed for submission to the U.S. LCI Database.

Manufacturing

Energy Requirements and Emissions. Energy use at the Dryvit plant is primarily electricity to blend the Primus, Quarzputz, and Backstop NT constituents in large vessels and package them into 5 gal pails. The quantity of electricity used for each product is provided in the Table below.

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[95] Sheehan, J. et al., Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

Table 3.34: Energy Requirements for Mixing Dryvit Outsulation and Outsulation Plus Materials

Dryvit Product	*kWh/lb*
Primus	6.26 E-4
Quarzputz	1.28 E-3
Backstop NT	7.47 E-4
Total	**2.65 E-3**

Electricity production fuels and burdens come from the U.S. LCI Database. Any fine material particulates released during blending is captured by a dust collection system, so no particulates or other emissions are released. No manufacturing waste is produced.

Transportation. Transportation distances of the product components were provided by Dryvit and range from 1 770 km (1 100 mi) for the fillers and 1 086 km (675 mi) for the aggregate, down to 80 km (50 mi) for the solvent. These are transported by diesel truck, as modeled in the U.S. LCI Database.

Transportation

Dryvit products, plus the EPS and fiberglass mesh (neither of which are produced by Dryvit), are modeled, by default, as being transported an average of 402 km (250 mi) by diesel truck to the building site. The BEES user is free to change this assumed transport distance.

Installation

Dryvit's components described above, plus the EPS and fiberglass mesh, are installed together at the building site to produce the Outsulation and Outsulation Plus products. These materials are specified in the following two tables. Note that while sheathing, weather resistive barriers, and other ancillary materials are required to complete the exterior wall system, these materials are not included in the system boundaries for BEES exterior wall finishes.

Table 3.35: Dryvit EIFS Constituents for Outsulation

Constituent	*Specification*	*Quantity per 9 m^2 (100 ft^2) of EIFS*
EPS	2 ft x 4 ft x 1.5 in	5.67 kg (12.5 lb)
Fiberglass Mesh	4.3 oz/yd^2	1.35 kg (2.98 lb)
Primus	5 gal pail = 60 lb = 110 ft^2	25 kg (55 lb)
Quarzputz	5 gal pail = 70 lb = 130 ft^2	24.43 kg (53.85 lb)

Table 3.36: Dryvit EIFS Constituents for Outsulation Plus

Constituent	*Specification*	*Quantity per 9 m^2 (100 ft^2)of EIFS*
EPS	2 ft x 4 ft x 1.5 in	5.67 kg (12.5 lb)
Fiberglass Mesh	4.3 oz/yd^2	1.35 kg (2.98 lb)
Primus	5 gal pail = 60 lb = 110 ft^2	25 kg (55 lb)
Quarzputz	5 gal pail = 70 lb = 130 ft^2	24.43 kg (53.85 lb)
Backstop NT Texture	5 gal pail = 60 lb = 275 ft^2	9.89 kg (21.8 lb)

EPS is produced by licensed EPS molders to a specification that has been established by Dryvit and ASTM. Fiberglass mesh also is produced to Dryvit specification and ASTM standard. The Dryvit basecoats, weather barriers, and finishes are used on the jobsite by trained plasterers. The process of applying EIFS Cladding begins once the stud walls are constructed and sheathing is up. (For consistency with other exterior wall finish products, sheathing is not included in the product model.) The EPS is applied to the sheathing with Primus as the adhesive and then again coated with Primus for a basecoat. In the field, Primus is mixed with equal amounts of cement. The fiberglass mesh is embedded into the basecoat. After 24 h of drying time, the textured finish, Quarzputz, is placed as the top coat. Outsulation Plus installation includes a layer of Backstop NT for the added layer of air and moisture barrier.

Data for EPS resin production and blowing into foam insulation and fiberglass are based on the SimaPro database. For the BEES system, these are included with the raw material acquisition stage data since they are considered part of the main product. Portland cement (mixed with Primus) is included with the use stage of the product model, and its data comes from the U.S. LCI Database. For detailed information on this latter material, see Generic Portland Cement Concrete Products.

According to the manufacturer, installation waste can run from 1 % to 5 %; 2.5 % is modeled for BEES. This waste is assumed to go to landfill.

Use

Any maintenance or cleaning over the life, if needed, is done manually and with relatively few materials. Because maintenance can vary from owner to owner based on frequency and degree, representative data was neither available nor included in the model.

It is important to consider thermal performance differences when assessing environmental and economic performance for exterior wall finish product alternatives. Thermal performance affects building heating and cooling loads, which in turn affect energy-related LCA inventory flows and building energy costs over the BEES 50-year use stage.

For exterior wall finishes, thermal performance differences are optionally assessed for 14 U.S. cities spread across a wide range of climate and fuel cost zones, and for electricity, distillate oil, and natural gas heating fuel types (electricity is assumed for all cooling). When selecting wall finish alternatives for analysis, if the BEES user chooses to account for thermal performance, he or she selects the U.S. city closest to the building location and the building heating fuel type, so that thermal performance differences may be customized to these important contributors to building energy use.

Three BEES products affect thermal performance: generic brick and mortar, Dryvit Outsulation, and Dryvit Outsulation Plus. Assuming a thermal resistance value of R-13 is required by code for exterior walls, then R-13 insulation on a brick and mortar wall will increase its thermal performance to about R-15, and on a Dryvit Outsulation or Dryvit Outsulation Plus wall, to about R-19. If the BEES user chooses to account for thermal performance, use energy savings for these three products, over and above that provided by R-13 insulation, are accounted for in the BEES results.[96]

End of Life

Both Dryvit products are assumed to have useful lives of 50 years. At end of life, it is assumed that Outsulation and Outsulation Plus materials are waste and sent to a landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 7.0 LCA Software*. 2005. The Netherlands.

Sheehan, J. et al., *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus,* NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

Industry Contacts

Dr. Chander Patil, Dryvit Systems Inc. (August 2006)

3.5 Wall Insulation

3.5.1 Generic Cellulose

Blown cellulose insulation is produced primarily from post-consumer wood pulp (newspapers), typically accounting for roughly 80 % of the insulation by weight. Cellulose insulation is treated with fire retardant. Ammonium sulfate, borates, and boric acid are used most commonly and account for the other 20 % of the cellulose insulation by weight.

BEES performance data are provided for thermal resistance values of R-13 for a wall application and R-38 for a ceiling application. The amount of cellulose insulation material used per functional unit is shown in the following Table, based on information from the Cellulose Insulation Manufacturers Association (CIMA) and the U.S. Department of Energy.

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[96] Note that if generic brick and mortar and/or the two Dryvit products are the *only* alternatives being compared, use energy savings are computed relative to the selected alternative with the lowest R-value.

Table 3.37: Blown Cellulose Insulation by Application

Application	*Thickness cm (in)*	*Density kg/m^3 (lb/ft^3)*	*Mass per Functional Unit kg/m^2 (lb/ft^2)*
Wall--R-13	8.9 (3.5)	35.3 (2.20)	3.13 (0.641)
Ceiling--R-38	27.6 (10.9)	27.2 (1.70)	7.52 (1.54)

The detailed environmental performance data for these products may be viewed by opening the following files under the File/Open menu item in the BEES software:

- B2012A.DBF—Blown Cellulose R-13
- B3012A.DBF—Blown Cellulose R-38

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

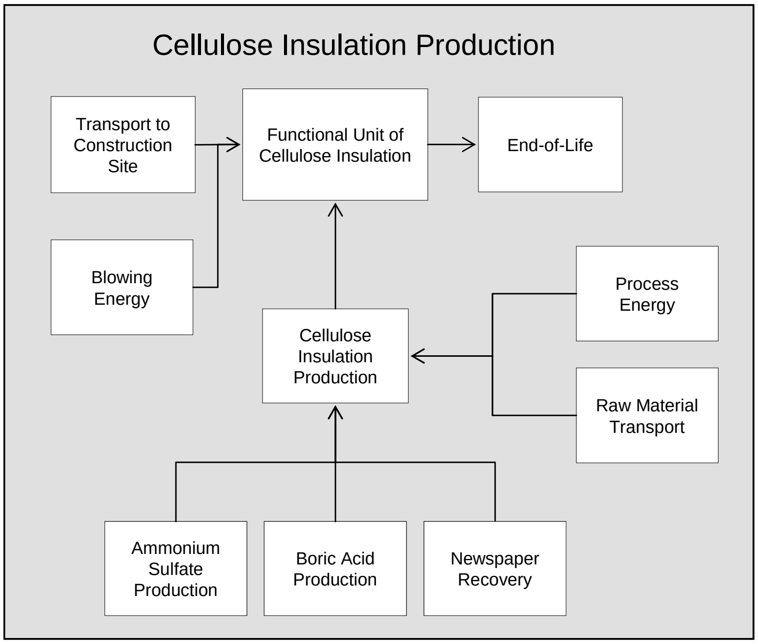

Figure 3.16: Cellulose Insulation System Boundaries

Raw Materials

Cellulose insulation is essentially shredded recovered wastepaper that is coated with fire retardants. The mix of constituents is provided in the following Table, with the fractions for ammonium sulfate and boric acid based on typical amounts used in North America.

Table 3.38: Cellulose Insulation Constituents

Constituent	*Mass Fraction (%)*
Recovered Newspaper	80
Ammonium Sulfate	15.5
Boric Acid	4.5

The only burdens for production of wastepaper are those associated with collection and transportation of wastepaper to the manufacturing facility. The impacts from removing waste paper from the existing wastepaper value chain are not included in the system boundaries.

Ammonium sulfate is assumed to be produced as a co-product of the production of caprolactam. The materials and energy used by the process are taken from the U.S. LCI Database. The boric acid flame retardant is assumed to be produced from borax.

Manufacturing

Energy Requirements and Emissions. There are no wastes or water effluents from the process of manufacturing cellulose insulation – the process is essentially the blending of waste paper with the different fire retardants. Manufacturing energy is assumed to come from purchased electricity, as shown below.

Table 3.39: Energy Requirements for Cellulose Insulation Manufacturing

Energy Carrier	*MJ/kg (Btu/lb)*
Electricity	0.35 (150)

Transportation. The raw materials are all assumed to be shipped 161 km (100 mi) to the manufacturing plant via diesel truck.

Waste. All waste produced during the production process is recycled back into other insulation materials. Therefore, no solid waste is generated during the production process.

Transportation

Transportation of cellulose insulation by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

Cellulose insulation has a functional lifetime of more than 50 years – there is no need to replace or maintain the insulation during normal building use. During the installation of loose fill insulation, any waste material is added into the building shell where the insulation is installed, so there is effectively no installation waste.

For loose fill insulation, a diesel generator is used to blow the insulation material into the space. For one h of operation, a typical 18 kW (25 hp) diesel engine can blow 818 kg (1 800 lb) of insulation. The emissions and energy use for this generator are included in the system boundaries for this product. No other installation energy is required.

Use

It is important to consider thermal performance differences when assessing environmental and economic performance for insulation product alternatives. Thermal performance affects building heating and cooling loads, which in turn affect energy-related LCA inventory flows and building energy costs over the 50-year use stage. Since alternatives for ceiling insulation all have R-38 thermal resistance values, thermal performance differences are at issue only for the wall insulation alternatives.

For wall insulation, thermal performance differences are separately assessed for 14 U.S. cities spread across a wide range of climate and fuel cost zones, and for electricity, distillate oil, and natural gas heating fuel types (electricity is assumed for all cooling). When selecting wall insulation alternatives for analysis, the BEES user selects the U.S. city closest to the building location and the building heating fuel type, so that thermal performance differences may be customized to these important contributors to building energy use. A NIST study of the economic efficiency of energy conservation measures (including insulation), tailored to these cities and fuel types, is used to estimate 50-year heating and cooling requirements per functional unit of insulation.[97] BEES environmental performance results account for the energy-related inventory flows resulting from these energy requirements. To account for the 50-year energy requirements in BEES economic performance results, 2005-2006 winter fuel prices by U.S. region[98] and U.S. Department of Energy fuel price projections over the next 30 years[99] are used to compute the present value cost of operational energy per functional unit for each R-value.

End of Life

While cellulose insulation is mostly recyclable, it is assumed that all of the insulation is disposed of in a landfill at end of life.

References

Life Cycle Data

Energy Information Administration, *Short-Term Energy Outlook—November 2006* (Washington, DC: U.S. Department of Energy, 2006), Table WF01.

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Petersen, S., *Economics and Energy Conservation in the Design of New Single-Family Housing (NBSIR 81-2380)* (Washington, DC: National Bureau of Standards, 1981).

Rushing, A.S. and Fuller, S.K., *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis –April 2006*, NISTIR 85-3273-21 (Washington, DC: National Institute of Standards and Technology, April 2006).

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[97] Petersen, S., *Economics and Energy Conservation in the Design of New Single-Family Housing, NBSIR 81-2380*(Washington, DC: National Bureau of Standards, 1981).

[98] Energy Information Administration, *Short-Term Energy Outlook—November 2006*(Washington, DC: U.S. Department of Energy, 2006), Table WF01.

[99] Rushing, A.S. and Fuller, S.K., *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis –April 2006*, NISTIR 85-3273-21 (Washington, DC: National Institute of Standards and Technology, April 2006).The year 30 DOE cost escalation factor is assumed to hold for years 31-50.

Industry Contacts

No industry contacts were identified to provide further insight on this product.

3.5.2 Generic Fiberglass

Fiberglass batt insulation is made by forming spun-glass fibers into batts. At an insulation plant, the product feedstock is weighed and sent to a melting furnace. The raw materials are melted in a furnace at very high temperatures. Streams of the resulting vitreous melt are either spun into fibers after falling onto rapidly rotating flywheels or drawn through tiny holes in rapidly rotating spinners. This process shapes the melt into fibers. Glass coatings are added to the fibers that are then collected on conveyers. The structure and density of the product is continually controlled by the conveyer speed and height as it passes through a curing oven. The cured product is then sawn or cut to the required size, such as for a batt. Off-cuts and other scrap material are recycled back into the production process.

BEES performance data are provided for fiberglass batt insulation with thermal resistance values of R-13, R-15, and R-19 for a wall application, and R-38 for a ceiling application.

Blown fiberglass insulation is made by forming spun-glass fibers using the same method as for batts but leaving the insulation loose and unbonded. For loose fill fiberglass insulation, BEES performance data are provided for a thermal resistance value of R-38 for a ceiling application.

The tables below specify fiberglass insulation by type and R-value:

Table 3.40: Fiberglass Batt Mass by Application

Application	*Thickness cm (in)*	*Density kg/m^3 (lb/ft^3)*	*Mass per Functional Unit kg/m^2 (oz/ft^2)*
Wall--R-13	8.9 (3.5)	12.1 (0.755)	1.07 (3.52)
Wall--R-15	8.9 (3.5)	22.6 (1.41)	2.01 (6.58)
Wall--R-19	15.9 (6.25)	7.0 (0.44)	1.11 (3.65)
Ceiling--R-38	30.5 (12.0)	7.7 (0.48)	2.35 (7.71)

Table 3.41: Blown Fiberglass Mass by Application

Application	*Thickness cm (in)*	*Density kg/m^3 (lb/ft^3)*	*Mass per Functional Unit kg/m^2 (oz/ft^2)*
Ceiling--R-38	37.7 (14.8)	8.8 (0.55)	3.32 (10.9)

The detailed environmental performance data for these products may be viewed by opening the following files under the File/Open menu item in the BEES software:

- B2012B.DBF—Fiberglass Batt R-19
- B2012C.DBF—Fiberglass Batt R-15
- B2012E.DBF—Fiberglass Batt R-13

- B3012B.DBF—Fiberglass Batt R-38
- B3012D.DBF—Blown Fiberglass R-38

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

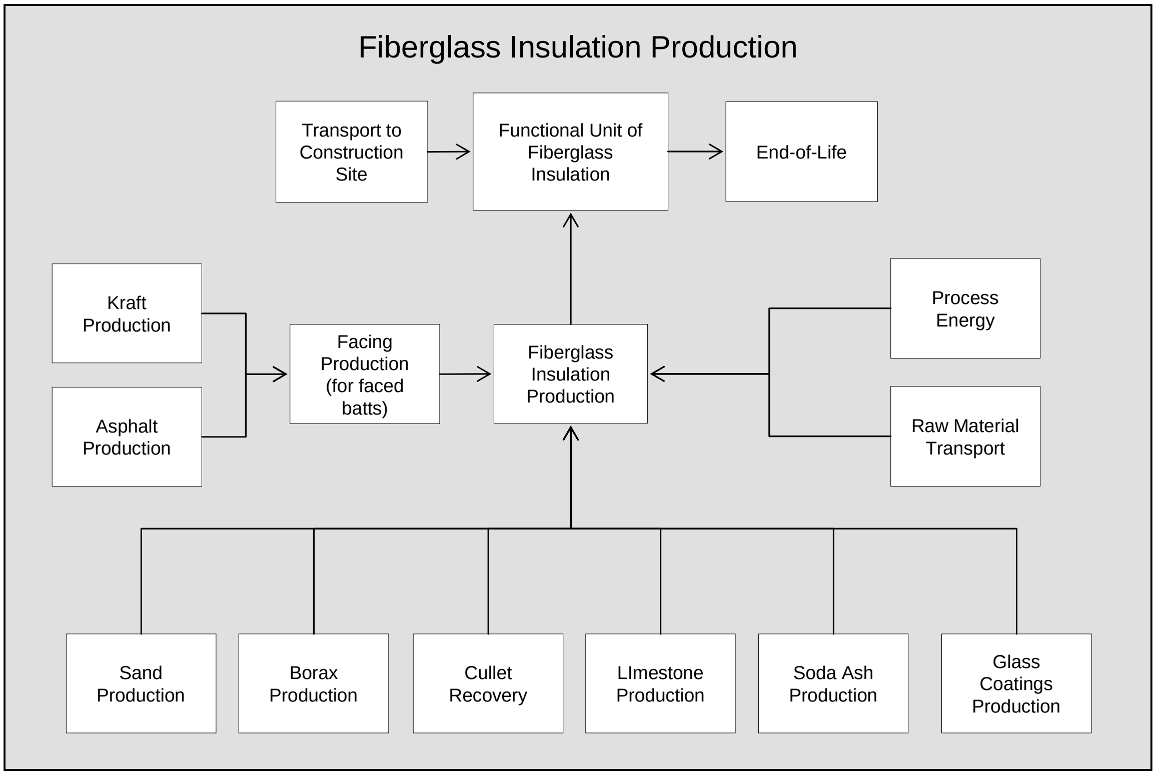

Figure 3.17: Fiberglass Insulation System Boundaries

Raw Materials

Fiberglass insulation is made with a blend of sand, limestone, soda ash, and recycled glass cullet. Recycled window, automotive, or bottle glass is increasingly used in the manufacture of glass fiber, and it now accounts for approximately 30 % to 50 % of the raw material input. The recycled content is limited by the amount of usable recycled material available in the market – not all glass cullet is of sufficient quality to be used in the glass fiber manufacturing process. The use of recycled material has helped to steadily reduce the energy required to produce insulation products.

The raw materials used to produce fiberglass insulation are show in the following Table.

Table 3.42: Fiberglass Insulation Constituents

Constituent	*Batt Mass Fraction (%)*	*Loose Fill Mass Fraction (%)*
Soda Ash	9	9.5
Borax	12	13
Glass Cullet	35	37
Limestone	9	9.5
Glass Coatings	6	<1
Sand	29	31

The life cycle environmental profiles for the constituents of fiberglass insulation are based on surrogate life cycle data from the SimaPro software tool and data from the U.S. LCI Database.

Manufacturing

Energy Requirements and Emissions. The energy requirements for melting the glass constituents into fibers and drying of the completed batt involve a mixture of natural gas and electricity. The energy demands are outlined in the following Table.

Table 3.43: Energy Requirements for Fiberglass Insulation Manufacturing

Energy Carrier	*MJ/kg (Btu/lb)*
Natural Gas	1.99 (857)
Electricity	1.37 (591)
Total	**3.36 (1450)**

The manufacturing process generates air emissions from the combustion of the fuels used to melt the raw materials and from the drying of the insulation material prior to cutting and packaging. Emissions from fuel combustion are captured in the fuel use data included in the BEES model; additional emissions are listed in the Table below.

Table 3.44: Emissions for Fiberglass Insulation Manufacturing

Emission	*Bonded Batts g/kg (lb/ton)*	*Unbonded Loose Fill g/kg (lb/ton)*
Particulates	2.380 (4.759)	1.610 (3.220)
VOC	0.759 (1.52)	0.083 (0.165)

Transportation. The raw materials are all shipped to the manufacturing plant via diesel truck. The average shipping distances are as follows:

Table 3.45: Raw Material Transportation Distances

Constituent	*Distance to Plant km (mi)*
Borax	805 (500)
Soda Ash	805 (500)
Glass Cullet	161 (100)
Limestone	161 (100)
Glass Coatings	322 (200)
Sand	161 (100)

Waste. All waste produced during the cutting and blending process is either recycled into other insulation materials or added back into the glass mix. Thus, no solid waste is generated during the production process.

Transportation

Transportation of fiberglass insulation by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

Fiberglass insulation has a functional lifetime of more than 50 years – there is no need to replace or maintain the insulation during normal building use. During the installation of fiberglass batts and loose fill insulation, any waste material is added into the building shell where the insulation is installed - there is effectively no installation waste.

Installing batt insulation is primarily a manual process; no energy or emissions are included in the model. For blown fiberglass insulation, a diesel generator is used to blow the insulation material into the ceiling space. For one h of operation, a typical 18 kW (25 hp) diesel engine can blow 818 kg (1 800 lb) of insulation. No other installation energy is required.

Use

It is important to consider thermal performance differences when assessing environmental and economic performance for insulation product alternatives. Thermal performance affects building heating and cooling loads, which in turn affect energy-related LCA inventory flows and building energy costs over the 50-year use stage. Since alternatives for ceiling insulation all have R-38 thermal resistance values, thermal performance differences are at issue only for the wall insulation alternatives.

For wall insulation, thermal performance differences are separately assessed for 14 U.S. cities spread across a wide range of climate and fuel cost zones, and for electricity, distillate oil, and natural gas heating fuel types (electricity is assumed for all cooling). When selecting wall insulation alternatives for analysis, the BEES user selects the U.S. city closest to the building location and the building heating fuel type, so that thermal performance differences may be customized to these important contributors to building energy use. A NIST study of the economic efficiency of energy conservation measures (including insulation), tailored to these cities and fuel types, is used to estimate 50-year heating and cooling requirements per functional unit of insulation.[100] BEES environmental performance results account for the energy-related inventory flows resulting from these energy requirements. To account for the 50-year energy requirements in BEES economic performance results, 2005-2006 winter fuel prices by U.S. region[101] and U.S. Department of Energy fuel price projections over the next 30 years[102] are used to compute the present value cost of operational energy per functional unit for each R-value.

End of Life

While fiberglass insulation is mostly recyclable, it is assumed that all of the insulation is disposed of in a landfill at end of life.

References

Life Cycle Data

Energy Information Administration, *Short-Term Energy Outlook—November 2006* (Washington, DC: U.S. Department of Energy, 2006), Table WF01.

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Petersen, S., *Economics and Energy Conservation in the Design of New Single-Family Housing (NBSIR 81-2380)* (Washington, DC: National Bureau of Standards, 1981).

Rushing, A.S. and Fuller, S.K., *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis –April 2006*, NISTIR 85-3273-21 (Washington, DC: National Institute of Standards and Technology, April 2006).

Industry Contacts

Clarke Berdan II, Owens Corning (January 2006 – May 2006)

3.5.3 Generic Mineral Wool

Blown mineral wool insulation is made by spinning fibers from natural rock (rock wool) or iron ore blast furnace slag (slag wool). Rock wool and slag wool are manufactured by melting the constituent raw materials in a cupola. A molten stream is created and poured onto a rapidly spinning wheel or wheels. The viscous molten material adheres to the wheels and the centrifugal force throws droplets of melt away from the wheels, forming fibers. The fibers are then collected and cleaned to remove non-fibrous material. During the process a phenol formaldehyde binder and/or a de-dusting agent are sometimes applied to reduce free, airborne wool during application.

BEES performance data are provided for a thermal resistance value of R-13 for a wall

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[100] Petersen, S., *Economics and Energy Conservation in the Design of New Single-Family Housing, NBSIR 81-2380* (Washington, DC: National Bureau of Standards, 1981).

[101] Energy Information Administration, *Short-Term Energy Outlook—November 2006* (Washington, DC: U.S. Department of Energy, 2006), Table WF01.

[102] Rushing, A.S. and Fuller, S.K., *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – April 2006*, NISTIR 85-3273-21 (Washington, DC: National Institute of Standards and Technology, April 2006).The year 30 DOE cost escalation factor is assumed to hold for years 31-50.

application and R-38 for a ceiling application. The Table below specifies mineral wool insulation for these applications.

Table 3.46: Blown Mineral Wool Mass by Application

Application	*Thickness* *cm (in)*	*Density* *kg/m^3 (lb/ft^3)*	*Mass per Functional Unit* *kg/m^2 (lb/ft^2)*
Wall--R-13	7.9 (3.1)	64.1 (4.00)	5.06 (1.04)
Ceiling--R-38	30.6 (12.1)	27.2 (1.70)	8.34 (1.71)

The detailed environmental performance data for these products may be viewed by opening the following files under the File/Open menu item in the BEES software:

- B2012D.DBF—Blown Mineral Wool R-13
- B3012C.DBF—Blown Mineral Wool R-38

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

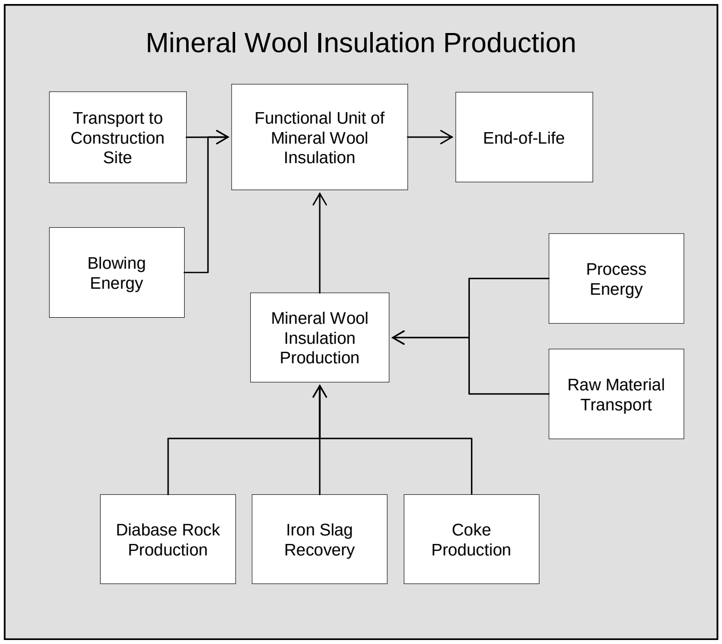

Figure 3.18: Mineral Wool Insulation System Boundaries

Raw Materials

Mineral wool can be manufactured using iron ore slag (slag wool) or natural diabase or basalt rock (rock wool). Some products contain both materials; about 80 % of North American mineral wool is manufactured using iron ore slag. Loose fill mineral wool insulation is generally unbonded, that is, no resin is used to bind the fibers together. The BEES model for this product represents a weighted mix of the different types of mineral wool insulation used in North

America, as given in the Table below.

Table 3.47: Mineral Wool Insulation Constituents

Constituent	***Mass Fraction (%)***
Diabase Rock/Basalt	22
Iron Ore Slag	78

The life cycle environmental profiles for the constituents of mineral wool insulation are based on surrogate life cycle data in the SimaPro software tool and the U.S. LCI Database.

Manufacturing

Energy Requirements and Emissions. The energy requirements for melting the product constituents into fibers and drying of the fibers involve a mixture of coke and electricity. The energy demands are outlined in the following Table.

Table 3.48: Energy Requirements for Mineral Wool Insulation Manufacturing

Energy Carrier	***MJ/kg (Btu/lb)***
Coke	6.38 (2740)
Electricity	1.0 (430)
Total	**7.38 (3170)**

The manufacturing process generates air emissions from the combustion of the fuels used to melt the raw materials and from the drying on the insulation material prior to packaging. Emissions from fuel combustion are captured in the fuel use data included in the BEES model; additional emissions are included in the Table below.

Table 3.49: Emissions for Mineral Wool Insulation Manufacturing

Emission	***Unbonded Loose Fill g/kg (lb/ton)***
Particulates	2.061 (4.122)
Fluorides	0.019 (0.038)

Transportation. The raw materials are all assumed to be shipped 161 km (100 mi) to the manufacturing plant via diesel truck.

Waste. All waste produced during the production process is either recycled into other insulation materials or added back into the melt. Therefore, no solid waste is generated during the production process.

Transportation

Transportation of mineral wool insulation by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

Mineral wool insulation has a functional lifetime of more than 50 years – there is no need to replace or maintain the insulation during normal building use. During the installation of loose fill insulation, any waste material is added into the building shell where the insulation is installed - there is effectively no installation waste.

A diesel generator is used to blow the insulation material into the building shell. For one h of operation, a typical 18 kW (25 hp) diesel engine can blow 818 kg (1 800 lb) of insulation. The emissions and energy use for the generator are included in the system boundaries for this product. No other installation energy is required.

Use

It is important to consider thermal performance differences when assessing environmental and economic performance for insulation product alternatives. Thermal performance affects building heating and cooling loads, which in turn affect energy-related LCA inventory flows and building energy costs over the 50-year use stage. Since alternatives for ceiling insulation all have R-38 thermal resistance values, thermal performance differences are at issue only for the wall insulation alternatives.

For wall insulation, thermal performance differences are separately assessed for 14 U.S. cities spread across a wide range of climate and fuel cost zones, and for electricity, distillate oil, and natural gas heating fuel types (electricity is assumed for all cooling). When selecting wall insulation alternatives for analysis, the BEES user selects the U.S. city closest to the building location and the building heating fuel type, so that thermal performance differences may be customized to these important contributors to building energy use. A NIST study of the economic efficiency of energy conservation measures (including insulation), tailored to these cities and fuel types, is used to estimate 50-year heating and cooling requirements per functional unit of insulation.[103] BEES environmental performance results account for the energy-related inventory flows resulting from these energy requirements. To account for the 50-year energy requirements in BEES economic performance results, 2005-2006 winter fuel prices by U.S. region[104] and U.S. Department of Energy fuel price projections over the next 30 years[105] are used to compute the present value cost of operational energy per functional unit for each R-value.

End of Life

While mineral wool insulation is mostly recyclable, it is assumed that all of the insulation is disposed of in a landfill at end of life.

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[103] Petersen, S., *Economics and Energy Conservation in the Design of New Single-Family Housing, NBSIR 81-2380*(Washington, DC: National Bureau of Standards, 1981)

[104] Energy Information Administration, *Short-Term Energy Outlook—November 2006* (Washington, DC: U.S. Department of Energy, 2006), Table WF01.

[105] Rushing, A.S. and Fuller, S.K., *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – April 2006*, NISTIR 85-3273-21 (Washington, DC: National Institute of Standards and Technology, April 2006).The year 30 DOE cost escalation factor is assumed to hold for years 31-50.

References

Life Cycle Data

Energy Information Administration, *Short-Term Energy Outlook—November 2006* (Washington, DC: U.S. Department of Energy, 2006), Table WF01.

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Petersen, S., *Economics and Energy Conservation in the Design of New Single-Family Housing (NBSIR 81-2380)* (Washington, DC: National Bureau of Standards, 1981).

Rushing, A.S. and Fuller, S.K., *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis –April 2006*, NISTIR 85-3273-21 (Washington, DC: National Institute of Standards and Technology, April 2006).

Industry Contacts

Anders Schmidt, dk-Teknik Energy & Environment (November 2005 – January 2006)

3.6 Framing

3.6.1 Generic Steel Framing

Steel is an important construction framing material. Cold-formed steel studs for framing are manufactured from blanks sheared from sheets cut from coils or plates, or by roll-forming coils or sheets. Both these forming operations are done at ambient temperatures. Cold-formed steel shapes are made from flat-rolled 0.46 mm to 2.46 mm) (18 mil to 97 mil) carbon steel as either single bent shapes or bent shapes welded together. Two basic types of steel framing, nailable and nonnailable, are available in both punched and solid forms. Zinc chromate primer, galvanized, and painted finishes are available. Steel stud and joist systems have been adopted as an alternative to wood and masonry systems in most types of construction. Steel framing is also used extensively for interior partitions because it is fire-resistant, easy to erect, and makes installation of utilities more convenient. Cold-formed steel framing can be installed directly at the construction site or it can be prefabricated off- or on-site for quicker installation. The assembly process relies on a number of accessories usually made of steel, such as bridging, bolts, nuts, screws, and anchors, as well as devices for fastening units together, such as clips and nails.

The functional unit of comparison for BEES framing alternatives is 0.09 m^2 (1 ft^2). The steel framed exterior wall has 33 mil galvanized steel studs placed 61 cm (24 in) on center, and has a service life of 75 years. Self-tapping steel screws, used as fasteners for the steel studs, are included. While the exterior wall is constructed as an assembly with sheathing components and insulation, for the BEES framing category, only the framing material is accounted for, not the full assembly.

The detailed environmental performance data for this product may be viewed by opening the file B2013A.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

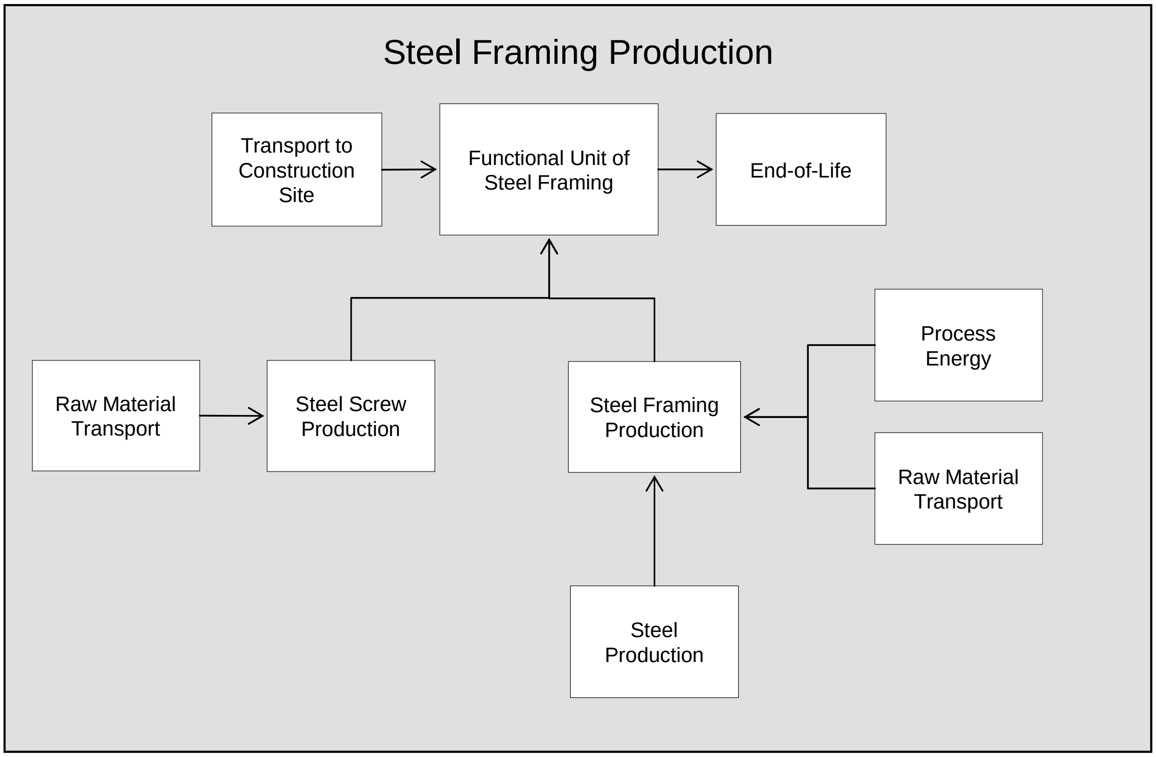

Figure 3.19: Steel Framing System Boundaries

Raw Materials and Manufacturing

BEES modeling of the production of raw materials necessary for steel stud and fastener manufacture is based on data from the American Iron and Steel Institute (AISI) and the International Iron and Steel Institute (IISI), which represent late 1990s world-wide production of steel and account for recycling loops. Energy requirements and emissions from manufacturing cannot be itemized, since the industry data are in fully-aggregated form.

Secondary data were obtained from LCA databases and published literature.

Transportation

Transportation of the steel framing by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

During installation of the steel stud framing, 1 % of the installation materials are assumed to be lost as waste, which is recycled by contractors following “green building” practices. Approximately 0.0056 kg (0.0123 lb) of galvanized steel screws are assumed to be used per ft^2 of steel framing. The installation of the framing is assumed to be a manual process, so no energy inputs or emissions are included in the model.

Use

Steel framing is assumed to have a useful life of 75 years. This is a conservative value; steel studs have a very long life due to their galvanized treatment.

End of Life

All the steel framing and its components are assumed to be recycled at end of life.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Industry Contacts

Bill Heenan, President, Steel Recycling Institute (January 2006)
Greg Crawford, Vice President, Steel Recycling Institute (January 2006)

3.6.2 Generic Wood Framing

Wood framing is the most common structural system used for non-load-bearing and load-bearing interior and exterior walls, and consists of lumber and specific applications of treated lumber. The load-bearing walls support floors, ceilings, roof and lateral loads, and nonbearing walls carry only their own weight. Interior walls can be either non-load bearing or load bearing, whereas all exterior walls should be considered load bearing. Exterior walls are comprised of one or two top and bottom plates and vertical studs. Sheathing or diagonal bracing ensures lateral stability. When the wall is on a concrete foundation or slab, building code requires that the sill or sole plate (also called bottom plate) that is in contact with the concrete must be treated wood.

In general, dimensions for framing lumber are given in nominal in, that is, 2x4 and 2x6, but the actual dimensions of a 2x4 are 3.8 cm x 8.9 cm (1.5 in x 3.5 in) and of a 2x6, 3.8 cm x 14 cm (1.5 in x 5.5 in). Framing lumber must be properly grade-marked to be acceptable under the major building codes. Such grade marks identify the grade, species or species group, seasoning condition at time of manufacture, producing mill, and the grading rules-writing agency.

Wood studs are produced in a sawmill, where harvested wood is debarked and sawn into specific dimensions. The lumber is then dried in a controlled environment until the desired moisture content (between 12 % and 19 %) is reached. Framing lumber may be treated with preservatives in order to guard against insect attack or fungal decay. Treated lumber is used for any application where wood is in contact with concrete or the ground. All wood, including framing, used in places with serious termite problems, such as in Hawaii, must be treated.

The functional unit of comparison for BEES framing alternatives is 0.09 m^2 (1 ft^2) of load-bearing exterior wall. The wood-framed wall consists of wood studs placed 41 cm (16 in) on center, and has a service life of 75 years. While the exterior wall is constructed as an assembly with sheathing components and insulation, for the BEES system, only the framing material—either treated or untreated wood--is accounted for, not the full assembly.

The detailed environmental performance data for these products may be viewed by opening the file B2013B.DBF, for treated wood framing, and B2013C.DBF, for untreated wood framing, under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

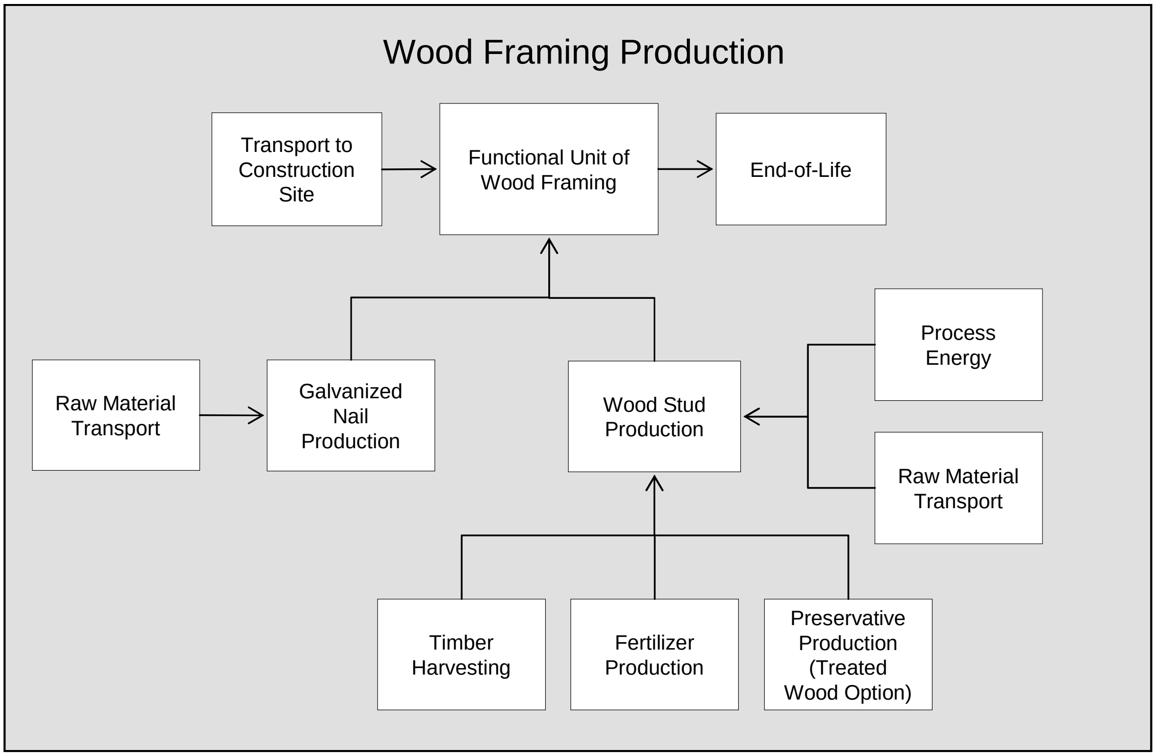

Figure 3.20: Wood Framing System Boundaries

Raw Materials

For BEES, data were collected for the harvested trees used to produce the dimension lumber necessary for framing load-bearing walls. The lumber is primarily produced in the Pacific Northwest (PNW) and the Southeastern United States (SE). For PNW the species of wood used are Douglas Fir and Western Hemlock, while for SE the wood species is Southern Yellow Pine, which is actually a group of six different softwood species.

The data to grow and harvest softwood logs for a composite forest management scenario for PNW and SE is found in a study by CORRIM.[106] The growing and harvesting of wood includes a mix of low-, medium-, and high-intensity managed timber. Energy use for wood production includes electricity for greenhouses to grow seedlings, gasoline for chain saws, diesel fuel for

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[106] Bowyer, J., et. al., *Phase I Final Report: Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction*. (Seattle, WA: Consortium for Research on Renewable Industrial Materials-- CORRIM, Inc./University of Washington, 2004). Found at: http://www.corrim.org/reports; data also submitted to US LCI Database.

harvesting mechanical equipment, and a small amount of fertilizer. Emissions associated with production and combustion of gasoline and diesel fuel, and those for the production and delivery of electricity, are based on the U.S. LCI Database. Fertilizer production data is adapted from European data in the U.S. LCI Database. Electricity use for greenhouse operation is based on the grids for the regions where the seedlings are grown, while the U.S. average electricity grid is used for fertilizer production. BEES adopts the CORRIM study's equally-weighted average of forest management practices in PNW and SE. The weight of wood harvested for lumber is based on an average oven-dry density of 510 kg/m^3 (31.8 lb/ft^3).

BEES modeling accounts for the absorption of carbon dioxide by trees as they grow; the carbon becomes part of the wood, and the oxygen is released to the atmosphere. The "uptake" of carbon dioxide from the atmosphere during the growth of timber is about 1.84 kg (4.06 lb) of carbon dioxide per kilogram of harvested wood (in oven-dry weight terms).

Chromated Copper Arsenate (CCA), the lumber treatment assumed in previous versions of BEES, is no longer permitted for use in the United States. An article from the Treated Wood Council website reports that alkaline copper quaternary (ACQ), a copper-based preservative, is the most popular replacement preservative for CCA.[107] This contains 66.7 % copper oxide and 33.3 % didecyldimethyl ammonium chloride. The data used in BEES for copper oxide is based on European data for copper production, provided by the SimaPro database. For lack of better available data, proxy data was used to represent didecyldimethyl ammonium chloride; esterquat, a type of quaternary ammonium, was used as the proxy, and its production data comes from a European study on detergents.[108] The treated wood in BEES is assumed to contain 4.0 kg/m^3 (0.25 lb/ft^3) ACQ.[109]

Manufacturing

Energy Requirements and Emissions. The energy requirements allocated to the production of softwood lumber for wood framing are listed in the Table below. These requirements are based on average manufacturing conditions in the PNW and SE regions of the United States. The energy comes primarily from burning wood and bark waste generated in the sawmill process. Other fuel sources include natural gas for boilers, and propane and diesel for forklifts and log haulers at the sawmill. The production and combustion of the different types of fuel are based on the U.S. LCI Database. The electricity grid used is an average by fuel breakdown for both regions.

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[107] Frome, A., "Wood Treaters Switch to New Chemical," *TimberLine Online Newspaper* (April 2004). Found at: http://www.treatedwood.com/news/industry_articles/new_chemical_040104.pdf.

[108] Dall'Acqua, S., et al., Report #244 (St. Gallen: EMPA, 1999).

[109] Southern Pine Council, "Table 12: AWPA Standards for Softwood Lumber & Plywood," *Southern Pine Use Guide* (Kenner, LA: Southern Pine Council, 2003), pp. 17. Found at: http://www.southernpine.com/awpatable1_03.pdf.

Table 3.50: Lumber Production Energy

Energy Carrier	***Quantity per lb Lumber in SE***	***Quantity per lb Lumber in PNW***
Electricity	1.80E+05 J (0.05 kWh)	2.88E+05 J (0.08 kWh)
Natural Gas	4.81E-08 L (1.7 E-09 ft^3)	23 L (0.82 ft^3)
Diesel fuel	0.56 mL (1.5 E-04 gal)	0.98 mL (2.6 E-04 gal)
Kerosene	0.001 mL (3.8 E-07 gal)	--
LPG	7.95E-05 mL (2.1 E-08 gal)	2.69E-04 mL (7.1 E-08 gal)
Gasoline	0.05 mL (1.2 E-05 gal)	0.06 mL (1.7 E-05 gal)
Hogfuel/Biomass (oven-dry basis)	118 g (0.26 lb)	73 g (0.16 lb)

The allocated process-related air emissions from lumber production are based on the CORRIM study and reported in the Table below. Allocation is based on mass and a multi-unit process analysis to correctly assign burdens. Note: In the BEES model, CO_2 generated by combustion of biofuel (hogged wood fuel) and fossil fuel are tracked separately since CO_2 from biomass is considered environmentally impact-neutral by the U.S. EPA, and as such is not considered when determining the Global Warming Potential impact.

Table 3.51: Lumber Production Emissions

Air Emission	***Quantity per lb Lumber from SE***	***Quantity per lb Lumber from PNW***
Particulates (unspecified)	0.44 g (9.7 E-04 lb)	0.01 g (3.0 E-05 lb)
VOC (unspecified)	0.50 g (1.1 E-03 lb)	0.09 g (1.9 E-04 lb)

Treating Wood. Data for treating wood comes from a treated lumber producer.[110] Lumber is put into a vacuum chamber where air is removed from the wood cells. Preservative is pumped into the chamber, and with the pressure in the chamber raised, the preservative is forced into the wood. At the end of the treatment, a vacuum removes excess preservative from wood cells.

Transportation. Sawmills are often located close to tree harvesting areas. For transportation of logs to the sawmill, CORRIM surveys report an average truck transportation distance of 103 km (64 mi) for harvested wood. The delivery distances are one-way with an empty backhaul. For preservative-treated lumber, truck transportation of 322 km (200 mi) is assumed for transport of the preservative.

Transportation

Transportation of wood framing by heavy-duty truck to the building site is modeled as a variable of the BEES system.

The weight of wood shipped includes its moisture content. For the shipping weight of lumber, the oven-dry density of lumber, 510 kg/m^3 (31.8 lb/ft^3), plus its moisture content of 19 % (an

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[110] See www.follen.com/faq.html#q3.

additional 97 kg of water), yields a shipping weight of 607 kg/m^3 (37.9 lb/ft^3). The ACQ-treated lumber is usually shipped green, so a 40 % to 60 % moisture content is assumed.

Installation

Installation of wood framing is assumed to be done primarily by manual labor, so there are no installation emissions. It is assumed that wood studs are placed 16 in on center and are fastened with galvanized steel nails. Production of the galvanized steel for nails is based on data from the International Iron and Steel Institute.[111]

At installation, 5 % of the product is lost to waste, and all of this waste is disposed of in a landfill. It is assumed that 0.04 kg (0.09 lb) of galvanized nails are needed to install the framing.

Use

Based on U.S. Census data, the mid-service life of a wood-framed house in the United States is over 85 years. To be conservative, CORRIM assumes a life of 75 years for the residential shell, including wood framing. The product is therefore assumed to have a useful life of 75 years.

There is no routine maintenance for the framing over its lifetime. The building envelope (roof and siding) should be maintained to ensure water tightness and prevent water damage to the shell.

End of Life

All the wood framing is assumed to be disposed of in landfill at end of life. The practice of recycling is increasing, but data are not available to quantify this practice.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Bowyer, J., et. al., *Phase I Final Report: Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction*. (Seattle, WA: Consortium for Research on Renewable Industrial Materials. (CORRIM, Inc.)/University of Washington, 2004). Found at: http://www.corrim.org/reports.

Frome, A., "Wood Treaters Switch to New Chemical," *TimberLine Online Newspaper* (April 2004). Found at: http://www.treatedwood.com/news/industry_articles/new_chemical_040104.pdf.

Dall'Acqua, S., et al., Life Cycle Inventories for the Production of Detergent Ingredients, Report #244 (St. Gallen: EMPA, 1999).

Southern Pine Council, "Table 12: AWPA Standards for Softwood Lumber & Plywood," *Southern Pine Use Guide*, (Kenner, LA: Southern Pine Council, 2003), pp. 17. Found at: http://www.southernpine.com/awpatable1_03.pdf.

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[111] Life Cycle Inventory Data Sheet for Steel Products issued to First Environment in January 2006. Data represent the years 1999-2000.

Industry Contacts

Jim Wilson, Oregon State University/CORRIM, Inc. (August 2005-Jan 2006)

3.7 Exterior Sealers and Coatings

3.7.1 BioPreserve SoyGuard Wood Sealer

Produced by BioPreserve in Erie, Pennsylvania, SoyGuard Premium Water Repellent & Wood Sealer is a biobased, non-toxic exterior wood coating with a weak odor and low VOC. It can be applied to new, old, and pressure-treated wood surfaces that are exposed to moisture and weather, such as outdoor decks, siding, furniture, fences, and doors. SoyGuard contains methyl soyate, a natural solvent derived from soybean oil that penetrates the wood surface and encapsulates wood cells with a protective polymer resin made from recycled polystyrene.

For the BEES system, the functional unit for the sealer and coating category is sealing or coating 9.29 m^2 (100 ft^2) of surface. At an application rate of 23.2 m^2 (250 ft^2) per gal and a density of 3.4 kg (7.5 lb) per gal, this amounts to use of 1.36 kg (3 lb) of SoyGuard per application. The detailed environmental performance data for this product may be viewed by opening the file B2040A.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product as it is modeled for BEES.

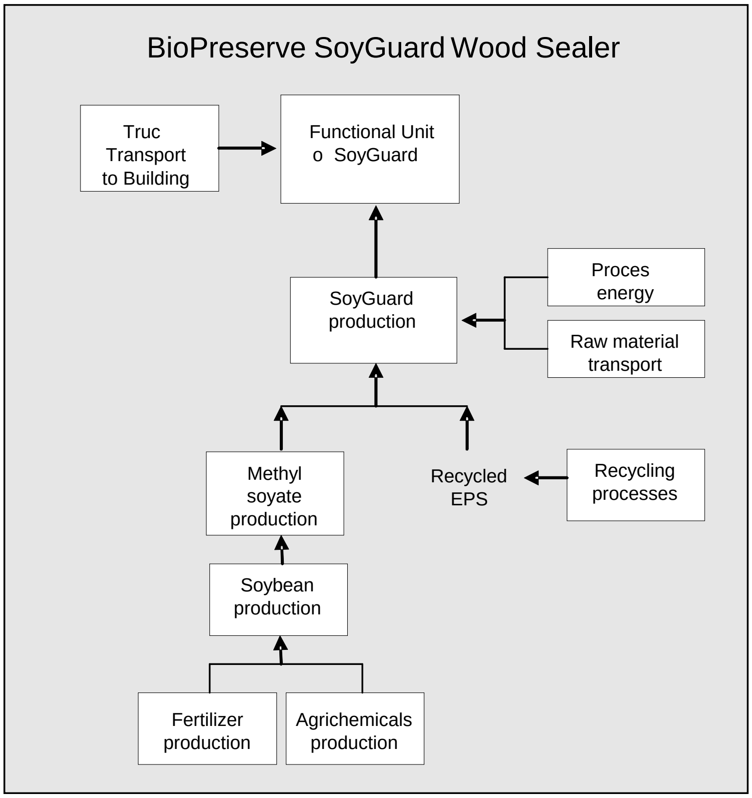

Figure 3.21: SoyGuard System Boundaries

Raw Materials

The SoyGuard constituents are used in the following proportions.

Table 3.52: SoyGuard Constituents

Constituent	*Mass Fraction (%)*
Methyl Soyate	92
Recycled expanded polystyrene (EPS)	8

Methyl soyate production data comes from the life cycle data for biodiesel production developed for a U.S. Department of Agriculture (USDA) study that compared petroleum-based diesel fuel to biodiesel.[112] Data for soybean production comes from the U.S. LCI Database.

The production of virgin extruded polystyrene (EPS) is not accounted for since recycled EPS is used in the product, but data for recycling the EPS is included and encompasses the following subprocesses: collection at end of life, shredding and grinding, milling, separation, and granulation. This data is 1990s European data on mixed polymers and comes from the SimaPro database. Transportation of the recycled EPS to the BioPreserve plant is included.

Manufacturing

Energy Requirements. Data to heat and mix the materials into the final product is calculated using the energy consumed and quantity produced in an 8-h shift, and amounts to 0.0022 kWh/kg (0.001 kWh/lb) of product. Electricity is modeled using the U.S. average electricity grid from the U.S. LCI Database. A small amount of volatile organic compounds (VOC) and particulate emissions are released during the process: 1.4 E-5 kg (3.0 E-5 lb) of VOC and 1.4 E-6 kg (3.0 E-6 lb) of particulates per lb of SoyGuard produced. A small amount of solid waste is generated as well: 4.5 E-7 kg (1.0 E-6 lb) of filtered solid particles from recycled EPS per lb of SoyGuard produced. All of these outputs are accounted for in the BEES product model.

Transportation. Methyl soyate is transported approximately 1368 km (850 mi) to the plant, while the EPS comes from only 8 km (5 mi) away. Materials are transported by diesel truck, which is modeled based on the U.S. LCI Database.

Transportation

As a default, product transport to the customer is assumed to average 563 km (350 mi) by diesel truck, modeled based on the U.S. LCI Database. The BEES user is free to change the default transportation distance.

Installation and Use

SoyGuard requires that one thin coat be applied with a brush, roller, or power sprayer, but for the product to be fully effective it must be applied only at a rate the surface can absorb. For BEES, SoyGuard is modeled as being manually applied. One application lasts approximately 2 years. As with all BEES products, re-application over the 50-year use period–a total of 25 applications in all–is accounted for in the model.

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[112] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

End of Life
No end-of-life is modeled since the product is fully consumed during the use phase.

References
Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Sheehan, J. et al., Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

BioPreserve, SoyGuard Wood Protection Premium Water Repellent and Sealer: Product Information and Application Instructions. Found at: http://www.biopreserve.com.

Industry Contacts

Brad Davis, BioPreserve (January 2006)

3.8 Roof Coverings

3.8.1 Generic Asphalt Shingles

Asphalt shingles, available in a wide range of colors and styles, are suitable for use on roofs with pitches from 2:12 to 21:12.[113,114] Asphalt shingles are commonly made from fiberglass mats impregnated and coated with a mixture of asphalt and mineral filler for both a decorative finish and a wearing layer. The shingles are nailed over roofing underlayment installed over a deck of sheathing, typically oriented strand board.

The market for asphalt shingles has changed significantly in the past 10 years, from primarily 3-tab shingles to now over 56 % of the market consisting of laminated/multi-layered products. Laminate asphalt shingles typically are available in dimensions of 30 cm by 91 cm (12 in by 36 in). Roof coverings such as asphalt shingles are evaluated in BEES on the basis of a functional unit of roof area covered: 1 square (9.29 m^2, or 100 ft^2). Allowing for the recommended overlap, a typical number of shingles required to cover one square is about 80 standard shingles or 65 metric shingles, with an average weight of about 14 kg/m^2 (280 lb/square).[115]

The type of underlayment used has typically been asphalt-impregnated organic felt, although self-adhering polymer modified bituminous sheet materials have been experiencing 20 % to 30 % growth in use over the past several years. For roof pitches from 3:12 to 4:12, two layers of

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[113] Pitch ratio expressed as rise in in: run in in.

[114] Asphalt Roofing Manufacturers Association (ARMA), *Asphalt Roofing Manufacturers Association (ARMA) Residential Asphalt Roofing Manual* (Calverton, MD: Asphalt Roofing Manufacturers Association, 1997) pp. 17.

[115] Shingle dimensions and weight per square based on survey of product information available in ICC reports on laminated asphalt shingles produced by various manufacturers (http://www.icc-es.org/reports/index.cfm?search=search). Number of shingles per square from survey of laminated asphalt shingle products on ebuild.com.

Type-15 felt underlayment are used, while roof pitches greater than 4:12 shed water more quickly and thus require only one layer of Type-15 felt.[116]

For BEES, a roof covering of asphalt laminated shingles with a 20-year life, installed with one layer of type-15 roofing underlayment and galvanized steel nails, is analyzed. The roof sheathing is not considered in the analysis. The detailed environmental performance data for this product may be viewed by opening the file B3011A.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

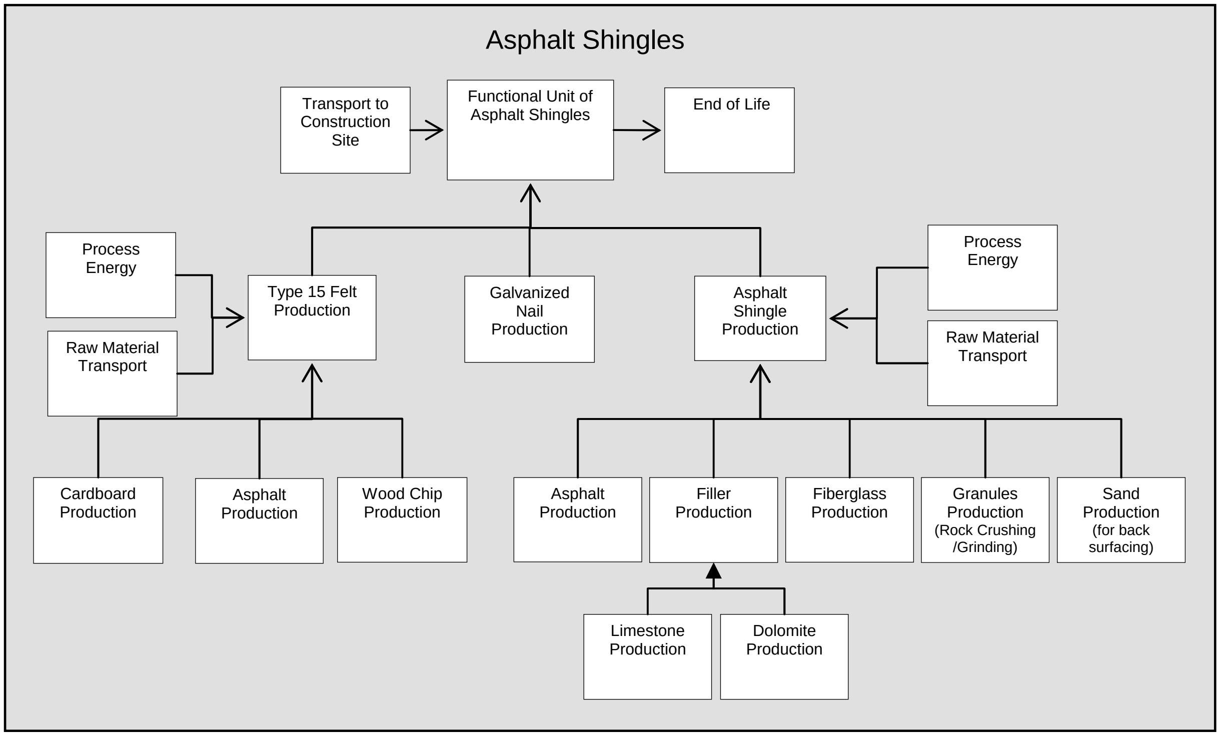

Figure 3.22: Asphalt Shingles System Boundaries

Raw Materials

The composition of asphalt shingles is shown in the Table below. Granules production is modeled as rock mining and grinding.

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[116] Crowe, J. P. “Steep-slope roof systems require different underlayment installations.” Professional Roofing (May 2005).

Table 3.53: Asphalt Shingle Constituents

Constituent	*Kg/m^2 (lb/square)**	*Mass Fraction*
Asphalt	2.7 (56)	20 %
Filler	5.9 (120)	43 %
Fiberglass Mat	0.7 (14)	5 %
Granules	3.4 (70)	25 %
Back surfacing (sand and talc)	1.0 (19.6)	7 %
Total	14 (280)	100 %

*One square is equivalent to 9.29 m^2 (100 ft^2)

Type-15 felt consists of asphalt and organic felt. The composition is shown in the following Table. The organic felt is assumed to consist of 50 % recycled cardboard and 50 % wood chips.

Table 3.54: Type 15 Felt Underlayment Constituents

Constituent	*Kg/m^2 (lb/square)**	*Mass Fraction*
Asphalt	0.3 (5.4)	45 %
Organic Felt	0.2 (4.8)	40 %
Limestone	0.06 (1.2)	10 %
Sand	0.03 (0.6)	5 %
Total	0.6 (12)	100 %

*One square is equivalent to 9.29 m^2 (100 ft^2)

Data for the production of underlayment materials and asphalt shingle constituents are from the SimaPro LCA database and U.S. LCI Database.

Manufacturing

Energy Requirements and Emissions. According to the Asphalt Roofing Manufacturers Association (ARMA), asphalt shingles are produced by nine manufacturers in about 22 states. Data on production and combustion of fuels for shingle manufacture is from the U.S. LCI Database.

Table 3.55: Energy Requirements for Asphalt Shingle Manufacturing

Energy Carrier	*MJ/m^2 (Btu/ft^2)*
Natural Gas	2.3 (202)
Electricity	0.89 (78)
Total	**3.19 (280)**

Emissions pertaining to manufacturing asphalt shingle roofing materials follow.[117]

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[117] Trumbore, D. et al. “Emission Factors for Asphalt-Related Emissions in Roofing Manufacturing.” Environmental Progress 24:3 (2005): 268-278.

Table 3.56: Asphalt Shingle Production Emissions

Air Emission	***Emission factor g/kg (lb/ton) asphalt***
Particulates (unspecified)	0.04 (0.08)
Sulfur oxides	0.45 (0.9)
Carbon monoxide	0.35 (0.7)
Nitrogen oxide	0.03 (0.06)
Total organic compounds	0.02 (0.04)

Transportation. Asphalt is assumed to be transported 402 km (250 mi) by truck, rail, and pipeline in equal proportions. Limestone, sand, talc, and granules are assumed to be transported by truck and rail, also over the same distance and in equal proportions. Fiberglass materials are assumed to be transported the same distance by truck.

Roofing underlayment raw materials are also assumed to be transported 402 km (250 mi). Asphalt is assumed to be transported by truck, train, and pipeline in equal proportions, while the cardboard and wood chips are assumed to be transported by truck.

Waste. Solid wastes generated during the manufacturing process that are not internally recycled within the process are sent off site to either be landfilled or incorporated into other products.

Transportation

Transportation of asphalt shingles by heavy-duty truck to the building site is modeled as a variable of the BEES system. Roofing underlayment and nails are assumed to be transported 161 km (100 mi) by truck to the building site.

Installation

In areas with normal wind conditions, four nails should be used to fasten each shingle, while six nails per shingle are recommended in high wind regions. Galvanized roofing nails should be used, with a minimum nominal shank diameter of 12 gauge, 0.267 cm (0.105 in), and a minimum head diameter of 0.953 cm (3/8 in).[118] At four nails per shingle, 320 nails per square are required to secure standard shingles (80 shingles/square), and 260 nails per square are required for metric shingles (65 shingles/square). Installation of one layer of Type-15 felt underlayment is assumed to require an additional 120 nails per square. The weight of 440 nails (for 80 standard shingles with underlayment) is 2.2 kg (4.9 lb) and the weight of nails for 65 metric shingles including underlayment is 1.9 kg (4.2 lb).

Installation of asphalt shingles is assumed to be done primarily by manual labor, so the installation phase in BEES is free of environmental burdens; however, equipment such as conveyors may be used to move the roofing materials from ground level to rooftop, and compressors may be used to operate nail guns used to install roofing materials. There were not enough data to quantify this aspect.

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[118] Asphalt Roofing Manufacturers Association (ARMA), *Asphalt Roofing Manufacturers Association (ARMA) Residential Asphalt Roofing Manual*, pages 20-23.

Installation waste from scrap is estimated at approximately 10 % of the installed weight. Installation scrap is generally landfilled, although some manufacturers offer an incentive for contractors to return scrap for recycling into shingles. Data were not available to quantify installation scrap recycling.

Use

At 20 years, new shingles are installed over the existing shingles. No additional underlayment is generally required, since the original roof covering left in place serves the same purpose as the underlayment.[119] At 40 years, the two layers of shingles and the original underlayment are removed before installing replacement shingles with underlayment.

It is important to consider solar reflectivity differences among roof coverings of different materials and colors when assessing the environmental and economic performance of roof covering alternatives. "Cool" roofs reflect and emit solar radiation well, and thus stay cooler in the sun than less reflective, less emissive materials. The cool temperature results in building-scale cooling energy savings ranging from 2 % to 60 %.[120] A much less significant rise in building heating energy costs also occurs. BEES accounts for solar reflectivity performance in computing energy-related LCA inventory flows and building energy costs over the 50-year use stage for roof covering products.

For roof coverings, thermal performance differences are separately assessed for 16 U.S. cities spread across a range of Sunbelt climate and fuel cost zones. When selecting roof covering alternatives for use in Sunbelt climates,[121] the BEES user chooses 1) the roof covering material and color, 2) the U.S. Sunbelt climate city closest to the building location, 3) the building type (new or existing), 4) its heating and cooling system (electric air-source heat pump or gas furnace/central air conditioning heating and cooling systems), and 5) its duct placement (uninsulated attic ducts or ducts in the conditioned space), so that thermal performance differences may be customized to these important contributors to building energy use. Energy use data provided to the National Institute of Standards and Technology by Lawrence Berkeley National Laboratory (and which LBL developed for the U.S. EPA Energy Star Roof Products program), tailored to these five parameters, are used to estimate 50-year heating and cooling requirements per functional unit of roof covering.[122] BEES environmental performance results account for the energy-related inventory flows resulting from these energy requirements (stored in USEENVIR.DBF), and BEES economic performance results account for the present value cost resulting from these energy requirements (stored in USEECON.DBF).

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[119] Ibid, p. 71.

[120] Memorandum from Sarah Bretz/Lawrence Berkeley National Laboratory to Barbara Lippiatt/National Institute of Standards and Technology, 12/18/98.

[121] In cold climates, the amount of roof insulation is more important to thermal performance than the color of the roof covering.

[122] LBL data were developed for BEES by LBL's Sarah Bretz, based on Konopacki and Akbari, *Simulated Impact of Roof Surface Solar Absorptance, Attic, and Duct Insulation on Cooling and Heating Energy Use in Single-Family New Residential Buildings*, LBNL-41834, Lawrence Berkeley National Laboratory, Berkeley, CA, 1998, and on Parker *et al.*, "Measured and Simulated Performance of Reflective Roofing Systems in Residential Building," *ASHRAE Transactions*, SF-98-6-2, Vol. 104, 1998, p. 1.

End of Life

When the two layers of shingles and underlayment are removed after 40 years, all materials (shingles, underlayment, and nails) are assumed to be disposed of in a landfill, and are modeled as such. However, there is a growing trend to recycle shingles into pavement products.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Trumbore, D. et al. "Emission Factors for Asphalt-Related Emissions in Roofing Manufacturing". *Environmental Progress* 24:3 (2005): 268-278.

Asphalt Roofing Manufacturers Association (ARMA), *Asphalt Roofing Manufacturers Association (ARMA) Residential Asphalt Roofing Manual* (Calverton, MD: Asphalt Roofing Manufacturers Association, 1997) pp. 17.

Crowe, J. P. "Steep-slope roof systems require different underlayment installations." *Professional Roofing* (May 2005) Found at http://www.professionalroofing.net/article.aspx?A_ID=640.

Industry Contacts

Russ Snyder, Vice President, Asphalt Roofing Manufacturers Association, December 2005 – February 2006

3.8.2 Generic Clay Tile

Clay tiles are manufactured from clay, shale, or similar naturally-occurring earthy substances and subjected to heat treatment at elevated temperatures (known as firing). The most commonly used clay tiles are the one-piece "S" mission tile and the two-piece mission tile. One-piece "S" tile accounts for about 60 % of the clay roof tile market. Red-colored tiles are still quite popular, although there is now a wide range of colors and blends available.

Roof coverings such as clay tile are evaluated in BEES on the basis of a functional unit of roof area covered: 1 square (9.29 m^2, or 100 ft^2). The weight of the one-piece "S" tile is 357 kg to 381 kg (788 lb to 840 lb) per square, with 75 to 100 pieces of tile per square. The two-piece mission tile weighs approximately 476 kg (1 050 lb) per square, with 150 pieces of tile (75 tops and 75 pans) per square.

Clay tiles are installed over a deck of wood sheathing, typically oriented strand board covered with underlayment, which is generally asphalt-impregnated organic felt. For roof pitches from 4:12 to 10:12, two layers of Type-30 felt are used, while roof pitches of greater than 10:12 use one layer of Type-30 felt.[123]

For the BEES system, a roof covering of red Spanish one-piece "S" clay tiles, one layer of Type II No. 30 roofing felt, and galvanized nails is studied. The weight of the clay tile is 381 kg (840

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[123] Crowe, J. P. "Steep-slope roof systems require different underlayment installations." Professional Roofing (May 2005).

lb) per square, with 75 to 100 pieces of tile per square. The detailed environmental performance data for this product may be viewed by opening the file B3011B.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

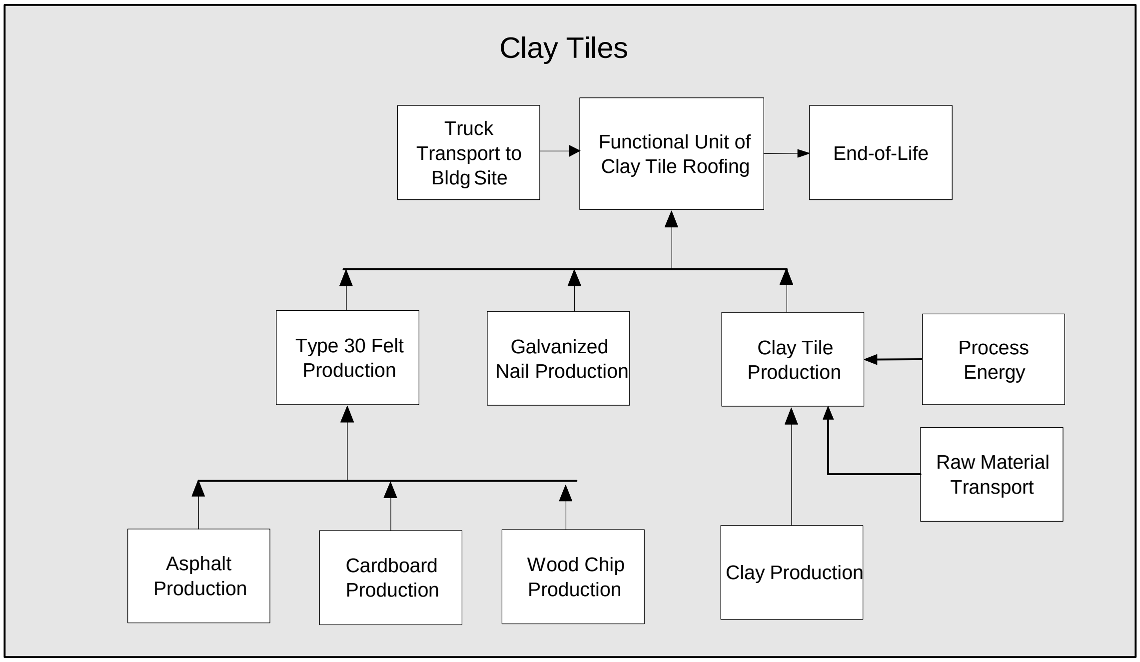

Figure 3.23: Clay Roof Tile System Boundaries

Raw Materials

The clay tile is composed of fired clay. Raw material sources are typically located relatively close to tile plants, so an 80 km (50 mi) transport distance is assumed in the model. For the underlayment, Type II No. 30 roofing felt is used, which consists of asphalt and organic felt in the quantities given in the Table below. The organic felt is assumed to consist of 50 % recycled cardboard and 50 % wood chips. The production of clay and felt materials is based on the SimaPro LCA database and U.S. LCI Database.

Table 3.57: Type-30 Roofing Felt Constituents

Constituent	*Kg/m^2 (lb/square)*[*]	*Mass Fraction*
Asphalt	0.57 (12)	45 %
Organic Felt	0.51 (10)	10 %
Limestone	0.13 (2.6)	5 %
Sand	0.06 (1.3)	40 %
Total	1.27 (25.9)	100 %

[*] One square is equivalent to 9.29 m^2 (100 ft^2)

Manufacturing

Energy Requirements and Emissions. In the United States, the top three (by market share) clay roofing tile manufacturers are located in Southern California, Northern California, and Ohio. All clay tile manufacturers use 100 % natural gas to fire the kilns; most plants, however, are at least partially automated and use the latest technology, which requires electricity. Natural gas and electricity use reported by one tile producer were 8.7 therms (873 390 Btu) of natural gas and 110 MJ (30.5 kWh) of electricity per 381 kg (840 lb) square of tile. No other production data was available; these values were taken as representative.

Table 3.58: Energy Requirements for Clay Tile Manufacturing

Energy Carrier	***MJ/kg (Btu/lb)***
Natural Gas	2.42(1040)
Electricity	0.29 (120)
Total	**2.7 (1160)**

Data on electricity generation and production and on combustion of natural gas are from the U.S. LCI Database.

Transportation. The clay raw material is assumed to be transported 80 km (50 mi) to the manufacturing plant, and to be evenly split between train and truck modes of transport. All components of roofing felt are assumed to be transported 402 km (250 mi). Asphalt is assumed to be transported by truck, train, and pipeline in equal proportions, while the cardboard and wood chips are assumed to be transported by truck.

Waste. Clay tile scrap or rejects that occur before the firing process are recycled back into the manufacturing process. After firing, any scrap or rejects are recycled by crushing for use on tennis courts, baseball fields, and other applications.

Transportation

Transportation of clay tile by heavy-duty truck to the building site is modeled as a variable of the BEES system. Roofing underlayment and nails are assumed to be transported 161 km (100 mi) by truck to the building site.

Installation

Rollers, conveyors, or cherry pickers are used to move the tile up to the roof; however, no data quantifying the associated energy use were available. Nailing of clay tiles is done by hand; nail guns are not used. Galvanized steel or copper nails can be used for installation; galvanized nails are cheaper and are more commonly used, so are assumed for the BEES analysis. For installation, one nail per tile is used for a roof pitch less than 7:12.[124] For roofs with a pitch greater than 7:12, two nails are required per tile, or 150 to 200 nails per square. In BEES, the tiles are assumed to be installed using one nail per tile.

Clay tile roofing requires at least one layer of Type II No. 30 felt, and one layer is assumed for

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[124] 7:12 pitch = 7 in rise per 12 in run.

the model. The underlayment uses 30 to 40 “roofing top” nails per square. Each galvanized steel nail is assumed to weigh 0.002 kg (0.004 lb). Installation waste from scrap is estimated at 2 % to 5 % of the installed weight.

Use

Clay roof tile has a long service life. Many clay roofs have been in existence for more than one hundred years. Clay tile generally does not need to be replaced; however, the underlayment may need replacement after 10 years to 15 years. When the underlayment is replaced, the roof tiles are typically reused. The tiles themselves are replaced after 70 years.

It is important to consider solar reflectivity differences among roof coverings of different materials and colors when assessing the environmental and economic performance of roof covering alternatives. “Cool” roofs reflect and emit solar radiation well, and thus stay cooler in the sun than less reflective, less emissive materials. The cool temperature results in building-scale cooling energy savings ranging from 2 % to 60 %.[125] A much less significant rise in building heating energy costs also occurs. BEES accounts for solar reflectivity performance in computing energy-related LCA inventory flows and building energy costs over the 50-year use stage for roof covering products.

For roof coverings, thermal performance differences are separately assessed for 16 U.S. cities spread across a range of Sunbelt climate and fuel cost zones. When selecting roof covering alternatives for use in Sunbelt climates,[126] the BEES user chooses 1) the roof covering material and color, 2) the U.S. Sunbelt climate city closest to the building location, 3) the building type (new or existing), 4) its heating and cooling system (electric air-source heat pump or gas furnace/central air conditioning heating and cooling systems), and 5) its duct placement (uninsulated attic ducts or ducts in the conditioned space), so that thermal performance differences may be customized to these important contributors to building energy use. Energy use data provided to the National Institute of Standards and Technology by Lawrence Berkeley National Laboratory (and which LBL developed for the U.S. EPA Energy Star Roof Products program), tailored to these five parameters, are used to estimate 50-year heating and cooling requirements per functional unit of roof covering.[127] BEES environmental performance results account for the energy-related inventory flows resulting from these energy requirements (stored in USEENVIR.DBF), and BEES economic performance results account for the present value cost resulting from these energy requirements (stored in USEECON.DBF).

End of Life

At end of life, clay tiles are recovered and re-used. Usually, clay tile removed for underlayment replacement is saved on a pallet for re-use on the same building. If the tile is not to be replaced

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[125] Memorandum from Sarah Bretz/Lawrence Berkeley National Laboratory to Barbara Lippiatt/National Institute of Standards and Technology, 12/18/98.

[126] In cold climates, the amount of roof insulation is more important to thermal performance than the color of the roof covering.

[127] LBL data were developed for BEES by LBL’s Sarah Bretz, based on Konopacki and Akbari, *Simulated Impact of Roof Surface Solar Absorptance, Attic, and Duct Insulation on Cooling and Heating Energy Use in Single-Family New Residential Buildings*, LBNL-41834, Lawrence Berkeley National Laboratory, Berkeley, CA, 1998, and on Parker *et al.*, “Measured and Simulated Performance of Reflective Roofing Systems in Residential Building,” *ASHRAE Transactions*, SF-98-6-2, Vol. 104, 1998, p. 1.

on the building, the roofer will use it on another building that specifies the same tile type and color. The trend today is that old clay tiles are in demand and are often considered more valuable than the newly produced clay tile. Recovered clay roofing tiles are offered by wholesalers to the public worldwide via the Internet, local advertising, and trade magazines. Regardless of condition, used clay tile is not thrown away. All clay tile can be 100 % re-used, re-sold, or crushed for use on tennis courts, baseball fields, and other applications.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Crowe, J. P. “Steep-slope roof systems require different underlayment installations.” *Professional Roofing* (May 2005).

Industry Contacts

Yoshi Suzuki, General Manager, MCA Superior Clay Roof Tile (February 2006)

3.8.3 Generic Fiber Cement Shingles

Fiber cement shingles are considered a synthetic equivalent to wood shingles. In general, these roofing materials can last longer that wood or asphalt products. In the past, fiber cement shingles were manufactured using asbestos fibers. Now asbestos fibers have been replaced with cellulose fibers.

Roof coverings such as fiber cement shingles are evaluated in BEES on the basis of a functional unit of roof area covered: 1 square (9.29 m^2, or 100 ft^2). For the BEES system, a 45-year fiber cement shingle consisting of portland cement, fly ash, silica fume, sand, and cellulose fibers is studied. The shingle size modeled is 36 cm x 76 cm x 0.4 cm (14 in x 30 in x 5/32 in). Type-30 roofing felt and galvanized nails are used for installation.

The detailed environmental performance data for this product may be viewed by opening the file B3011C.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

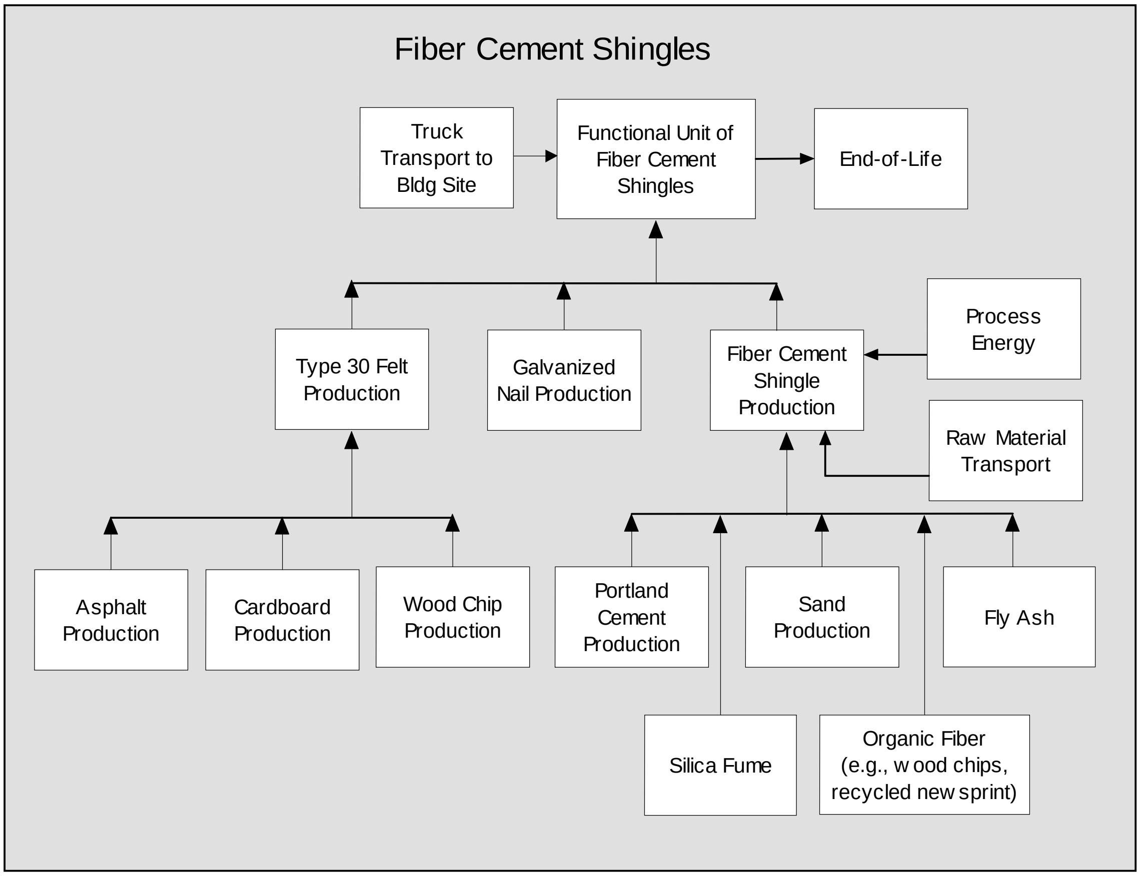

Figure 3.24: Fiber Cement Shingles System Boundaries

Raw Materials

Fiber cement shingles are composed primarily of portland cement, fly ash, organic fiber, and fillers. The relative proportions of these and other product constituents are provided in the following Table.

Table 3.59: Fiber Cement Shingle Constituents

Constituent	*Mass* kg/m^2 (lb/ft^2)	*Mass Fraction (%)*
Portland cement	6.35 (1.30)	40
Fly ash	5.27 (1.08)	33
Silica fume	1.29 (0.26)	8
Filler (sand)	1.61 (0.33)	10
Organic fiber (including wood chips, recycled newsprint)	1.29 (0.26)	8
Pigments (oxides)	0.11 (0.02)	1
Total	**15.93 (3.26)**	**100**

Production of portland cement is described under the Portland Cement Concrete Products documentation. Fly ash is a waste product from coal combustion in electric utility boilers, and silica fume is a waste product from the manufacture of silicon and ferrosilicon alloys. These waste products are assumed to be environmentally “free” input materials; however, transport of these materials to the shingle plant is included. Data for the production of other input materials is from the SimaPro LCA database and U.S. LCI Database.

Sources of organic fiber include wood chips and recycled newsprint. The amount of each is likely to vary by manufacturer; one manufacturer reports that recycled newsprint accounts for 3 % of the mass fraction of their product.

For the underlayment, Type II No. 30 roofing felt is used, which consists of asphalt and organic felt as listed in the Table below. The organic felt is assumed to consist of 50 % recycled cardboard and 50 % wood chips. The production of felt materials is based on the SimaPro LCA database and U.S. LCI Database.

Table 3.60: Type-30 Roofing Felt Constituents

Constituent	***Kg/m^2 (lb/square)****	***Mass Fraction***
Asphalt	0.57 (11.5)	45 %
Organic Felt	0.51 (10.4)	10 %
Limestone	0.13 (2.6)	5 %
Sand	0.06 (1.3)	40 %
Total	1.27 (25.9)	100 %

*One square is equivalent to 9.29 m^2 (100 ft^2)

Manufacturing

Energy Requirements and Emissions. Fiber cement is manufactured by blending the raw materials; the blend is then cured to produce shingles. Energy—of the types and amounts given below—is required for blending and for curing of the final product. Data on production and combustion of fuels, including electricity generation, is from the U.S. LCI Database.

Table 3.61: Energy Requirements for Fiber Shingle Manufacturing

Energy Carrier	***MJ/kg (Btu/lb)***
Natural Gas	2.08 (894)
Electricity	0.69 (297)
Total	**2.77 (1 191)**

Transportation. Most shingle raw materials are assumed to be transported to the manufacturing plant 402 km (250 mi) by truck. A small percentage, assumed to be approximately 2 %, of the shingle material inputs may be transported more then 3 219 km (2 000 mi); due to economic constraints, it is assumed that these products are transported by rail rather than by truck. Roofing felt raw materials are also assumed to be transported 402 km (250 mi) by truck.

Waste. No data were available on types and quantities of solid wastes generated from the shingle manufacturing process; no waste was assumed to be generated.

Transportation

Transportation of fiber cement shingles by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

Installation of fiber cement shingles is assumed to be primarily a manual process, however, equipment such as conveyors may be used to move the roofing materials from ground level to rooftop, and compressors may be used to operate nail guns used to install roofing materials. The energy and emissions from the potential use of equipment and tools is not included within the system boundaries of the BEES model.

The mass of fiber cement shingles is assumed to be 16 kg/m^2 (325 lb/square), based on 36 cm x 76 cm x 0.4 cm (14 in x 30 in x 5/32 in) size shingles. One layer of Type-30 felt underlayment is used under the shingles. To install the shingles and underlayment, 13 galvanized steel nails per m^2 (120 nails per square) are assumed to be used for the underlayment, and 32 nails per m^2 (300 nails per square) are used for the shingles. Each galvanized steel nail is assumed to weigh 0.002 kg (0.004 lb). Installation scrap is estimated at 5 % of the installed weight and is assumed to be landfilled.

Use

The product is assumed to have a useful life of 45 years. At replacement, it is assumed that a new layer of felt is applied beneath the new shingles.

It is important to consider solar reflectivity differences among roof coverings of different materials and colors when assessing the environmental and economic performance of roof covering alternatives. "Cool" roofs reflect and emit solar radiation well, and thus stay cooler in the sun than less reflective, less emissive materials. The cool temperature results in building-scale cooling energy savings ranging from 2 % to 60 %.[128] A much less significant rise in building heating energy costs also occurs. BEES accounts for solar reflectivity performance in computing energy-related LCA inventory flows and building energy costs over the 50-year use stage for roof covering products.

For roof coverings, thermal performance differences are separately assessed for 16 U.S. cities spread across a range of Sunbelt climate and fuel cost zones. When selecting roof covering alternatives for use in Sunbelt climates,[129] the BEES user chooses 1) the roof covering material and color, 2) the U.S. Sunbelt climate city closest to the building location, 3) the building type (new or existing), 4) its heating and cooling system (electric air-source heat pump or gas furnace/central air conditioning heating and cooling systems), and 5) its duct placement (uninsulated attic ducts or ducts in the conditioned space), so that thermal performance

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[128] Memorandum from Sarah Bretz/Lawrence Berkeley National Laboratory to Barbara Lippiatt/National Institute of Standards and Technology, 12/18/98.

[129] In cold climates, the amount of roof insulation is more important to thermal performance than the color of the roof covering.

differences may be customized to these important contributors to building energy use. Energy use data provided to the National Institute of Standards and Technology by Lawrence Berkeley National Laboratory (and which LBL developed for the U.S. EPA Energy Star Roof Products program), tailored to these five parameters, are used to estimate 50-year heating and cooling requirements per functional unit of roof covering.[130] BEES environmental performance results account for the energy-related inventory flows resulting from these energy requirements (stored in USEENVIR.DBF), and BEES economic performance results account for the present value cost resulting from these energy requirements (stored in USEECON.DBF).

End of Life

When the shingles and underlayment are removed after 45 years, all materials (shingles, underlayment, nails) are assumed to be disposed of in a landfill, and are modeled as such.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Industry Contacts

Martha VanGeem, P.E., Construction Technology Laboratories, Inc. (on behalf of the Portland Cement Association), August-October 2005

Medgar Marceau, P.E., Construction Technology Laboratories, Inc. (on behalf of the Portland Cement Association), August-October 2005.

3.9 Roof Coatings

3.9.1 Prime Coatings Utilithane

Utilithane 1600, according to its manufacturer Prime Coatings, Inc., is a tough, flexible, abrasion and chemical resistant polyurethane used as a protective coating and liner for a broad spectrum of applications including concrete and steel substrates and roofs. Utilithane contains no solvents and meets all VOC regulations.[131]

Utilithane is a two-component system in which 2 parts of resin are mixed with 1 part activator, and is spray applied using plural component airless spray equipment. The product can be applied from 0.5 mm (20 mils) to 12.7 mm (500 mils) or more in thickness during a single application. Ultimate thickness specifications vary for each application depending on intended use and material applied. The application modeled for BEES is a Utilithane roof coating with an

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[130] LBL data were developed for BEES by LBL's Sarah Bretz, based on Konopacki and Akbari, *Simulated Impact of Roof Surface Solar Absorptance, Attic, and Duct Insulation on Cooling and Heating Energy Use in Single-Family New Residential Buildings*, LBNL-41834, Lawrence Berkeley National Laboratory, Berkeley, CA, 1998, and on Parker *et al.*, "Measured and Simulated Performance of Reflective Roofing Systems in Residential Building," *ASHRAE Transactions*, SF-98-6-2, Vol. 104, 1998, p. 1.

[131] See www.utilithane.com.

average applied thickness of 2.54 mm (100 mils).

The functional unit for Utilithane is 1 ft^2 of roof protection. Its density is 4.20 kg (9.25 lb) per gal and its coverage is approximately 148.6 m^2 (1 600 ft^2) per gal at one mil thickness. At this density and coverage rate, 0.26 kg (0.58 lb) of Utilithane are needed per ft^2.

The detailed environmental performance data for this product may be viewed by opening the file B3013A.DBF under the File/Open menu item in the BEES software.

Flow Diagram

This manufacturer considers this information confidential.

Raw Materials

This manufacturer considers this information confidential.

Manufacturing

Energy Requirements. Manufacturing involves electricity use for heating and mixing components. Prime Coatings provided data on the mixing vessel, times, and temperatures of mixing, and capacity of operation. The following energy requirements were modeled based on these parameters:

Table 3.62: Prime Coatings Utilithane Manufacturing Energy

Energy Carrier	***kWh/ ft^2***
Electricity	0.001
Natural gas	0.014

No air emissions data (except for those related to energy use) are available. Electricity and natural gas use in a boiler are modeled based on the U.S. LCI Database.

Transportation. The resin components of the product are transported an average of 161 km (100 mi) to the manufacturing facility and the activator is transported 805 km (500 mi). Materials are transported by diesel truck, which is modeled based on the U.S. LCI Database.

Transportation

Both the resin compound and activator are transported 1287 km (800 mi) to the site of installation in 55 gal drums or 250 gal totes. Diesel truck is the mode of transport, and its environmental burdens are modeled based on the U.S. LCI Database.

Installation and Use

Installation of Utilithane requires the use of a compressor to mix and spray the product and a small electric heater to heat the product prior to application. Based on the manufacturer’s data, the following installation energy requirements are modeled.

Table 3.63: Prime Coatings Utilithane Installation Energy

Energy Carrier	*kWh/ ft^2*
Electricity	0.004
Diesel fuel	0.04

End of Life

Utilithane has a useful life of over 50 years. At the end of its life, it is assumed to be disposed of in a landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Sheehan, J. et al., *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus,* NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

Industry Contacts

Steve Crandal, Prime Coatings (2004)

3.10 Partitions

3.10.1 Generic Gypsum

Gypsum board, also known as “drywall” or “plaster board,” consists of a core of gypsum surrounded with a paper covering. Several varieties of gypsum board products are available; each is comprised of a specially formulated gypsum plaster mix and facing paper specifically developed for the intended application. These gypsum board products include regular gypsum wallboard, moisture-resistant gypsum board, and type-X fire-resistant gypsum board.

For the BEES system, 0.9 m^2 (1 ft^2) of 13 mm (½ in) gypsum wallboard, joint tape, joint treatment compound, and wallboard nails are studied. The bulk density of wallboard is assumed to be 769 kg/m^3 (48 lb/ft^3). Gypsum wallboard is assumed to be nailed to wood studs, 41 cm (16 in) on center.

The detailed environmental performance data for this product may be viewed by opening the file C1011A.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

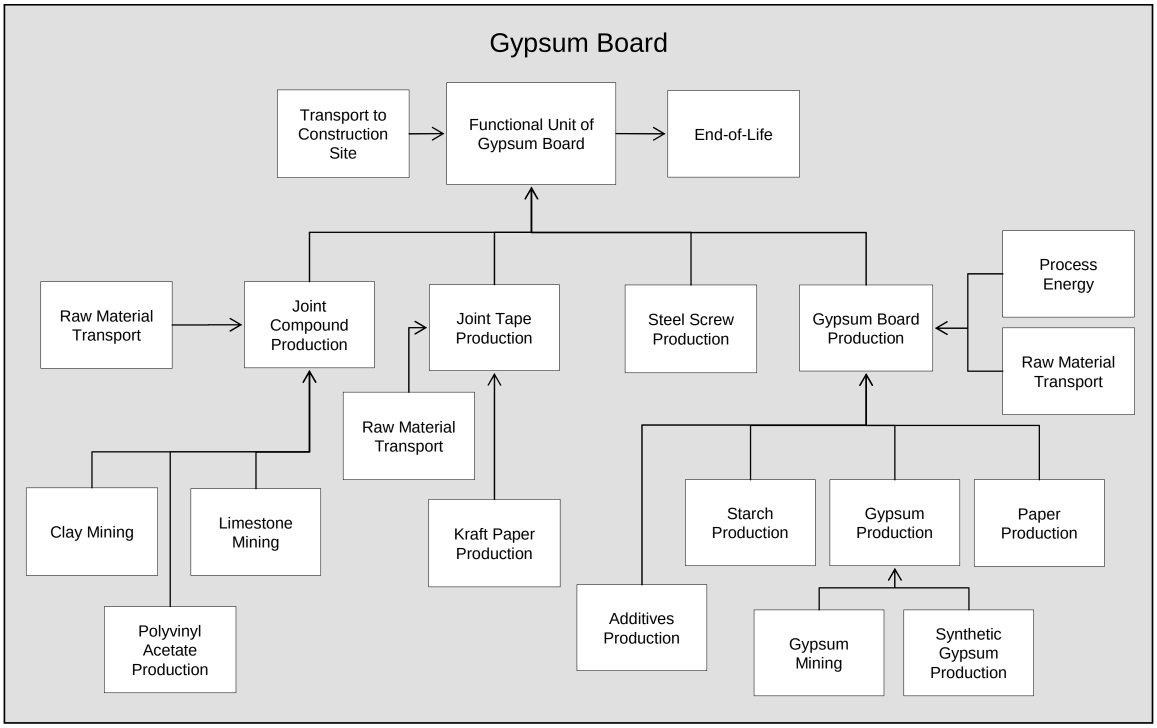

Figure 3.25: Gypsum Board System Boundaries

Raw Materials

Drywall primarily consists of gypsum that is mixed with additives and backed on both sides with kraft paper. The following Table shows the proportions of materials used in producing drywall.

Table 3.64: Gypsum Board Constituents

Constituent	*Kg/m^2 (lb/ft^2)*	*Mass Fraction*
Gypsum	8.326 (1.705)	85 %
Paper	0.981 (0.201)	10 %
Additives	0.294 (0.060)	3 %
Starch	0.196 (0.040)	2 %
Total	9.796 (2.006)	100 %

Data for the production of each of these raw materials comes from both the U.S. LCI Database and SimaPro.

Manufacturing

Energy Requirements and Emissions. Gypsum board is produced using partially dehydrated or calcinated gypsum. The gypsum is fed into a mixer where it is combined with water and other ingredients to form a slurry or paste. The slurry is spread onto a moving belt of face paper and then covered with a backing paper. As the materials move down the production line, the edges of the face paper are folded over the backing paper to create one of several edge types. The board then progresses down the production line where it is cut into specific lengths. The individual boards are subsequently run through dryers. Once dry, the wallboard moves further down the line where it is trimmed to an exact length, paired with another board, bound on both ends with a labeling tape, and stacked in a bundle. The bundles are taken into the warehouse, where they are selected for shipment to either distributors or building sites.

The energy requirement for manufacturing is essentially natural gas used for the drying process - the specific amount of natural gas consumed is provided in the following Table.

Table 3.65: Energy Requirements for Gypsum Board

Energy Carrier	*MJ/kg (Btu/lb)*
Natural Gas	19.02 (8 196)

Emissions from the production of gypsum are included in the product data for the raw materials acquisition life-cycle stage. Emissions from manufacturing are based on U.S. EPA AP-42 emissions factors for gypsum processing. These emissions consist primarily of particulate emissions (known as PM-10) during the cutting and sawing stage in the plant. Only the PM-10 emissions are included in the manufacturing life-cycle stage data.

Table 3.66: Emissions from Gypsum Board Manufacturing

Emissions	*kg/m^2 (g/ft^2)*
PM-10	0.000027 (0.00251)
Filterable Particulates	0.000036 (0.00334)

Transportation. The transportation of the gypsum, starch, and additives to the gypsum board facility is taken into account, and assumed to require 80 km (50 mi) by truck. The paper used to back the gypsum board is assumed to be shipped in rolls 402 km (250 mi) by truck to the plant.

Waste. Approximately 2.25 % of the gypsum board produced is lost as waste during the manufacturing process.

Transportation

Transportation of gypsum board by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

Gypsum board may be attached to wood framing, cold-formed steel framing, or existing surfaces using nails, staples, screws, and adhesives appropriate for the application. Joints between gypsum boards may be sealed or finished using paper or glass fiber mesh and one or more layers of joint treatment compound. Joint treatment compound is available in ready-mixed or dry powder form. The ready mixed variety is usually a vinyl-based, ready-to-use product that contains limestone to provide body. Clay, mica, talc, or perlite are often used as fillers. Ethylene glycol is used as an extender, and antibacterial and anti-fungal agents are also included. The dry powder form of joint treatment compound is available in normal drying (dries primarily by evaporation) and accelerated setting (chemically setting) formulations.

Approximately 2.04 kg (4.5 lb) of wallboard nails are used for each 92.90 m^2 (1 000 ft^2) of wallboard.[132] Joints are assumed to be treated with 52 mm-wide (2-1/16 in-wide) paper joint tape and ready-mixed, all-purpose joint treatment compound. Approximately 62.6 kg (138 lb) of joint compound are assumed to be used for every 92.90 m^2 (1 000 ft^2) of wallboard.[133] About 12 % of the installation materials are assumed to go to waste, all of which is disposed of in a landfill.

Use

Gypsum board is assumed to have a useful life of 75 years, provided it is well maintained and protected. There are no emissions from the use of gypsum board and repairs required to patch holes or tears are not included in the product system boundaries.

End of Life

While there is some recovery of gypsum board at end of life, most of the material is disposed of in a landfill. No recycling is included in the system boundaries.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

USG Corporation, *The Gypsum Construction Handbook.* (Chicago, IL: USG Corporation, 2000). Found at http://www.usg.com/resources/handbooks/ViewGCH.do.

Industry Contacts

Michael Gardiner, Gypsum Association (Nov 2005 – Jan 2006)

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[132] USG Corporation, *The Gypsum Construction Handbook*. (Chicago, IL: USG Corporation, 2000).

[133] *Ibid.*

3.10.2 Trespa Virtuon and Athlon Panels

See documentation on all Trespa composite panels under Fabricated Toilet Partitions.

3.10.3 P&M Plastics Altree Panels

Altree panels, manufactured by P&M Plastics, Inc., are biobased composite panels composed of wood fiber from invasive tree species, or of scrub and plastic from recycled milk bottles. According to the manufacturer, the encapsulation of plastic in the product makes Altree less susceptible than other types of wood composite boards to thickness swelling when exposed to high humidity or water. The plastic also reduces the opportunity for decay from fungus, mold, and mildew and aids in resistance to termites and other insects, rodents, and parasites.

Altree panels are used in a variety of exterior and interior applications. For BEES, Altree panels are found in the Partitions product category.

The detailed environmental performance data for this product may be viewed by opening the file C1011D.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

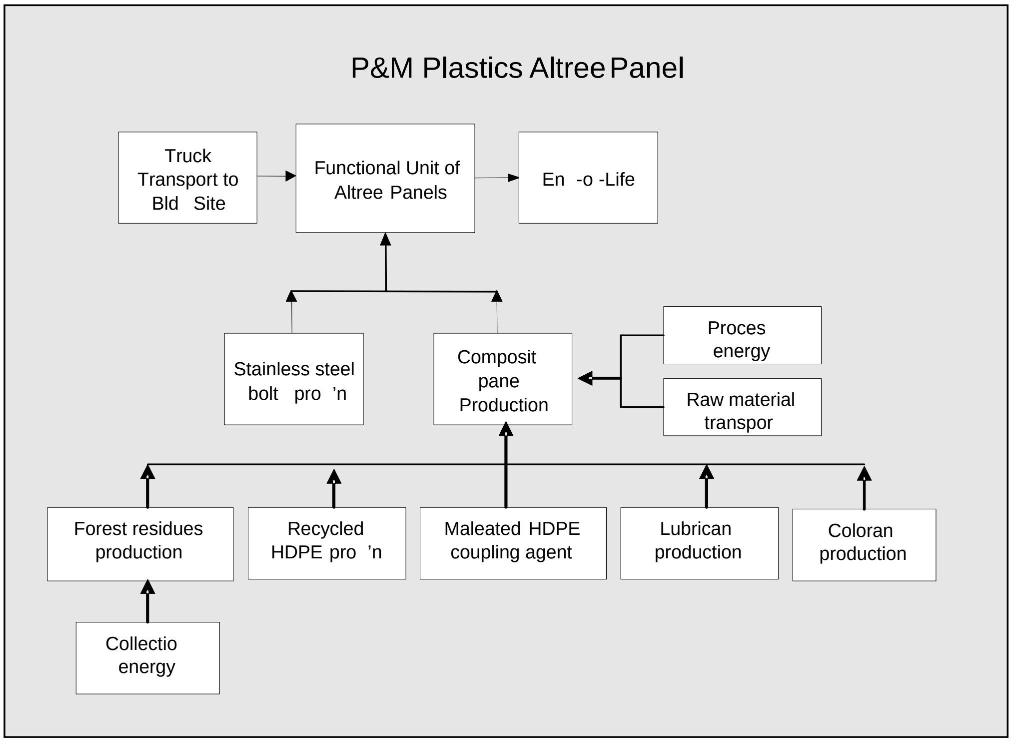

Figure 3.25a: P&M Plastics Altree Panel System Boundaries

Raw Materials

Altree panels are comprised of the materials given in the table below.

Table 3.66a: P&M Plastics Altree Panel Constituents

Constituent	*Mass Fraction (%)*
Woody forest residues	38.3
Recycled HDPE	57.3
Maleated HDPE coupling agent	2.2
Surfactant with lubricant	2.2
Colorant	0.6

Altree panels consist of wood fiber from invasive species, which is taken whole (and includes needles, branches, bark, and small and large woody stems) or in chips at the acquisition site. Because the wood used is either residuals from the forest or shrubs with no other use or value, and no planting has been done, the modeling of this input takes into account only the fuel used to collect the material.

The modeling of recycled high density polyethylene (HDPE) is based on the energy to produce clean flakes from milk jugs, and is calculated from an industry report to be 0.22 kWh/kg (0.36 MJ/lb) produced. Electricity is based on the U.S average grid mix and data is based on the U.S. LCI Database.

The maleated HDPE coupling agent is assumed to be a combination of maleic anhydride and virgin HDPE. Most of the data for maleic anhydride comes from a chemical process report produced for the U.S. Department of Energy. HDPE data comes from the U.S. LCI Database. For lack of other data on the specific lubricating surfactant used in Altree panels, it is modeled as linear alkylbenzene sulphonate (LAS) based on its anionic surfactant properties. Data for LAS comes from a European life-cycle inventory containing late 1990s data on European detergent production. The colorant is excluded because its exact composition is unknown and it only accounts for 0.6 % of the mass of raw materials.

Manufacturing

Energy Requirements and Emissions. At manufacturing, the forest residue is ground to a fine fibrous state. This and the other raw materials are compounded or fed and blended into the molten polymer. The compounded material is then pressed or shaped into an end product. These process stages require purchased electricity and natural gas in a boiler in the following amounts.

Table 3.66b: P&M Plastics Altree Panel Energy Requirements

Energy Carrier	*Quantity per kg Altree panel*
Electricity[134]	4.3 MJ (1.2 kWh)
Natural gas[135]	0.43 MJ (0.12 kWh)

In addition to energy, 0.061 L (0.016 gal) of cooling water is used per kg of product. No data are

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[134] This figure is based on a purchased electricity rate of 5 MW of total yearly production and the estimated operating time, as provided by the manufacturer.

[135] This figure is based on total ft^3 of natural gas purchased and total yearly production, as provided by the manufacturer.

available on particulates resulting from the grinding process.

Transportation. Data for the transportation of raw materials from the supplier to the manufacturer is provided by P&M Plastics, with diesel truck as the mode of transportation. Diesel trucking is modeled based on the U.S. LCI Database.

Transportation

Diesel truck and rail are the modes of Altree panel transport from manufacturing to use, with the average distance traveled being 402 km (250 mi), shared equally by truck and rail. Both modes of transport are modeled based on the U.S. LCI Database.

Use

Altree is assumed to be installed using an average of 0.0023 kg (0.0051 lb) of stainless steel bolts for each 0.09 m^2 (1 ft^2) of panel. The production of steel comes from the U.S. LCI Database. Approximately 3 % of the panel is lost to waste during the installation process from cutting the panels to fit the installation area.

End of Life

Altree is assumed to have a lifetime of 50 years. After year 50, the panel is removed and is modeled as being recycled, or reused, 20 % of the time and landfilled 80 % of the time.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Climenhage, David, *Recycled Plastic Lumber* (Ontario, Canada, Environment and Plastics Industry Council and Corporations Supporting Recycling, January 2003), p. 34. Found at: http://www.cpia.ca/epic/

BRIDGES to Sustainability, *A Pilot Study of Energy Performance Levels for the U.S. Chemical Industry*, Contract # DE-AC05-00OR22725 (Oak Ridge, TN, U.S. Department of Energy, June 2001).

Dall'Acqua, S., et al., *Life Cycle Inventories for the Production of Detergent Ingredients*, Report #244 (St. Gallen: EMPA, 1999).

Industry Contacts

John Youngquist, P&M Plastics, Inc. (November 2004)

3.11 Fabricated Toilet Partitions, Lockers, Ceiling Finishes, Fixed Casework, Table Tops/Counter Tops/Shelving

3.11.1 Trespa Composite Panels

Based in The Netherlands, Trespa International BV is the world's largest manufacturer of solid composite panels. Trespa entered the U.S. market in 1991, and now produces millions of ft^2 of sheet material annually. Trespa North America's products offer an alternative to thin laminate and epoxy-resin products. Each of Trespa's four composite panel lines has been designed for a particular use:

1. Athlon, a panel developed for a wide range of interior applications including durable fittings;
2. Meteon, a panel developed for exterior applications such as such as facade cladding, roof edgings, canopies & street furniture;
3. TopLab*PLUS*, a panel that is highly resistant to chemicals and designed for laboratory work surface areas; and
4. Virtuon, an interior panel system that is impact, moisture, and stain resistant, thus suggested for applications in public areas and areas where cleanliness is very important.

In October 2005, the GREENGUARD Environmental Institute awarded GREENGUARD Indoor Air Quality Certification to Trespa's Athlon, Virtuon, and TopLab*PLUS* panels, which were tested for chemical emissions performance under the GREENGUARD Standard for Low Emitting Products.[136] According to GREENGUARD, these panels can be specified with the confidence that they will not impact the indoor air.[137]

For the BEES system, the functional unit for composite panels, regardless of application, is 0.09 m^2 (1 ft^2) of panel.

The detailed environmental performance data for these products may be viewed by opening the following files under the File/Open menu item in the BEES software:

- C3030B.DBF—Athlon
- B2011F.DBF—Meteon
- E2021A.DBF— TopLab*PLUS*
- C3030A.DBF—Virtuon

Flow Diagram

The flow diagram below shows the major elements of the production of these products, as they are currently modeled for BEES.

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[136] GREENGUARD Environmental Institute, "Trespa phenolic panels earn GREENGUARD Indoor Air Quality certification," (Atlanta, Georgia, October 2005).

[137] Ibid.

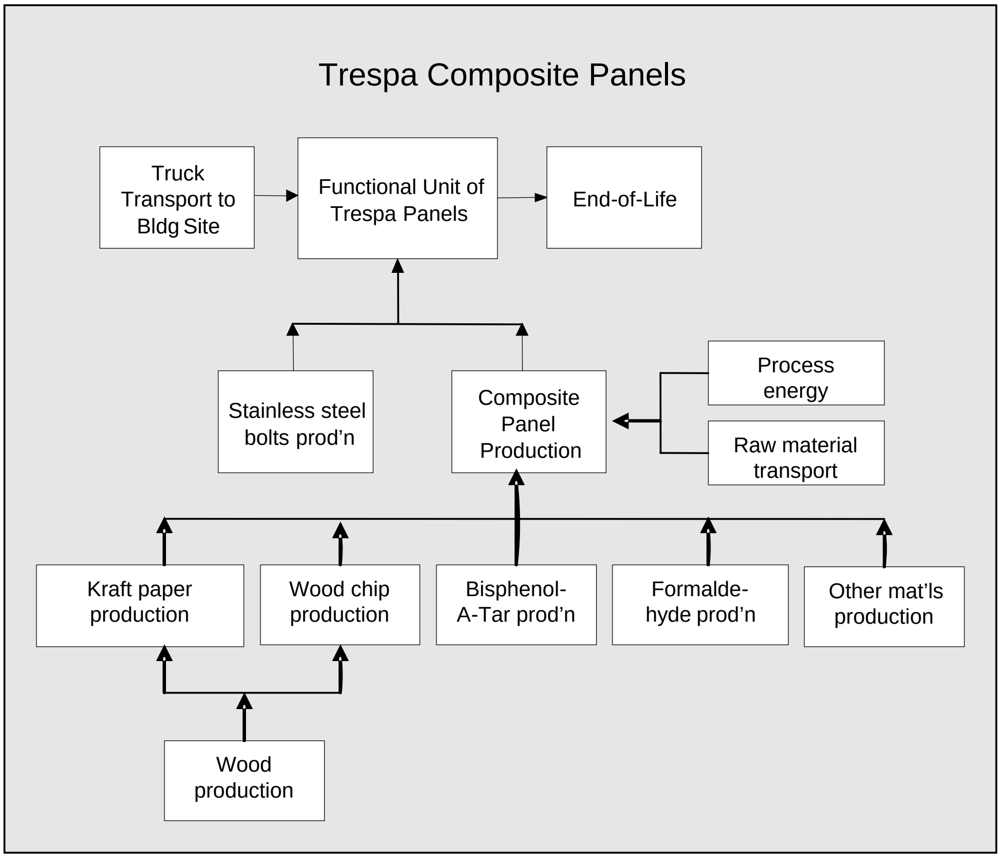

Figure 3.26: Trespa Composite Panels System Boundaries

Raw Materials

All Trespa panels are made in the same way – with an interior core material and a layer of decorative facing on both sides. The core and facing materials come from different sources for different applications, so the overall mix of raw material inputs is different for each product as shown in the Table below.

Table 3.67: Trespa Composite Panel Constituents by Mass Fraction

Constituent	*Athlon*	*Meteon*	*TopLabPLUS*	*Virtuon*
Kraft paper (recycled)	52 %	17 %	17 %	44 %
Wood chips	0 %	38 %	38 %	0 %
Bisphenol-A-Tar	18 %	17 %	17 %	15 %
Formaldehyde	28 %	28 %	28 %	24 %
Other Materials	2 %	0 %	0 %	18 %

The kraft paper used in the panels is recycled, so no raw material inputs for this product constituent are modeled, with the exception of its transport to the manufacturing site. Wood chips come from pine. Pine wood chip production is a coproduct of timber production, whose BEES model includes raising pine seedlings, planting, fertilizer, and harvesting. Energy use and other life cycle data for southern pine tree production and harvesting in the Southeastern United States are based on CORRIM data,[138] which is also found in the U.S. LCI Database.

Bisphenol-A-Tar is used as a binder in the panels. Tar is a co-product of Bisphenol A production, so a portion of the production burdens of Bisphenol A are allocated to the production of the tar. Formaldehyde is also used as a binder in the panels, and is assigned the same upstream production data as that for other BEES products with formaldehyde. BEES data for formaldehyde, Bisphenol A, and the other materials in the Trespa products are derived from the contents of the SimaPro database.

Manufacturing

Energy Requirements and Emissions. Trespa composite panel manufacturing consists of bonding the core panel and the two decorative panels. The manufacturing process requires natural gas, diesel oil, and electricity as energy inputs. To produce one square meter of panel, Trespa uses 2.6 kWh (9.4 MJ) of electricity, 23.4 kWh (84.4 MJ) of natural gas, and 0.17 kWh (0.6 MJ) of diesel oil. All energy data, including electricity, diesel equipment, and natural gas use in boilers are modeled using the U.S. average electric grid from the U.S. LCI Database.

Transportation. Data for the transport of raw materials from the supplier to the manufacturer are provided by Trespa, with diesel truck as the mode of transportation. Diesel trucking is modeled based on the U.S. LCI Database.

Transportation

Trespa panels are shipped from the production facility in The Netherlands to a U.S. port – a distance that is modeled as 10 000 km (6 214 mi) by sea. The transportation emissions allocated to each of the four Trespa panel products are based on the overall mass of the product, as given in the Table below. Transportation from the U.S. port of entry to the building site, by diesel truck, is modeled as a variable in BEES.

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[138] Bowyer, J., et. al., Phase I Final Report: Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction. (Seattle, WA: Consortium for Research on Renewable Industrial Materials--CORRIM, Inc./University of Washington, 2004) Found at http://www.corrim.org/reports.

Table 3.68: Trespa Composite Panel Density

Product	*Mass per Applied Area kg/m^2 (lb/ft^2)*	*Density kg/m^3 (lb/ft^3)*
All products (10 mm or 0.39 in thickness)	14 (2.9)	1 400 (87.40)

Diesel trucking and transportation via ocean freighter are modeled based on the U.S. LCI Database.

Installation and Use

Trespa panels are installed using stainless steel bolts. On average, 0.025 kg (0.055 lb) of stainless steel bolts are required to install 1 m^2 (11 ft^2) of composite panel. Approximately 3 % of the panel is lost as waste during the installation process due to scrap from cutting the panels to fit the installation area.

End of Life

Trespa panels are assumed to have a lifetime of 50 years. After year 50, the panels are removed and about 50 % of the waste is reused in other products, while the remaining 50 % is sent to a landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

GREENGUARD Environmental Institute, “Trespa phenolic panels earn GREENGUARD Indoor Air Quality certification,” (Atlanta, Georgia, October 2005).

Bowyer, J., et. al., Phase I Final Report: Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction. (Seattle, WA: Consortium for Research on Renewable Industrial Materials--CORRIM, Inc./University of Washington, 2004) Found at http://www.corrim.org/reports.

3.12 Wall Finishes to Interior Walls

3.12.1 Generic Latex Paint Products

Conventional paints are generally classified into two basic categories: water-based (in which the solvent is water) and oil-based (in which the solvent is an organic liquid, usually derived from petrochemicals). Oil-based paints are sometimes referred to as solvent-based. Paints essentially consist of a resin or binder, pigments, and a carrier in which these are dissolved or suspended. Once the paint is applied to a surface, the carrier evaporates, leaving behind a solid coating. In oil-based paints the carrier is a solvent consisting of volatile organic compounds (VOC), which can adversely affect indoor air quality and the environment. As a result, government regulations and consumer demand are forcing continuing changes in paint formulations. These changes have led to formulations containing more paint solids and less solvent, and a shift away from oil-based paints to waterborne or latex paints.

BEES considers three neutral-colored, latex-based paint alternatives for interior use: virgin latex paint plus two types of latex paint that contain leftover household paint, or post-consumer (PC) paint--consolidated and reprocessed. Because they do not use solvents as the primary carrier, latex paints emit far fewer volatile organic compounds (VOC) upon application. They also do not require solvents for cleaning of the tools and equipment after use. Water with a coalescing agent is the carrier for latex paints. The coalescing agent is typically a glycol or glycol ether. The binder is synthetic latex made from polyvinyl acetate and/or acrylic polymers and copolymers. Titanium dioxide is the primary pigment used to impart hiding properties in white or light-colored paints. A range of pigment extenders may be added. Other additives include surfactants, defoamers, preservatives, and fungicides.

Consolidated paint facilities are often located at or near county or city recycling and Household Hazardous Waste (HHW) facilities. These facilities generally have relatively small-scale operations in which paint meeting a certain quality is blended and repackaged and sold or given away to the public. In larger consolidating operations, some virgin materials are added to the paint. Reprocessed paint is generally produced in a larger-scale facility and varies by producer and PC paint content; reprocessed paint can contain 50 % to over 90 % PC paint.

The three latex paint alternatives are applied the same way. The surface to be painted is first primed and then painted with two coats of paint. One coat of paint is then applied every 4 years. In reality, the three paint options vary in quality, but for BEES they are assumed to be of the same quality, with one gal covering 37.2 m^2 (400 ft^2).

The detailed environmental performance data for these products may be viewed by opening the following files under the File/Open menu item in the BEES software:

- C3012A.DBF—Virgin Latex Paint
- C3012B.DBF—Consolidated Latex Paint
- C3012C.DBF—Reprocessed Latex Paint

Flow Diagram

The flow diagram shown below shows the major elements of the production of these products as they are currently modeled for BEES.

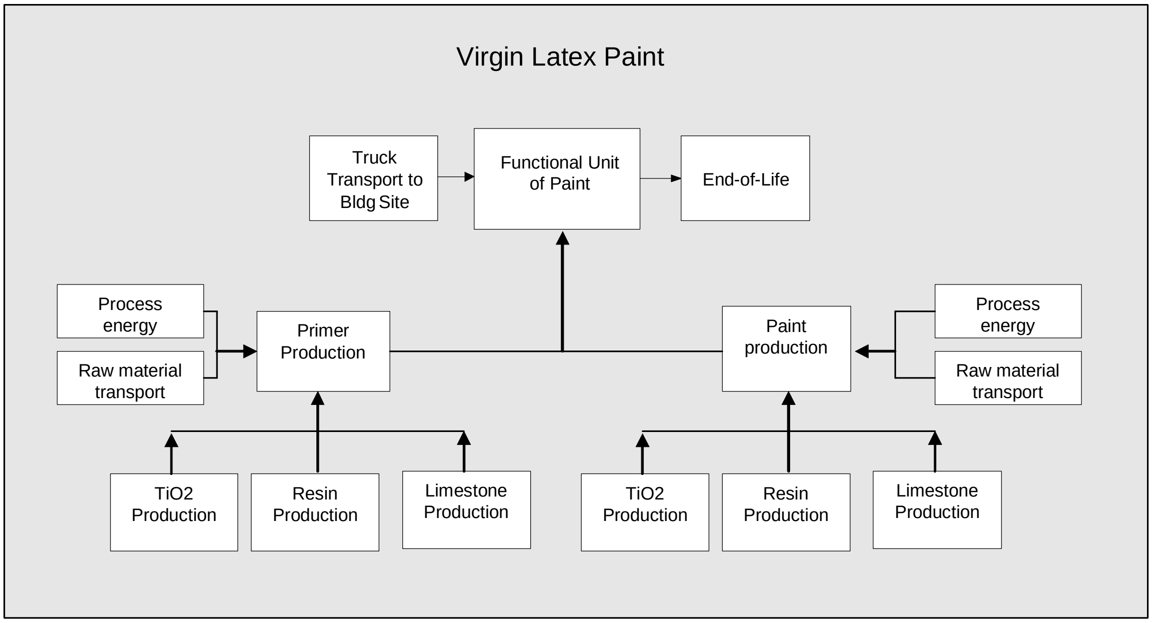

Figure 3.27: Virgin Interior Latex Paint System Boundaries

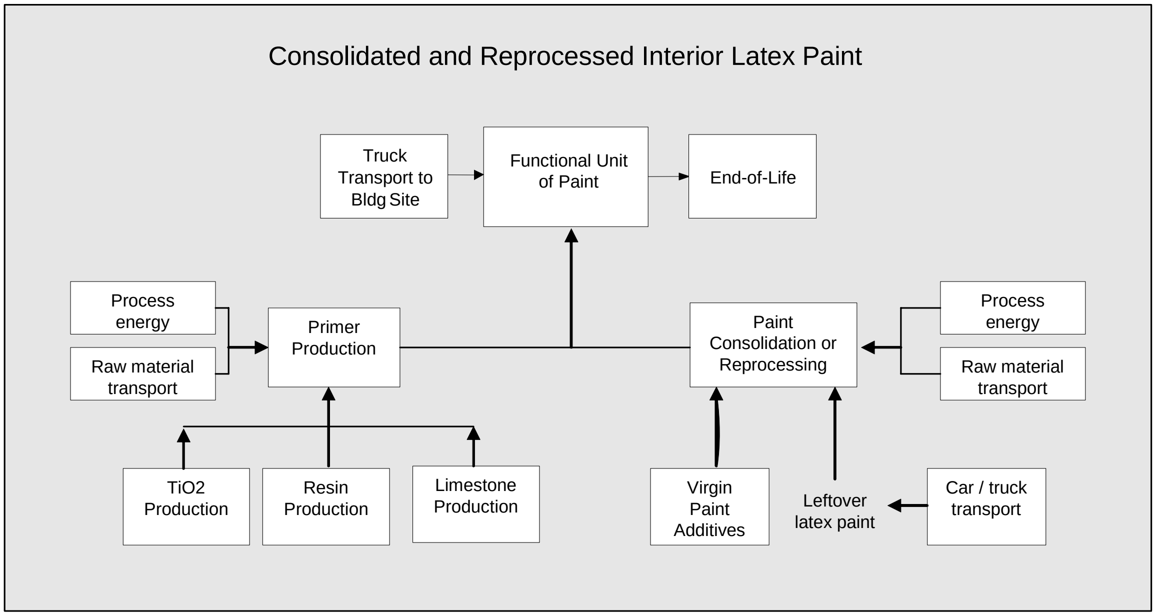

Figure 3.28: Consolidated and Reprocessed Interior Latex Paint System Boundaries

Raw Materials

Virgin latex paint. The major virgin latex paint constituents are resins (binder), titanium dioxide (pigment), limestone (extender), and water (thinner), which are mixed together until they form an emulsion. The average composition of the virgin latex paint/primer system modeled in BEES is listed in the Table below.

Table 3.69: Virgin Latex Paint Constituents

Constituent	*Paint Mass Fraction (%)*	*Primer Mass Fraction (%)*
Resin	25	25
Titanium dioxide	12.5	7.5
Limestone	12.5	7.5
Water	50	60

The data for titanium dioxide is 1990s European production data from the SimaPro database. Limestone data comes from the U.S. LCI Database. The Table below displays the market shares for the resins used for interior latex paint and primer as well as the components of each type of resin as they are modeled in BEES. The production of the monomers used in the resins is based on elements of the SimaPro database.

Table 3.70: Latex Paint Resin Constituents

Resin Type	*Market Share (%)*	*Constituents*	*Mass Fraction (%)*
Vinyl Acrylic	25	Vinyl Acetate	80 to 95
		Butyl Acrylate	5 to 20
Polyvinyl Acrylic	12.5	Polyvinyl Acrylic	100
Styrene Acrylic	12.5	Styrene	50
		Butyl Acrylate	50

Virgin latex paint is assumed to be sold in one-gal steel cans, which are included in the model. Steel data comes from life cycle inventories submitted by the American Iron and Steel Institute (AISI) and the International Iron and Steel Institute (IISI) and represents late 1990s worldwide production of steel.

Consolidated paint. A recent LCA study on leftover paint waste management[139] that surveyed paint consolidation plants all over the United States found the average percentage of virgin constituents to be approximately 1.5 %, with the remainder being leftover household paint. At 5.08 kg (11.2 lb) per gal this amounts to 0.08 kg (0.17 lb) of virgin additives, which are described above. Consolidated paint is usually repackaged in 19 L (5 gal) high density polyethylene (HDPE) plastic buckets, which are included in the BEES model. Data on HDPE comes from American Chemistry Council 2006 data developed for submission to the U.S. LCI Database.

Reprocessed paint. The leftover paint waste management study also surveyed paint reprocessing plants. Based on this survey, PC paint content ranged from 55 % to 93 %, with a weighted average of 76 %. Therefore, the quantity of virgin constituents was modeled as 24 %, amounting to 1.24 kg (2.74 lb) of virgin additives per gal of reprocessed paint, at an assumed

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[139] Franklin Associates and Four Elements Consulting, LLC, "Life Cycle Assessment Results for Six "Pure" Methods for Managing Leftover Paint. Draft Report" (Paint Product Stewardship Initiative, 2006). For more information, go to http://www.productstewardship.us.

density of 1.34 kg/L (11.2 lb/gal). These additives are described under the virgin latex paint raw materials section above. Reprocessed paint is packaged in both 19 L (5 gal) HDPE plastic buckets and 3.8 L (1 gal) steel containers; the BEES model assumes half the reprocessed paint is packaged in each option.

Manufacturing

Paint manufacture essentially consists of combining the ingredients, less some of the solvent, in a steel mixing vessel. In some cases the mixing is followed by a grinding operation to break up the dry ingredients, which tend to clump during mixing. Then, additional solvents or other liquids are added to achieve final viscosity, and supplemental tinting is added. Finally, the paint is strained, put into cans, and packaged for shipping.

Virgin latex paint. The blending energy for virgin latex paint and the paint primer is assumed to be 4.5 MJ (1.25 kWh) of purchased electricity per gal of paint blended and 7.0 MJ (1.94 kWh) of additional energy per gal.[140] In the absence of data on the source of the additional energy required, it is assumed to be natural gas. Emissions associated with paint and paint primer manufacturing, such as particulates to the air, are based on U.S. EPA AP-42 emission factors.

Truck transportation of raw materials to the paint manufacturing site is assumed to average 402 km (250 mi) for limestone, 2400 km (1500 mi) for titanium dioxide, and 80 km (50 mi) for the resins.

Consolidated latex paint. Before PC paint undergoes consolidation, it is sorted from solvent based paints, contaminated paint, and other HHW materials that come to a HHW facility. Once the paint in good condition is separated from other types of paint and HHW, the paint cans are opened manually or electrically and paint is poured into a mixing vessel. The cans are sometimes crushed using electrical equipment. Water is often used to clean facilities, as are absorbents to soak up paint from the floor. Waste is minimized as often the emptied containers are recycled. The following Table provides consolidation plant sorting inputs and outputs.

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[140] Based on the amount of purchased electricity reported in U.S. Department of Commerce, "2002 Census Report: Paint and Coating Manufacturing 2002," based on 1.3 billion gallons of all paints and coatings produced in 2002.

Table 3.71: Consolidated Paint Sorting Data

Flow	*Units*	*Amount*
Inputs		
Water used	L/L (gal/gal)	0.22 (0.22)
Absorbent used to absorb paint on floor	kg/L (lb/gal)	0.0002 (0.002)
Electricity	J/L (kwh/gal)	31 0227 (0.327)
Natural gas process fuel	m3/L (ft3/gal)	0.0001 (0.010)
Diesel fuel (mobile equipment)	L/L (gal/gal)	0.0009 (0.001)
Natural gas (mobile equipment)	L/L (gal/gal)	0.0003 (0.0003)
Propane (mobile equipment)	L/L (gal/gal)	0.005 (0.005)
Gasoline (mobile equipment)	L/L (gal/gal)	0.0002 (0.0002)
used oil	L/L (gal/gal)	0.001 (0.001)
Outputs		
Waste	kg/L (lb/gal)	0.102 (0.850)

Next, the paint is blended and repackaged. The following Table provides the consolidation process energy and water requirements.

Table 3.72: Consolidated Paint Processing Data

Flow	*Units*	*Amount*
Water used	L/L (gal/gal)	0.07 (0.07)
Electricity	J/L (kwh/gal)	55 092 (0.058)
Natural gas process fuel	m3/L (ft3/gal)	0.00001 (0.002)
Diesel fuel (mobile equipment)	L/L (gal/gal)	0.002 (0.002)
Propane (mobile equipment)	L/L (gal/gal)	0.007 (0.007)

The absorbent used to soak up paint from the facility floor is reported as cat litter, which is modeled as clay using the SimaPro database. All data on energy use and combustion in mobile equipment and boilers comes from the U.S. LCI Database.

The leftover paint waste management study found that about 60 % of the time, paint comes to a consolidation plant by truck from a HHW facility or a municipal solid waste transfer station. The remaining incoming paint comes directly from households via passenger vehicle. Based on the surveys, truck transportation is on average 161 km (100 mi) and car transport is on average 15 km (9.4 mi). The passenger vehicle mileage has been allocated to one-fourth its amount to account for the mass of other HHW drop-off items likely transported in the car plus driving for other errands during the same trip. The passenger vehicle is modeled as 50 % gasoline-powered car and 50 % sport utility vehicle, and gasoline usage and emissions data come from an EPA study on passenger vehicles.[141] Truck transportation data comes from the U.S. LCI Database.

Reprocessed latex paint. As with consolidated paint, before paint is reprocessed it must be

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[141] National Vehicle and Fuel Emissions Laboratory, “Annual Emissions and Fuel Consumption for an "Average" Passenger Car” and Annual Emissions and Fuel Consumption for an "Average" Light Truck (U.S. Environmental Protection Agency: EPA420-F-97-037, April 1997).

sorted from other incoming materials. Once the PC latex paint appropriate for reprocessing is sorted from other paints and materials, it is blended with virgin materials and packaged for sale. The following tables provide the inputs and outputs from sorting and reprocessing.

Table 3.73: Reprocessed Paint Sorting and Processing Data

Flow	*Quantity per L (per gal)*
Inputs:	
Water used	0.565 L (0.565 gal)
Electricity	0.425 MJ (0.447 kWh)
Propane (mobile equipment)	0.0023 L (0.0023 gal)
Gasoline (mobile equipment)	0.0009 L (0.0009 gal)
Outputs:	
Waste	0.0083 kg (0.07 lb)

Paint reprocessing facilities mostly receive leftover paint via truck from collection sites including HHW facilities. Because there are fewer reprocessing facilities, trucks travel on average a greater distance than to consolidation facilities; this distance is about 885 km (550 mi) according to the leftover paint study.

Transportation

Transportation of virgin and reprocessed latex paint from the manufacturing facility to the building site via heavy-duty truck is modeled as a variable of the BEES system. Transportation of the consolidated paint, also a BEES variable, is accomplished by gasoline-powered car and sport utility vehicle, typically traveling a much shorter distance due to the high number of local paint consolidation facilities and markets.

Installation

At the beginning of the 50-year BEES use period, one coat of primer is applied under the two coats of paint. The raw materials section above provides the material constituents for primer.

Use

Every four years, the wall is assumed to be painted over with one additional coat, amounting to 12 additional coats over the 50-year use period. As with all BEES products, these “replacements” are accounted for in the model. All three paint options are assumed to have a VOC content of 150 g (5.29 oz) per liter and to release 20.5 g (0.05 lb) VOC per functional unit over 50 years.

End of Life

At end of life, all the paint goes into the landfill with the wall on which it is applied.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Industry Contacts

David Darling, National Paint & Coating Association (2005)

3.13 Floor Coverings

3.13.1 Generic Ceramic Tile With Recycled Glass

Ceramic tile flooring consists of clay, or a mixture of clay and other ceramic materials, which is baked in a kiln to a permanent hardness. To improve environmental performance, recycled windshield glass is often added to the ceramic mix.

For the BEES system, a 50-year ceramic tile with 75 % recycled windshield glass content, installed using a latex-cement mortar, is studied. Each tile is 15 cm x 15 cm x 1.3 cm (6 in x 6 in x ½ in) and weighs 632.4 g (22.31 oz).

The detailed environmental performance data for this product may be viewed by opening the file C3020A.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

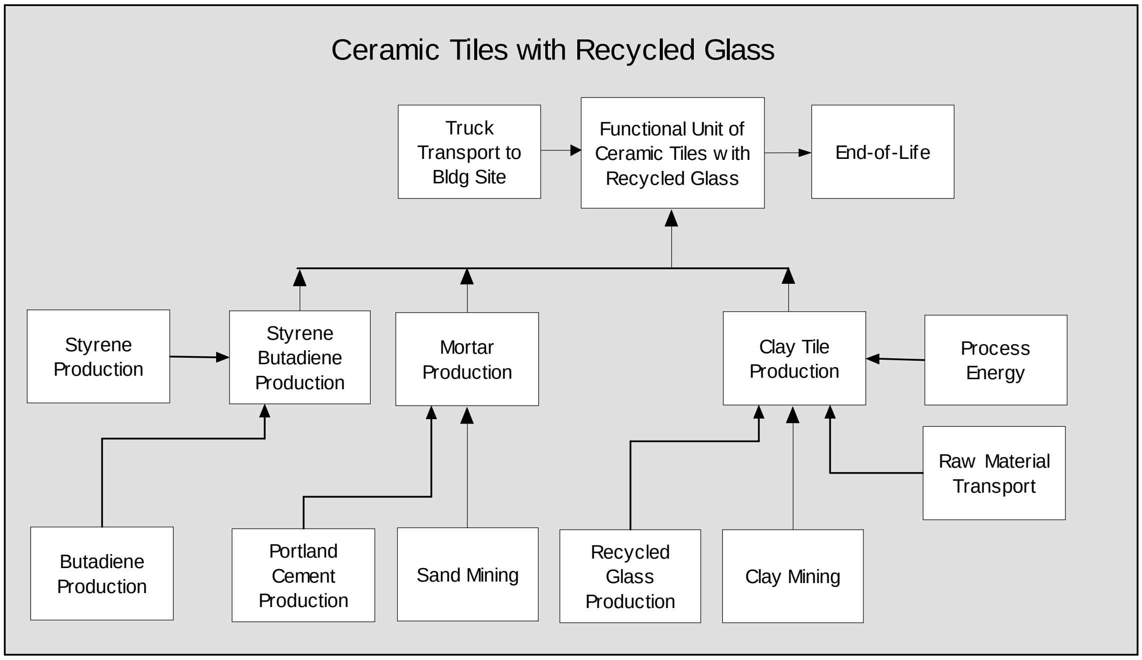

Figure 3.29: Ceramic Tile System Boundaries

Raw Materials

Clay and recycled glass are the primary constituents of the ceramic tile. The mass of each raw material is provided in the Table below.

Table 3.74: Ceramic Tile Constituents

Constituent	*Mass Fraction*	*kg/tile (oz/tile)*	*kg/m^2 (oz/ft^2)*
Clay	25 %	0.1581 (5.577)	6.807 (22.31)
Recycled Glass	75 %	0.4743 (16.73)	20.42 (66.92)

The environmental impacts for the production of clay are based on surrogate data in the SimaPro database. Burdens associated with glass production are allocated to the application for which the glass is initially produced (vehicle windshields), so the only burdens from recycled glass production are those associated with the collection and reprocessing of windshields.

The ceramic tiles are installed using a latex/mortar blend. The constituents of the latex/mortar blend are provided in the Table below.

Table 3.75: Latex/Mortar Blend Constituents

Constituent	*Mass Fraction*
Mortar	**69.6 %**
Portland Cement	17 %
Sand	83 %
Styrene-Butadiene Latex	**30.4 %**

Manufacturing

Energy Requirements and Emissions. The energy requirements for the drying and firing processes of ceramic tile production are listed in the Table below.

Table 3.76: Energy Requirements for Ceramic Tile Manufacturing

Energy Carrier	*Contribution*	*MJ/kg (Btu/lb)*
Coal	9.6 %	0.402 (173)
Natural Gas	71.9 %	3.013 (1 295)
Fuel Oil	7.8 %	0.327 (140)
Wood	10.8 %	0.448 (193)
Total	**100 %**	**4.19 (1 801)**

Emissions for ceramic tile firing and drying are based on U.S. EPA AP-42 data for emissions from the combustion of the specific fuel types.

Transportation. Transportation of the recycled glass to the tile facility is taken into account as 402 km (250 mi) by truck. The clay used to make the tiles is assumed to be shipped by truck 80 km (50 mi).

Waste. The manufacturing process generates no waste materials as all materials are reutilized in the plant.

Transportation

The distance for mortar transport to the end user is assumed to be 241 km (150 mi) by truck. Transportation of tiles by diesel truck to the building site is modeled as a variable of the BEES system.

Installation

Installing ceramic tile requires a layer of latex/mortar approximately 1.3 cm (½ in.) thick, which is equivalent to 0.567 kg (1.25 lb) per ft^2.[142] The relatively small amount of latex/mortar used between the tiles is not included. Installation of tile and mortar is assumed to be a manual process, so no there are no emissions or energy inputs. About 5 % of the installation materials are assumed to go to waste, all of which is disposed of in a landfill.

Use

Ceramic tile with recycled glass is assumed to have a useful life of 50 years. Maintenance of the tile floor during this period – e.g., cleaning, polishing – is not included within the system boundaries.

End of Life

All of the ceramic tile and latex/mortar are assumed to be disposed of in a landfill at end of life.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Industry Contacts

National Tile Contractors Association (2005)

3.13.2 Generic Linoleum Flooring

Linoleum is a resilient, organic-based floor covering consisting of a backing covered with a thick wearing surface. For the BEES system, 2.5 mm (0.098 in) sheet linoleum manufactured in Europe, with a jute backing and a polyurethane-acrylic finish coat, is studied. An acrylate copolymer adhesive is included for installation.

The detailed environmental performance data for this product may be viewed by opening the file C3020B.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below presents the major elements of the production of this product as it is currently modeled for BEES.

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[142] Average application rate at 0.5 in thickness reported at http://www.texascement.com/mortarcalc.html and http://www.c-cure.com/servref/covcalc/impmort/fimp.htm.

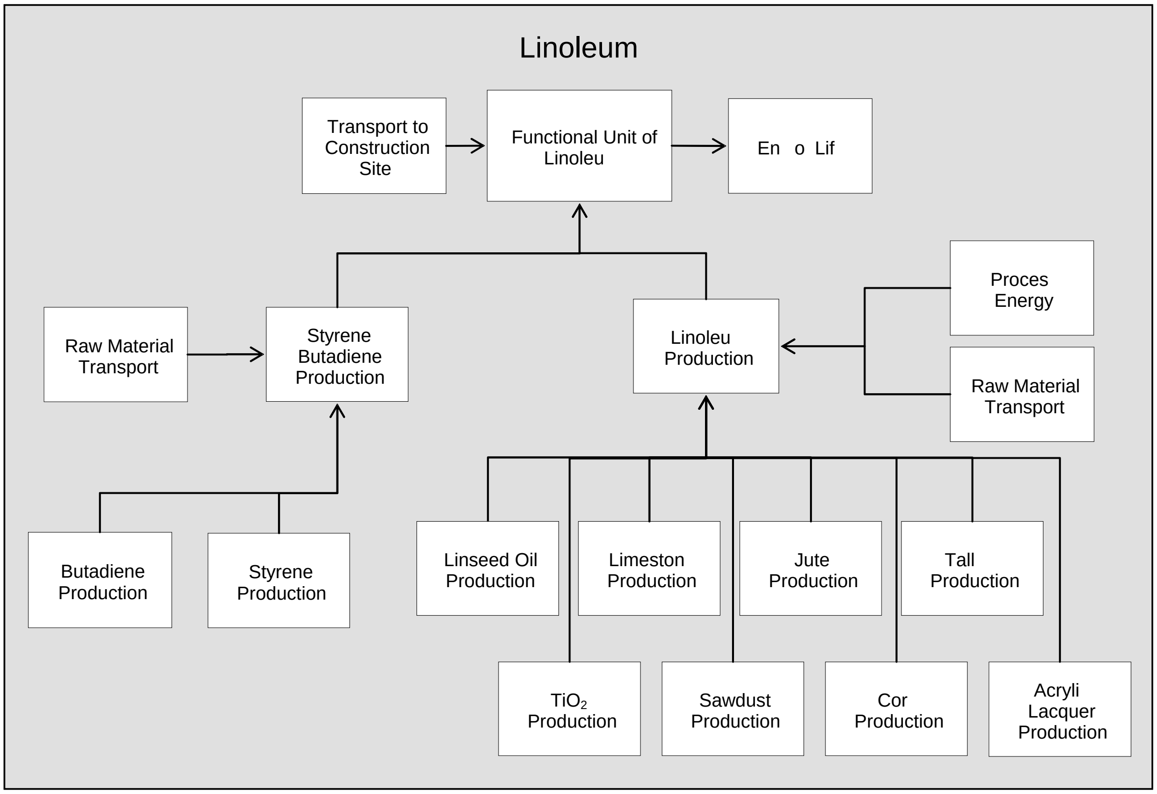

Figure 3.30: Linoleum Flooring System Boundaries

Raw Materials

The following Table lists the constituents of linoleum and their proportions. The data comes from a European study on the life cycle of flooring materials.[143] One square meter of 2.5 mm (0.098 in) linoleum weighs approximately 2.9 kg (6.4 lb).

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[143] Asa, J., et al.(Sweden: Chalmers University of Technology, 1995).

Table 3.77: Linoleum Constituents

Constituent	***Mass Fraction***	***g/m^2 (oz/ft^2)***
Linseed oil	23.3 %	670 (2.2)
Pine rosin/tall oil	7.8 %	224 (0.7)
Limestone	17.7 %	509 (1.7)
Wood flour	30.5 %	877 (2.9)
Cork flour	5.0 %	144 (0.5)
TiO_2 (pigment)	4.4 %	127 (0.4)
Jute (backing)	10.9 %	313 (1.0)
Acrylic lacquer	0.35 %	10 (0.03)
Total	**100 %**	**2 874 (9.4)**

The cultivation of linseed is based on a modified version of wheat production from the U.S. LCI Database (for lack of other available data), and inputs are presented below.

Table 3.78: Inputs to Linseed Agriculture

Input	***Kg/ha (lb/acre)***
Nitrogen Fertilizer	31 (28)
Phosphorus Fertilizer	20 (17)
Potassium Fertilizer	25 (22)
Pesticides (active compounds, with 20 % lost to the atmosphere)	0.7 (0.7)

To harvest the linseed, it is assumed that a diesel tractor is used, requiring approximately 0.61 MJ of diesel fuel per kg (263 Btu/lb) of linseed harvested. The yield of linseed is 1 038 kg per hectare (420 lb/acre). Energy requirements for linseed oil production include fuel oil and steam, and are allocated on an economic basis between linseed oil (87 %) and linseed cake (13 %). Allocation is necessary because linseed cake is a co-product of linseed oil production, so its production impacts should not be included in the BEES model for linoleum flooring. The emissions associated with linseed oil production are allocated on the same economic basis. The production of the fertilizers and pesticides is based on elements of the SimaPro database.

The production of tall oil is based on European data for kraft pulping, with inventory flows allocated between kraft pulp and its coproduct, tall oil.[144] The production of limestone comes from the U.S. LCI Database. Wood flour is sawdust produced as a coproduct of wood processing, and its production is based on the U.S. LCI Database. Cork flour is a coproduct of wine cork production. Cork tree cultivation is not included, but energy requirements for the processing of the cork is included as shown in the Table below.

Table 3.79: Electricity Inputs for Cork Flour Production

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[144] Fédération Européenne des Fabricants de Carton Ondulé (FEFCO), 2003. Found at: http://www.fefco.org/fileadmin/Fefco/pdfs/Technical_PDF/Corrected_database_2003.pdf.

Cork Product	***MJ/kg (Btu/lb)***
Cork Bark	0.06 (26)
Ground Cork	1.62 (696)

Production of the pigments used is based on the European production of titanium dioxide, from the SimaPro database. Linoleum backing, jute, is mostly grown in India, Bangladesh, Thailand, and China. Jute is predominantly rain-fed, requires little fertilizer and pesticides, and cultivation is generally done by manual labor. Data for the production of acrylic lacquer materials is based on elements of the SimaPro database.

Manufacturing

Energy Requirements. Producing linoleum requires electricity and natural gas; the following Table lists the energy requirements for linoleum production.[145]

Table 3.80: Energy Requirements for Linoleum Manufacturing

Energy Carrier	***MJ/kg (Btu/lb)***
Electricity	2 (859.8)
Natural Gas	10 (4 299.2)

Emissions. Since most linoleum manufacturing takes place in Europe, it is assumed to be a European product in the BEES model. European linoleum manufacturing results in the following air emissions in addition to those from energy use.

Table 3.81: Emissions from Linoleum Manufacturing

Emission	***g/kg (oz/lb)***
Volatile Organic Compounds (VOC)	1.6 (0.025)
Solvents	0.94 (0.015)
Particulates (unspecified)	0.23 (0.004)

Transportation. Data for linoleum raw material transport from point of origin to a European manufacturing location is shown in the Table below.[146]

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[145] Data is based on an average of public data and manufacturer-specific information.

[146] Asa, J., et. al., *Life-Cycle Assessment of Flooring Materials*(Sweden: Chalmers University of Technology, 1995).

Table 3.82: Linoleum Raw Materials Transportation

Raw Material	*Km (mi)*	*Mode*
Linseed oil	4 350 (2 703)	Ocean Freighter
	1,500 (932)	Train
Pine rosin/tall oil	2 000 (1 243)	Ocean Freighter
Limestone	800 (497)	Train
Wood flour	600 (373)	Train
Cork flour	2 000 (1 243)	Ocean Freighter
TiO_2 (pigment)	500 (311)	Diesel Truck
Jute (backing)	10 000 (6 214)	Ocean Freighter
Acrylic lacquer	500 (311)	Diesel Truck

Transport of the finished product from Europe to the United States is included in the model as part of the manufacturing process.

Waste. Most process waste is recycled at the plant and the remainder is sent to a landfill for disposal. For this model, 3 % of process input materials are assumed to go to a landfill.

Transportation

Transportation of linoleum by heavy-duty truck from the U.S. distribution facility to the building site is modeled as a variable of the BEES system Transportation data is based on the U.S. LCI Database.

Installation

For optimal adhesion, an acrylate copolymer adhesive is applied to a subfloor or other surface at a thickness of 0.29 mm and mass of 290 g/m². Usually linoleum seams are sealed against moisture by welding with a weld rod. This minimal amount of energy is not accounted for in the model.

Installation waste is assumed to be 5 % of the installed weight. In the United States, and in BEES, this waste is assumed to be sent to a landfill for disposal. (In Europe, this waste would go into incineration, which would generate 18.3 MJ/kg (2.31 kWh/lb) energy.)

Use

Linoleum is known for its durability. Through evaluation of actual lifetime data, is has been determined that linoleum has a useful life of 30 years.[147] As with all BEES products, the life cycle environmental impacts from this replacement during the 50-year use phase are included in the life cycle inventory data. Volatile organic compound (VOC) off-gassing from the adhesive is included in the BEES modeling.

End of Life

At end of life, it is assumed that linoleum is disposed of in a landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005.

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[147] Federal Association of the Sworn Experts for Room and Equipment e.V., *Guide to the Inquiry of Time Values and Decreases in Value of Floor Coverings*(Bonn, Germany: Federal Association of the Sworn Experts for Room and Equipment e.V.)

Golden, CO. Found at: http://www.nrel.gov/lci/database.
PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.
Asa, J., et. al., *Life-Cycle Assessment of Flooring Materials*, (Sweden: Chalmers University of Technology, 1995).
Fédération Européenne des Fabricants de Carton Ondulé (FEFCO), European Database for Corrugated Board Life Cycle Studies, 2003. Found at: http://www.fefco.org/fileadmin/Fefco/pdfs/Technical_PDF/Corrected_database_2003.pdf.
Federal Association of the Sworn Experts for Room and Equipment e.V., *Guide to the Inquiry of Time Values and Decreases in Value of Floor Coverings*, (Bonn, Germany: Federal Association of the Sworn Experts for Room and Equipment e.V.).

Industry Contacts

Jennifer Gaalswyk, Armstrong Corporation (Sept 2005 – Jan 2006)

3.13.3 Generic Vinyl Composition Tile

Vinyl composition tile (VCT) is a resilient floor covering. Relative to the other types of vinyl flooring (vinyl sheet flooring and vinyl tile), VCT contains a high proportion of inorganic filler. The tile size modeled in BEES is 30 cm x 30 cm x 0.3 cm (12 in x 12 in x 1/8 in), with a weight of about 0.613 kg (1.35 lb).

The detailed environmental performance data for this product may be viewed by opening the file C3020C.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

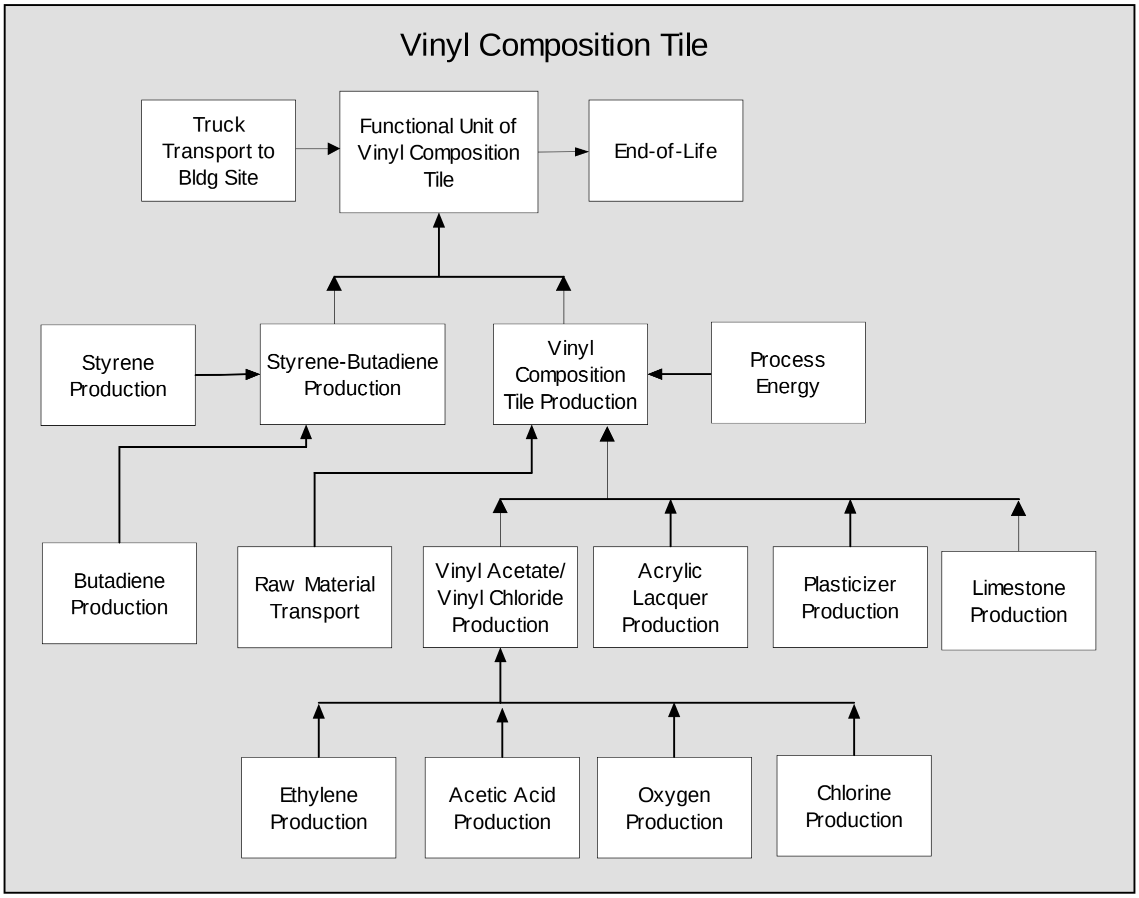

Figure 3.31: Vinyl Composition Tile System Boundaries

Raw Materials

The average makeup of vinyl composition tile is limestone, plasticizer, and a copolymer of vinyl chloride (95 %) and vinyl acetate (5 %). A layer of styrene-butadiene adhesive is used during installation.

The Table below lists the composition by weight of 30 cm x 30 cm x 0.3 cm (12 in x 12 in x 1/8 in) VCT. A finish coat of acrylic latex is applied to the tile at manufacture. The thickness of the finish coat is assumed to be 0.005 mm (0.2 mils). The production of these raw materials, and the styrene-butadiene adhesive, is based on the SimaPro database, the U.S. LCI Database, and American Chemistry Council 2006 data developed for submission to the U.S. LCI Database.

Table 3.83: Vinyl Composition Tile Constituents

Constituent	*Mass kg/m^2 (lb/ft^2)*	*Mass Fraction (%)*
Limestone	5.54 (1.14)	84
Vinyl resins: 5 % vinyl acetate / 95 % vinyl chloride	0.797 (0.163)	12
Plasticizer: 60 % BBP (butyl benzyl phthalate) / 40 % DINP (diisononyl phthalate)	0.269 (0.055)	4
Total	**6.61 (1.35)**	**100**

Internal recycling is quite common, with at least 99 % of the raw materials initially used in the manufacturing process being ultimately used in the finished product. Typically, all scrap and rejected materials are reused in the manufacturing process for VCT. In fact, the amount of recycled content from tile processing can range from 12 % to 50 % of a finished tile.

It is difficult to provide a representative number for tile recycled content from sources external to the plant, due to multiple manufacturing sites and the lack of a constant supply of both post-industrial and postconsumer polyvinyl chloride (PVC). The majority of the recycled materials used are post-industrial, and a conservative recycled content number from external sources is 1 % by weight of the tile.

Manufacturing

Energy Requirements and Emissions. Energy requirements for the manufacturing processes (mixing, folding/calendaring, finish coating, and die cutting) are listed in the Table below.

Table 3.84: Energy Requirements for Vinyl Composition Tile Manufacturing

Energy Carrier	*MJ/kg (Btu/lb)*
Electricity	1.36 (585)
Natural Gas	0.85 (365)
Total	**2.21 (950)**

Emissions associated with the manufacturing process arise from the combustion of natural gas and are modeled using the U.S. LCI Database.

Transportation. VCT producers are located throughout the country. The bulk of the product weight is limestone, a readily available and plentiful filler typically located in close proximity to manufacturing sites. The raw materials used in the manufacture of the tile are all assumed to be transported to the production facility via diesel truck over a distance of 402 km (250 mi). Transportation of adhesive to the end user is assumed to be 241 km (150 mi) via diesel truck.

Waste. Typically, less than 1 % waste is generated from the production of VCT. This waste is usually comprised of granulated VCT and VCT dust and is disposed of in a landfill.

Transportation

Transportation of vinyl composition tile by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

A layer of styrene-butadiene adhesive is used during installation. The thickness of the adhesive is 0.08 cm (1/32 in) at application. Approximately 0.0133 kg (0.0294 lb) of adhesive is applied per ft^2 of vinyl composition tile. The adhesive is applied wet, and a loss in volume arises due to evaporation of the water in the adhesive as it dries. Adhesives are typically water-based and thus few volatiles are emitted. Installation of vinyl composition tile is primarily a manual process, so no energy use is modeled for the installation phase.

Installation scrap varies depending on the job size. It is estimated that, on average, installation scrap for a commercial job is 2 % to 3 %. Scrap is sent to landfill.

Use

Vinyl composition floor tile is most commonly used in applications such as school cafeterias and classrooms, where there is relatively little exposure to abrasion from tracked-in grit and dirt. Based on historical observations, it is estimated that VCT in such applications lasts an average of 40 years before it is replaced due to wear. In extremely heavy traffic areas (which are normally much smaller in area), such as entryways in a school, the tile has a shorter life expectancy.

Because of differing VCT manufacturers' maintenance recommendations, there is not a single industry standard for maintenance of the product over its lifetime. Typically, VCT is stripped and polished annually. Many of the acrylic finishes used after the floor is installed consist of the same general materials as the factory-applied finishes. The equipment used to maintain the floor depends on the maintenance system selected by the building owner, often based on the desired overall appearance. Electric- or propane-powered floor machines may be used for stripping, polishing, and buffing. Frequency of refinishing, and types and quantities of stripping and polishing chemicals used each time, depend on the maintenance programs developed by individual building owners. Today, low-volatile organic compound (VOC) or no-VOC maintenance products are available for maintaining VCT floors. VOC off-gassing from the tile and adhesive at each installation are included in the BEES modeling.

End of Life

At end of life, the VCT and adhesive are assumed to be disposed of in a landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Industry Contacts

William Freeman, Resilient Floor Covering Institute, (September-November 2005)

3.13.4 Generic Composite Marble Tile

Composite marble tile is a type of composition flooring. It is a mixture of polyester resin and matrix filler, colored for a marble effect, that is poured into a mold to form tiles. The mold is then vibrated to release air and level the matrix. After curing and shrinkage the tile is removed from the mold, trimmed, and polished if necessary.

For the BEES system, a 30 cm x 30 cm x 0.95 cm (12 in x 12 in x 3/8 in) tile, installed using a latex-cement mortar, is studied. The detailed environmental performance data for this product may be viewed by opening the file C3020D.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The following flow diagram shows the major elements of the production of composite marble tile, as currently modeled in BEES.

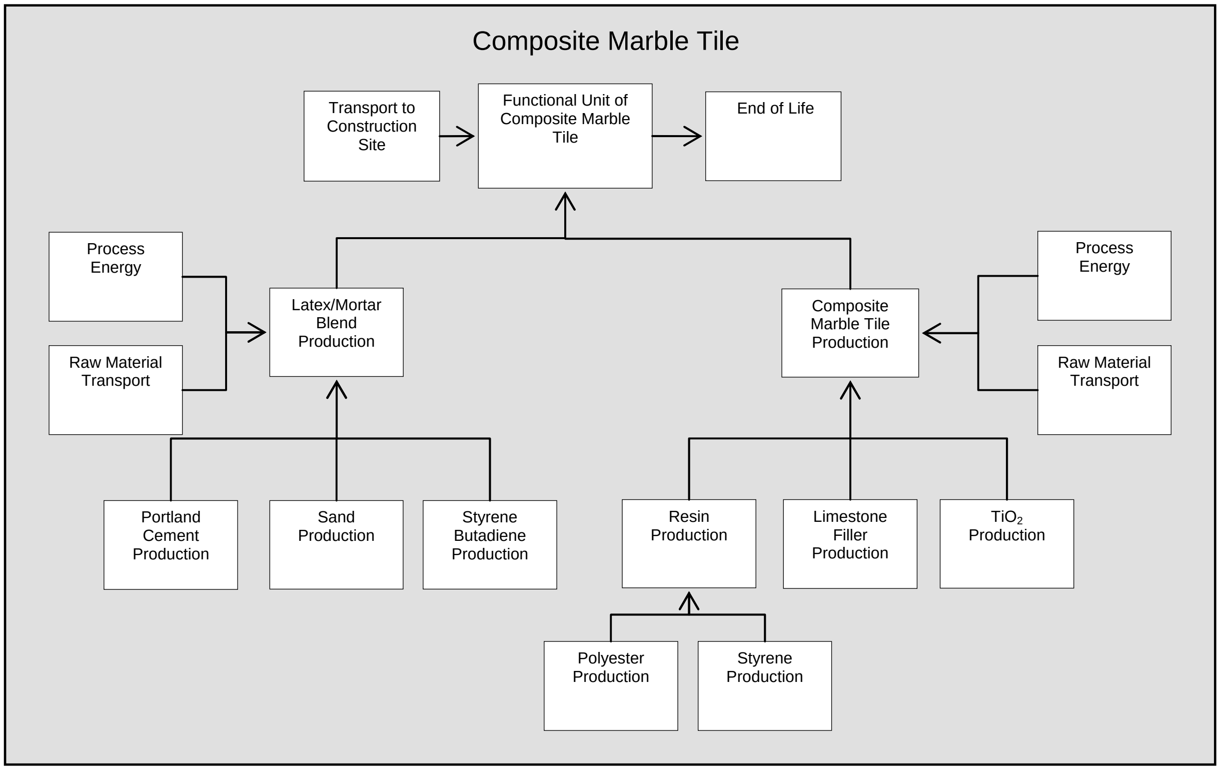

Figure 3.32: Composite Marble Tile System Boundaries

Raw Materials

The Table below gives the constituents included in the marble matrix and their proportions. It is assumed that 3 % of the material is lost at manufacture from the trimming process.

Table 3.85: Composite Marble Tile Constituents

Constituent	*Mass Fraction (%)*
Filler	78.25
Resin	20.01
Pigment (TiO_2)	1.50
Catalyst (MEKP)	0.24

The resin percentage given above is a weighted average, based on data from four sources ranging from 19 % to 26 % resin content. The remainder of the matrix is composed of filler, pigment, and catalyst. Since calcium carbonate is the typical filler used for U.S. composite marble tile production, it is the assumed filler material in the BEES model. The filler is composed of coarse and fine particles in a combination of two parts coarse to one part fine. Filler production involves the mining and grinding of calcium carbonate. The resin used in the matrix is an unsaturated polyester resin cross-linked with styrene monomer. The styrene content can range from 35 % to 55 %. An average value of 45 % is used for the model.

The main catalyst used in the United States for the marble matrix is Methyl Ethyl Ketone Peroxide (MEKP). This catalyst is used as a solvent in the mixture of resin and filler, so is consumed in the process; however, approximately 1 % of the MEKP catalyst is composed of unreacted MEK, which is assumed to be released during the reaction. The amount of catalyst is assumed to be about 1 % of the resin content, or 0.24 % of the total marble matrix. Due to a lack of public data on MEKP production, and the small mass fraction of the component, MEKP production is not included within the system boundaries.

A colorant may be used if necessary. The quantity depends on the color required. The colorant is usually added to the mixture before all the filler has been mixed. For the BEES study, titanium dioxide at 1.5 % is assumed.

Composite marble tiles are installed using a latex/mortar blend. The constituents of the latex/mortar blend are provided in the Table below.

Table 3.86: Latex/Mortar Blend Constituents

Constituent	*Mass Fraction (%)*
Portland Cement	38
Sand	22
Styrene-Butadiene Latex	40

Manufacturing

Energy Requirements and Emissions. Electricity is the only energy source involved in producing and casting the resin-filler mixture for composite marble tile. The tile is cured at room temperature. The Table below shows electricity use for composite marble tile manufacturing.

Table 3.87: Energy Requirements for Composite Marble Tile Manufacturing

Energy Carrier	***MJ/kg (Btu/lb)***
Electricity	0.047 (20.3)

The chief emissions from composite marble tile manufacturing are fugitive styrene and MEK air emissions. The styrene emissions come from the resin constituent and are assumed to be 2 % of the resin input. The MEK emissions come from the 1 % un-reacted MEK in the catalyst blend. Emissions of styrene from the matrix are assumed to be 0.129 kg/m^2 (0.026 lb/ft^2), and MEK emissions 0.00086 kg/ m^2 (0.00018 lb/ft^2).

Transportation. All product raw materials are assumed to be transported 402 km (250 mi) by truck. For the mortar raw materials, the portland cement and sand are assumed to be transported 48 km (30 mi) by truck to the packaging plant, and the latex raw materials are assumed to be transported 161 km (100 mi) to the production facilities.

Transportation

Shipping the cement, sand, and latex to the end user is assumed to cover 322 km (200 mi) via diesel truck. Transportation of tiles by diesel truck to the building site is modeled as a variable of the BEES system.

Installation

Installing composite marble tile requires a sub-floor of a compatible type, such as concrete. A layer of latex/mortar approximately 1.3 cm (½ in) thick is used, which is equivalent to 17.96 kg/m^2 (3.563 lb/ft^2). Installation of tile and mortar is assumed to be primarily a manual process, so there are no emissions or energy inputs. About 5 % of the installation materials are assumed to go to waste, all of which is disposed of in a landfill.

Use

With general maintenance, properly installed composite marble tile will have a useful life of 75 years. Maintenance – such as cleaning and sealing of the tile - is not included within the boundaries of the BEES model.

End of Life

At end of life, it is assumed that the composite marble tile and the latex/mortar used for installation are disposed of in a landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Industry Contacts

No industry contacts were found that were able to provide industry data.

3.13.5 Generic Terrazzo

Terrazzo is a type of composition flooring. It consists of a mix of marble, granite, onyx, or glass chips in portland cement, modified portland cement, or resinous matrix that is poured, cured, ground, and polished.

BEES evaluates an epoxy, or resinous, terrazzo containing a high proportion of inorganic filler (principally marble dust and chips), a pigment for aesthetic purposes, and epoxy resin. The materials are mixed and installed directly on site and, when dry, are polished. The epoxy terrazzo is 9.5 mm (3/8 in) thick.

The detailed environmental performance data for this product may be viewed by opening the file C3020E.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

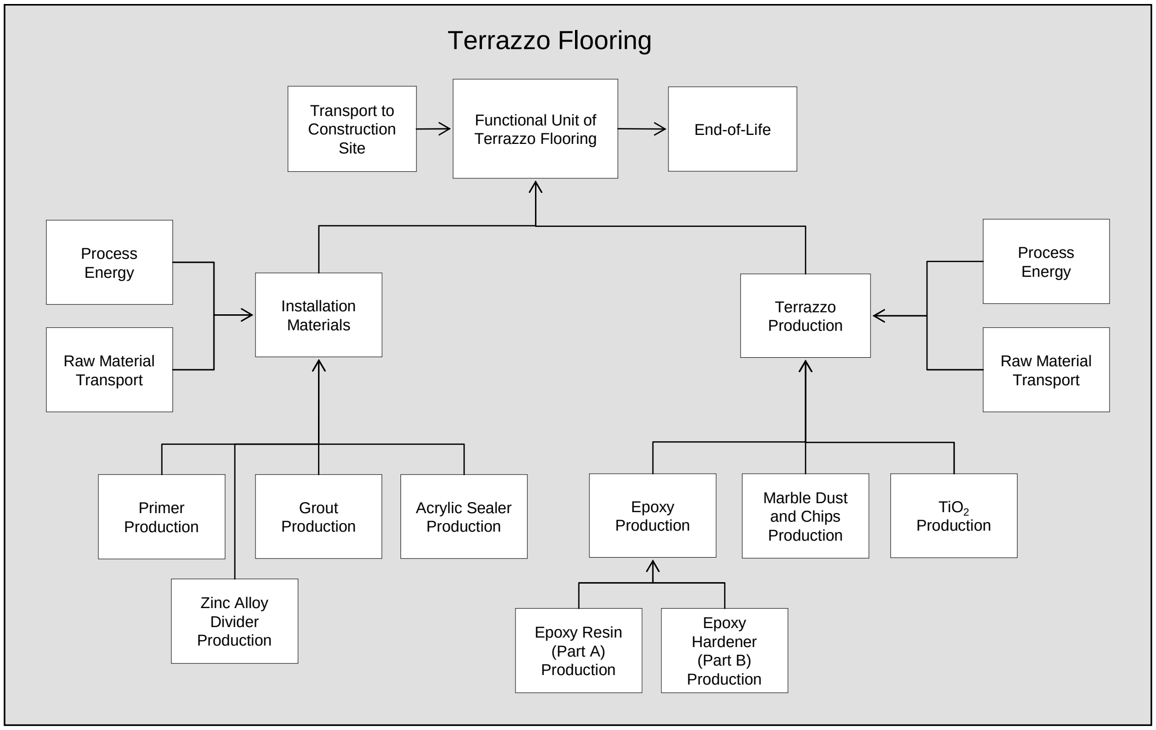

Figure 3.33: Terrazzo Flooring System Boundaries

Raw Materials

The Table below lists the constituents of epoxy terrazzo and their proportions.

Table 3.88: Terrazzo Flooring Constituents

Terrazzo Constituents	*Mass Fraction (%)*
Marble dust and chips	77
Epoxy resin	22
Pigment (titanium dioxide)	1

The term "marble" refers to all calcareous rocks capable of taking a polish (e.g., onyx, travertine, and some serpentine rocks). Marble is quarried, selected to avoid off-color or contaminated material, crushed, washed, and sized to yield marble chips for Terrazzo.[148] Note that because marble dust is assumed to be a coproduct rather than a waste byproduct of marble production, a portion of the burdens of marble quarrying is allocated to marble dust production.

Typical amounts of raw materials used are as follows: 1.5 kg (3.3 lb) of marble dust and 0.23 kg (0.51 lb) of marble chips per 0.09 m^2 (1 ft^2); 3.8 L (1 gal) of epoxy resin per 0.8 m^2 (8.5 ft^2); and, depending on customer selection, from 1 % to 15 % pigment content. The density of epoxy resin is approximately 1.1 kg/L (9.3 lb/gal).

Manufacturing

Energy Requirements and Emissions. Terrazzo is "manufactured" at the site of installation.

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[148] National Terrazzo and Mosaic Association, Inc. (NMTA) website, http://www.ntma.com; Phone conversation with NMTA representative February 2006.

The energy requirements for the on-site process include mixing the primer, mixing the terrazzo, grinding the surface (occurs before and after grouting), controlling the dust from grinding, mixing grout, and polishing the floor.

The only energy data available are for mixing the terrazzo, which is assumed to require a 5.97 kW (8 hp) gasoline-powered mixer running for 5 minutes.

Table 3.89: Energy Requirements for Terrazzo Manufacturing

Energy Carrier	***MJ/kg (Btu/lb)***
Gasoline	0.003 (1.17)

Transportation. The terrazzo constituents are assumed to be transported 402 km (250 mi) by diesel truck to the terrazzo supplier.

Waste. Approximately 1 % of the materials used to make the terrazzo are wasted during manufacturing. This waste is assumed to be disposed of in a landfill.

Transportation

Transportation of terrazzo flooring by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

Installing epoxy terrazzo requires a sub-floor of a compatible type, such as cement board, exterior grade plywood, concrete block, concrete, or cement plaster. Most systems adhere to concrete slabs.

Table 3.90: Terrazzo Flooring Installation Materials

Installation Materials	***Mass Fraction (%)***
Divider Strips (Zinc)	54.4
Epoxy Resin	34.3
Acrylic Sealer	11.3

To prevent the terrazzo from cracking, dividers are placed precisely above any concrete joints. Back-to-back "L" strip dividers are recommended for construction joints. Standard dividers are a 9.5 mm (3/8 in) wide, 16 gauge white zinc alloy, and weigh approximately 0.177 kg/m (0.119 lb/ft). A 10 cm (4 in) thick concrete slab should have concrete joints at a maximum spacing of 3.7 m (12 ft); therefore, 29 m (96 ft) of divider are required for every 13.4 m^2 (144 ft^2).

Manufacturer specifications suggest bonding the divider strips to the floor using 100 % solid epoxy resin. The BEES model does not account for the bonding material; the amount is assumed to be negligible.

Prior to applying the epoxy terrazzo, the sub-floor must be primed. The primer is made by mixing the epoxy resin components at a lower ratio than that used for the epoxy terrazzo.

Typical coverage is approximately 18.6 m^2 to 23.2 m^2 (200 ft^2 to 250 ft^2) per blended gal of primer.

After the terrazzo mixture has been applied and the surface has been grinded, the surface is grouted to fill and seal any voids. The grout is made by mixing the epoxy resin components in the same ratio used in the epoxy terrazzo. Typical coverage is approximately 46.5 m^2 to 65.0 m^2 (500 ft^2 to 700 ft^2) per blended gal of grout.

After the floor has been grouted and polished, two coats of acrylic sealer are applied at an approximate thickness of one to two mils. Typical coverage for a single coat is approximately 74.3 m^2 to 92.9 m^2 (800 ft^2 to 1 000 ft^2) per gal of sealer.

Use

With general maintenance, a properly installed terrazzo floor will have a useful life of 75 years. Maintenance – such as cleaning and sealing of the tile - is not included within the boundaries of the BEES model.

End of Life

At end of life, it is assumed that the terrazzo and any installation materials will be disposed of in a landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Industry Contacts

The National Terrazzo and Mosaic Association, Inc. (December 2005 – February 2006)

3.13.6 Generic Nylon Carpet

For the BEES analysis, nylon carpet with an 11-year life (broadloom) or 15-year life (tile) is studied. The mass for 0.09 m^2 (1 ft^2) of broadloom carpet is approximately 2.2 kg/m^2 (0.45 lb/ft^2), while the mass for 0.09 m^2 (1 ft^2) of carpet tile is approximately 4.8 kg/m^2 (0.98 lb/ft^2). Four different product combinations are included in the BEES database. These combinations are listed below, along with their corresponding environmental performance data file names. Data files may be viewed by opening them under the File/Open menu item in the BEES software.

- C3020F.DBF—Nylon Carpet Tile with Traditional Glue
- C3020I.DBF—Nylon Carpet Tile with Low-VOC Glue
- C3020L.DBF—Nylon Broadloom Carpet with Traditional Glue
- C3020O.DBF—Nylon Broadloom Carpet with Low-VOC Glue

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

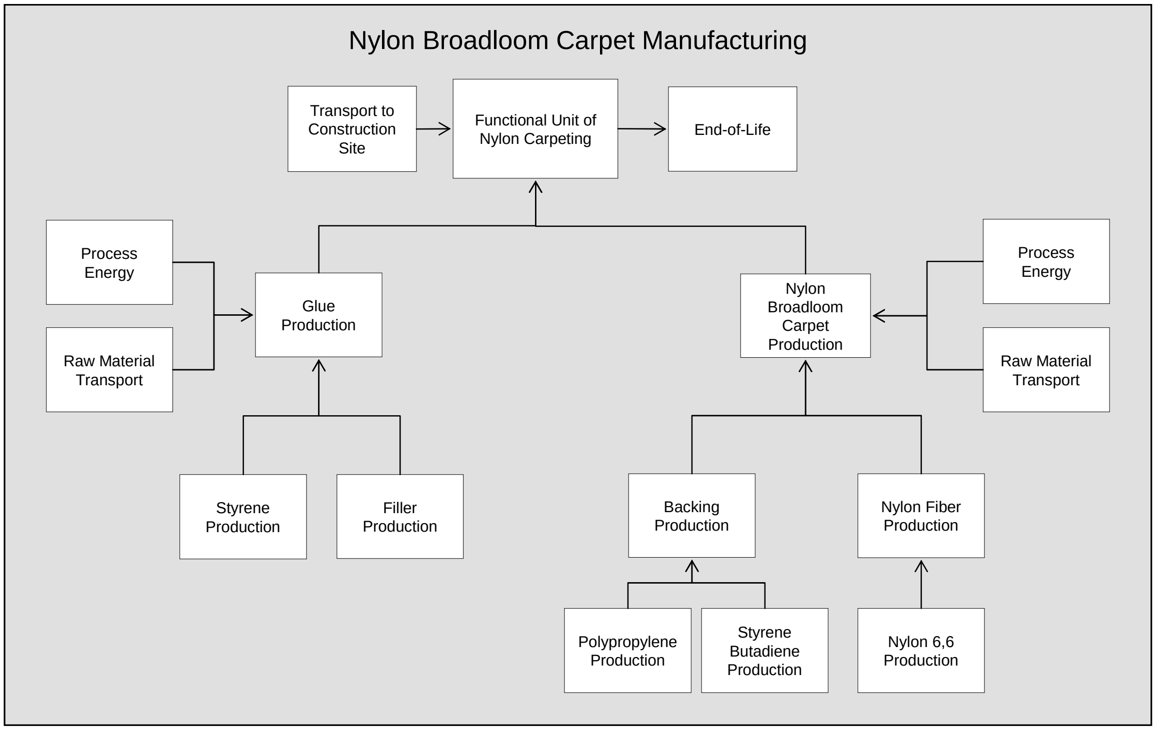

Figure 3.34: Nylon Broadloom Carpet System Boundaries

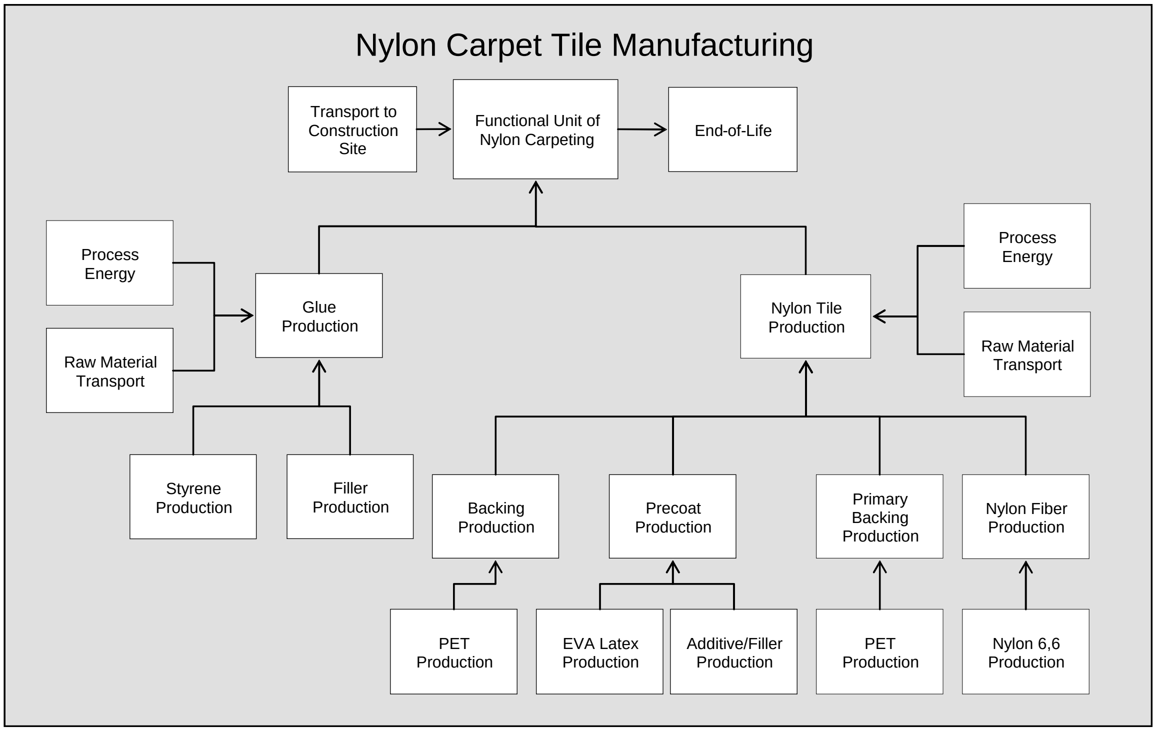

Figure 3.35: Nylon Carpet Tile System Boundaries

Raw Materials

Nylon carpeting consists of a mix of materials that make up the face and the backing of the product. The composition of broadloom carpet and carpet tiles differs significantly; specifications are provided in the following Table.

Table 3.91: Nylon Carpet Constituents

Constituent	*Material*	*g/m^2 (oz/ft^2)*
Broadloom		
Face Fiber	Nylon 6,6	1 029 (3.37)
Backing	Polypropylene	227 (0.74)
	Styrene butadiene latex	263 (0.86)
	Limestone ($CaCO_3$) filler	909 (2.98)
	Stainblocker	0.24 (0.001)
	Other additives	2 (0.01)
Tile		
Face Fiber	Nylon 6,6	787 (2.58)
Primary Backing	Polyester (PET) woven	161 (0.53)
Precoat	EVA latex	321 (1.05)
	Limestone ($CaCO_3$) filler	2 518 (8.25)
	Diisononyl phthalate	636 (2.08)
	poly(Ethylacrylate-co-vinyl chloride)	390 (1.28)
	Stainblocker	12.2 (0.04)
	Other additives	93 (0.30)
Fiberglass	Fiberglass	52 (0.17)
Backing	Virgin PVC	261 (0.86)

Data for Nylon 6,6 and styrene butadiene latex are based on recent European data from the plastics industry.[149,150] Data for polypropylene, PET, and PVC are based on American Chemistry Council 2006 data developed for submission to the U.S. LCI Database, and data for limestone comes directly from the U.S. LCI Database. Data for the remaining nylon carpet materials are derived from elements in the SimaPro database, which include North American and European data from the late 1990s and 2000s.

Manufacturing

Energy Requirements. Carpet manufacturing consists of a number of steps, including formation of the synthetic fibers; dyeing of the fibers; and construction, treatment, and finishing of the carpet. For both nylon carpet types, the nylon material is made into fibers and then 'tufted' to

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[149] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

[150] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005) and Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

produce the carpet face. The face yarn is attached, using a primary coating and tufting needles, to the polymer backing. The energy requirements for these process steps are provided in the following Table.

Table 3.92: Energy Requirements for Nylon Carpet Manufacturing

Energy Carrier	***Broadloom MJ/m^2 (Btu/ft^2)***	***Tile MJ/m^2 (Btu/ ft^2)***
Electricity	0.39 (34)	2.2 (197)
Fuel Oil	5.0 (437)	3.5 (306)
Heating Steam	1.67 (145)	2.4 (207)

Emissions. Emissions associated with the manufacturing process arise from the production of electricity and the combustion of fuel oil and natural gas, and are based on the U.S. LCI Database.

Solid Wastes. Approximately 9 % and 7 % waste is generated from the production of nylon broadloom carpet and carpet tile, respectively. Included in these figures are customer returns and off-specification production. All waste is assumed to be disposed of in a landfill.

Water Consumption. Approximately 0.96 kg/m^2 (0.20 lb/ft^2) and 0.93 kg/m^2 (0.19 lb/ft^2) of water is consumed during the manufacture of nylon broadloom carpet and carpet tile, respectively.

Transportation. Transport of raw materials to the carpet manufacturing plant is assumed to cover 402 km (250 mi) by truck.

Transportation

Transportation of nylon carpet by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

Nylon broadloom carpet and nylon carpet tiles are installed using either a standard latex glue or a low-VOC latex glue. For the tile, typical glue application is 0.012 kilograms (0.026 lb) of glue per ft^2 of installed tile. For the broadloom carpet, two applications of glue are required – 0.624 kg/m^2 (0.128 lb/ft^2) is applied to the product and then spots of glue are applied to the floor space at a rate of 0.022 kg/m^2 (0.004 lb/ft^2).

No glue is assumed to be wasted during the installation process, yet 5.7 % of the broadloom carpet and 2 % of the carpet tile are assumed to be lost as landfilled waste.

Use

The use phase of this product is either 11 years or 15 years depending on the type of nylon carpeting, broadloom or tile, respectively. As with all BEES products, life cycle environmental burdens from these replacements are included in the inventory data. Volatile Organic Compound (VOC) off-gassing from the carpet and both traditional and low-VOC adhesives are included in the BEES modeling.

End of Life

At end of life, a recycle rate of 0.7 % is assumed for broadloom carpet, while none of the carpet tile is recycled. The nylon carpet and its adhesives are assumed to be disposed of in a landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Boustead, I., Eco-profiles of the European Plastics Industry: POLYAMIDE 66 (NYLON 66) (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Boustead, I., Eco-profiles of the European Plastics Industry: STYRENE (Association of Plastics Manufacturers of Europe, March 2005).

Boustead, I., Eco-profiles of the European Plastics Industry: BUTADIENE (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

3.13.7 Generic Wool Carpet

In BEES, wool carpet with a 25-year life is studied. The mass of 0.09 m^2 (1 ft^2) of wool broadloom carpet or carpet tile is approximately 40 oz (1.13 kg). Four different product combinations are included in the BEES database. These combinations are listed below, along with their corresponding environmental performance data file names. Data files may be viewed by opening them under the File/Open menu item in the BEES software.

- C3020G.DBF—Wool Carpet Tile with Traditional Glue
- C3020J.DBF—Wool Carpet Tile with Low-VOC Glue
- C3020M.DBF—Wool Broadloom Carpet with Traditional Glue

C3020P.DBF—Wool Broadloom Carpet with Low-VOC Glue

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

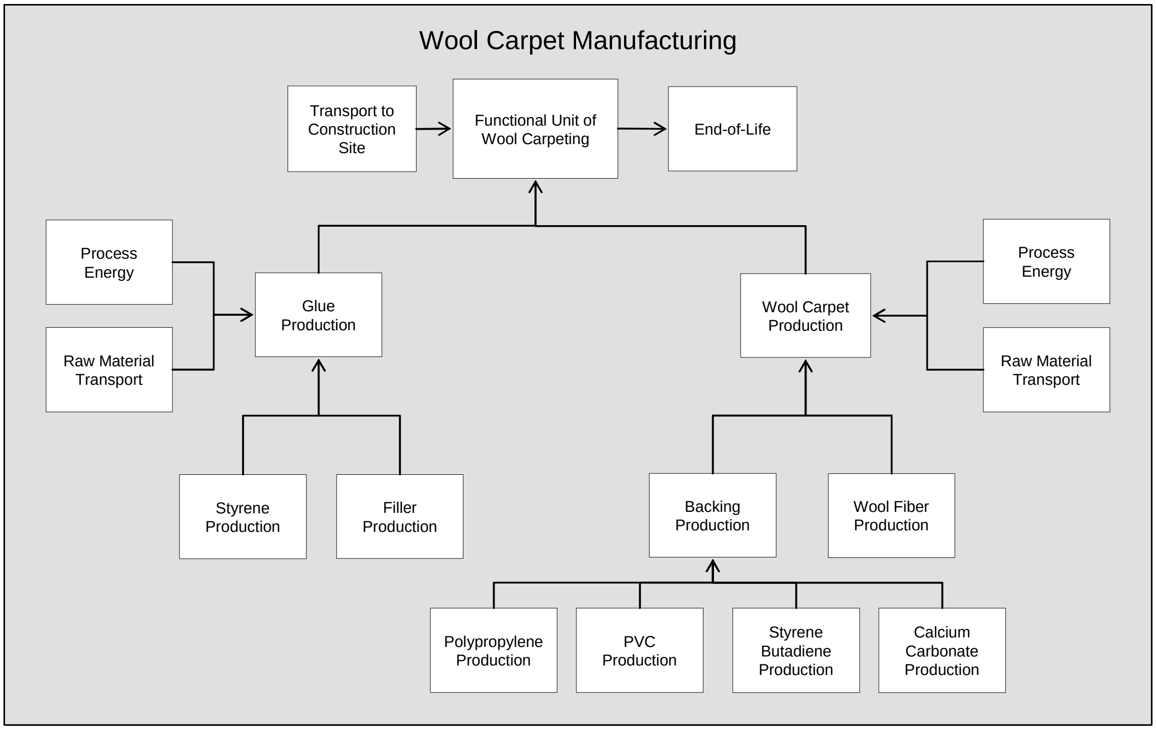

Figure 3.36: Wool Carpet System Boundaries

Raw Materials

Wool carpeting consists of a mix of wool for the facing, a polymer for the backing, and a styrene butadiene/limestone mix that is used to adhere the facing to the backing. The difference between the tile and broadloom carpets is the polymer that makes up the backing, as shown below.

Table 3.93: Wool Carpet Constituents

Constituent	*Material*	*g/m^2 (oz/ft^2)*
Broadloom		
Face Fiber	Wool	1 571 (5.11)
Backing	Polypropylene	139 (0.45)
	Styrene butadiene latex	254 (0.83)
	$CaCO_3$ filler	750 (2.44)
Tile		
Face Fiber	Wool	1 517 (4.94)
Backing	Virgin PVC	133 (0.43)
	Styrene butadiene latex	244 (0.79)
	$CaCO_3$ filler	724 (2.36)

Data for wool production comes from the U.S. LCI Database. Production data for the remaining materials in the carpet comes from the U.S. LCI Database and elements of the SimaPro database, which is based on North American and European data from the late 1990s and 2000s.

Raw wool is greasy and carries debris that needs to be washed off in a process called "scouring." The amount of washed wool per kg of raw wool is 80 %, as shown in the table below along with mass fractions for other raw wool constituents reported by the Wool Research Organization of New Zealand (WRONZ).

Table 3.94: Raw Wool Constituents

Constituent	*Mass Fraction (%)*
Clean fiber (ready to be carded and spun)	80
Grease	6
Suint salts	6
Dirt	8

Grease is recovered at an average rate of 40 %.[151] The scoured fiber is then dried, carded, and spun. The table below lists the main inflows and outflows for the production of wool yarn from raw wool as reported by WRONZ.[152]

Table 3.95: Wool Yarn Production Requirements

Flow	*Amount per kg (per lb) wool yarn*
Input	
Natural Gas	5.375 MJ (3.29 kWh)
Electricity	0.70 MJ (0.43 kWh)
Lubricant	0.063 kg (0.31 lb)
Water	37.5 L (21.79 gal)
Output	
Wool yarn[153]	1 kg (4.85 lb)
Water emissions due to scouring:	
Biochemical Oxygen Demand	4.125 g (0.02 lb)
Chemical Oxygen Demand	11.625 g (0.06 lb)

Most of the required energy is used at the scouring step. Since grease is a co-product of the scouring process, a mass-based allocation is used to determine how much of the energy entering this process is due exclusively to the production of washed wool. One-fourth of the required energy is used for drying. Lubricant is added for blending, carding, and spinning, and some lubricant is incorporated into the wool. Approximately 6 % of the wool is lost during the blending, carding, and spinning processes of yarn production; this waste is accounted for in the BEES data for the manufacturing life-cycle stage.

Manufacturing

Energy Requirements and Emissions.

Wool yarn production into carpet fiber requires additional steps including bleaching, dyeing, and finishing. The inputs to the bleaching process, provided in the table below, are based on a Best

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[151] The non-recovered grease exits the system (e.g., as sludge from water effluent treatment).

[152] These requirements also include processes such as dyeing and blending which take place at this stage.

[153] Accounts for the loss due to the 80 % mass fraction of clean fiber in raw wool.

Available Techniques document for the textile industry.[154] No energy data are available for bleaching, and information for dyeing and finishing is not sufficient to permit inclusion in the BEES model.

Table 3.96: Wool Yarn Bleaching Inputs

Input	*kg/kg (= lb/lb) Wool Yarn*
Stabilizer	0.030
Sodium Tri-Polyphosphate	0.015
Hydrogen Peroxide (35%)	0.200
Formic Acid (85%)	0.002
Sodium Hydrosulphite	0.008

For both wool carpet types, the wool must be "tufted" to produce the carpet face. The face yarn is attached, using a primary coating and tufting needles, to the carpet backing. The energy requirements for this process step are provided in the following table.

Table 3.97: Energy Requirements for Wool Carpet Tufting

Energy Carrier	*MJ/m^2 (kWh/ft^2)*
Electricity	1.79 (0.05)
Natural Gas (industrial boiler)	8.13 (0.21)
Total	9.92 (0.26)

Emissions associated with the manufacturing process arise from the production of electricity and the combustion of natural gas, and are based on the U.S. LCI Database.

Solid Wastes. Nearly 0.01 kg (0.02 lb) of waste is generated from the production of 0.09 m^2 (1 ft^2) of wool broadloom and tile carpeting. The waste is assumed to be disposed of in a landfill.

Transportation. Truck transport of raw materials to the manufacturing plant is assumed to require 402 km (250 mi) by truck, with the exception of wool, which is transported 1 600 km (1000 mi).

Transportation

The distance for transport of wool broadloom carpet and wool carpet tile by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

Wool broadloom carpet and wool carpet tile both are installed using either standard latex glue or a low-VOC latex glue. For the tile, a typical glue application is 0.13 kg/m^2 (0.03 lb/ft^2) of glue per unit installed tile. For the broadloom carpet, 0.13 kg/m^2 (0.14 lb/ ft^2) is applied.

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[154] European Commission, Integrated Pollution Prevention and Control (IPPC): Best Available Techniques for the Textile Industry (July 2003), p.135.

No glue is assumed to be wasted during the installation process, but 5.7 % of the broadloom carpet and 2 % of the wool tile are assumed to be lost as waste; this waste is accounted for in the BEES data for the manufacturing life-cycle stage. All waste is assumed to be disposed of in a landfill.

Use

With a life of 25 years, the carpet is installed twice over a 50-year period. As with all BEES products, the environmental burdens from replacement are included in the inventory data. VOC off-gassing from the carpet and its installation adhesives are included in the BEES modeling.

End of Life

At end of life, the wool broadloom carpet and carpet tile are assumed to be disposed of in a landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

European Commission, Integrated Pollution Prevention and Control (IPPC): Best Available Techniques for the Textile Industry (July 2003).

3.13.8 Forbo Linoleum

Linoleum is a resilient, organic-based floor covering consisting of a backing covered with a thick wearing surface. Oxidized linseed oil and rosin are mixed with the other natural ingredients to form linoleum granules. These granules are then calendared onto a jute backing, making a continuous long sheet. The sheets are hung in drying rooms to allow the naturally occurring process to continue until the product reaches the required flexibility and resilience. The sheets are then removed from the drying rooms, cut into rolls, and prepared for shipment.

Forbo Marmoleum may be installed using either a styrene-butadiene or a no-VOC adhesive. Both installation options are included in BEES. The detailed environmental performance data for these product options may be viewed by opening the following files under the File/Open menu item in the BEES software:

- C3020R.DBF—Forbo Marmoleum with Standard Adhesive
- C3020NN.DBF—Forbo Marmoleum with No-VOC Adhesive

Flow Diagram

The flow diagram below shows the major elements of the production of this product as it is currently modeled for BEES.

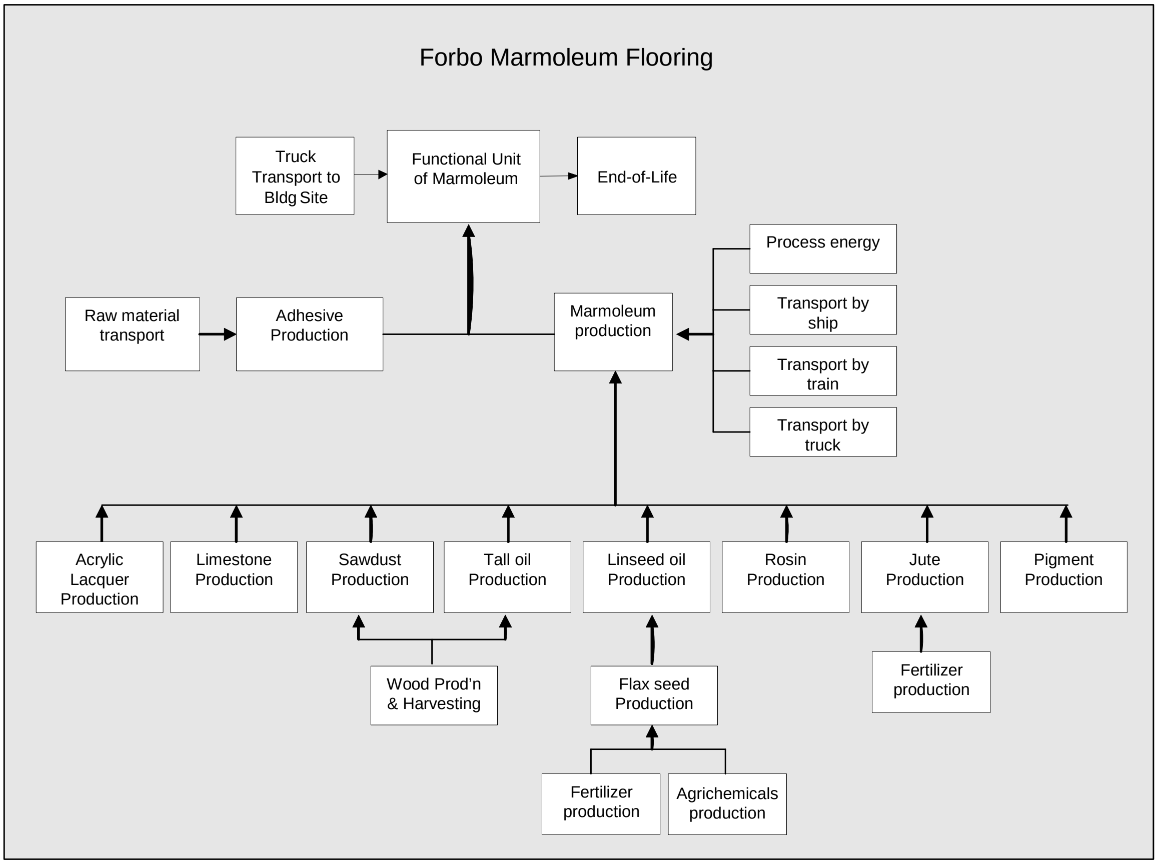

Figure 3.37: Forbo Marmoleum System Boundaries

Raw Materials

The Table below lists the constituents of 2.5 mm (0.10 in) linoleum and their proportions.

Table 3.98: Forbo Marmoleum Constituents

Constituent	*Mass Fraction*[155]	*Mass per Applied Area in g/m^2 (lb/ft^2)*
Linseed oil	20 %	588 (0.12)
Tall oil	13 %	398 (0.08)
Pine rosin	3 %	76 (0.02)
Limestone	20 %	592 (0.12)
Wood flour	31 %	901 (0.18)
Pigment	4 %	101 (0.02)
Jute (backing)	8 %	233 (0.05)
Acrylic lacquer	1 %	12 (0.00)
Total:	**100 %**	**2 901 (0.59)**

For lack of other available data, the cultivation of linseed is based on a modified version of wheat production from the U.S. LCI Database. To harvest the linseed, it is assumed that a diesel tractor is used – approximately 0.61 MJ (0.17 kWh) of diesel is consumed per kg (263 Btu/lb) of

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[155] Marieke Goree, Jeroen Guinée, Gjalt Huppes, Lauran van Oers(The Netherlands: Leiden University, 2000).

linseed harvested. The yield for linseed is 1 038 kg per hectare (420 lb per acre). Energy requirements for linseed oil production include fuel oil and steam, and are allocated on an economic basis between linseed oil (87 %) and linseed cake (13 %). Allocation is necessary because linseed cake is a co-product of linseed oil production, so its production impacts should not be included in the BEES model. The emissions associated with linseed oil production are allocated on the same economic basis. The production of the fertilizers and pesticides is based on elements of the SimaPro database.

The production of tall oil is based on European data for kraft pulping, with inventory flows allocated between kraft pulp and its coproduct, tall oil.[156] Pine rosin production is assumed to have no burdens, since the harvesting of raw pine rosin is done mainly by hand, according to Forbo.

The production of limestone comes from the U.S. LCI Database. Wood flour is sawdust produced as a coproduct of wood processing, and its production is based on the U.S. LCI Database.

Data for production of the pigments used in the product is modeled based on the European production of titanium dioxide, and comes from the SimaPro database. Linoleum backing, jute, is mostly grown in India, Bangladesh, Thailand, and China. Jute is a predominantly rain-fed and requires little fertilizer and pesticides, and cultivation is generally manual. Data for the production of acrylic lacquer materials is based on elements of the SimaPro database.

Manufacturing

Energy Requirements and Emissions. The production of each unit of Marmoleum (0.09 m^2 or 1 ft^2) requires 0.45 MJ (0.13 kWh) of electricity and 1.8 MJ (0.5 kWh) of natural gas. Burdens from the production and use of energy are based on the U.S. LCI Database.

Transportation. Transportation distances for shipment of the raw materials from the suppliers to the manufacturing plant in Europe are provided by Forbo. In addition to raw materials transport, the manufacturing life-cycle stage includes transport of the finished product from the European manufacturing plant to the United States. All of these requirements, involving transport by diesel truck, rail, and ocean freighter, are accounted for, with data based on the U.S. LCI Database.

Transportation

Transportation by diesel truck of the finished product from the U.S. distribution facility to the building site is modeled as a variable in BEES.

Installation

Marmoleum may be installed using 0.0003 kg (0.0007 lb) of either a styrene-butadiene or a no-VOC adhesive. Additionally, an acrylic sealant is applied to the flooring at each installation. Approximately 6 % of the flooring is wasted and landfilled at installation.

Use

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[156] Fédération Européenne des Fabricants de Carton Ondulé (FEFCO), 2003. Found at: http://www.fefco.org/fileadmin/Fefco/pdfs/Technical_PDF/Corrected_database_2003.pdf.

Linoleum is known for its durability. Through evaluation of actual lifetime data, it has been determined that linoleum has a useful life of 30 years.[157] As with all BEES products, the life cycle environmental burdens from replacement are included in the inventory data.

End of Life

At the end of its life, the used flooring is sent to a landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Marieke Goree, Jeroen Guinée, Gjalt Huppes, Lauran van Oers, Environmental Life Cycle Assessment of Linoleum (The Netherlands: Leiden University, 2000).

Fédération Européenne des Fabricants de Carton Ondulé (FEFCO), European Database for Corrugated Board Life Cycle Studies, 2003. Found at: http://www.fefco.org/fileadmin/Fefco/pdfs/Technical_PDF/Corrected_database_2003.pdf

Federal Association of the Sworn Experts for Room and Equipment e.V., *Guide to the Inquiry of Time Values and Decreases in Value of Floor Coverings*, (Bonn, Germany: Federal Association of the Sworn Experts for Room and Equipment e.V.).

Industry Contacts

Tim Cole, Forbo Industries (2002)

3.13.9 UTT Soy Backed Nylon Carpet

Based in Dalton, GA, Universal Textile Technologies (UTT) supplies the carpet and synthetic turf industries with multiple backing systems, including polyurethane backings. BEES includes a nylon carpet made with Biocel, a polyurethane backing for carpets and artificial turf in which a soybean-based polyol replaces a portion of the inputs required to make traditional polyurethane backing.

The detailed environmental performance data for this nylon carpet with a soy polyol backing may be viewed by opening the file C3020U.DBF, for installation with a standard adhesive, and C3020PP.DBF, for installation with a low-VOC adhesive, under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product as it is currently modeled for BEES.

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[157] Federal Association of the Sworn Experts for Room and Equipment e.V., *Guide to the Inquiry of Time Values and Decreases in Value of Floor Coverings*(Bonn, Germany: Federal Association of the Sworn Experts for Room and Equipment e.V.).

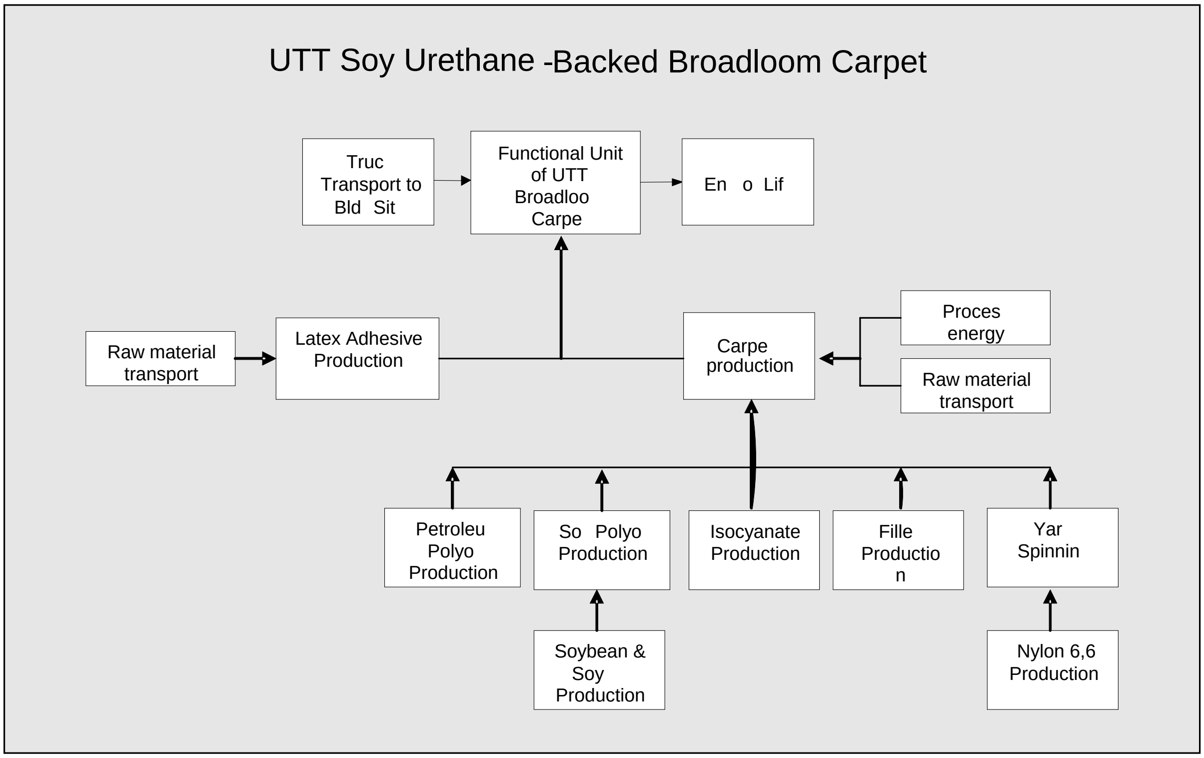

Figure 3.38: UTT Broadloom Carpet System Boundaries

Raw Materials

The following Table presents the product constituents and their relative shares of the product mass.

Table 3.99: UTT Broadloom Carpet Constituents

Constituent	*Mass Fraction*
Soy Polyol	11 %
Petroleum Polyol	11 %
Nylon Yarn	31 %
Isocyanate	9 %
Fillers	31 %
Other Additives	7 %

The yarn consists of Nylon 6,6, represented in BEES by European data from the plastics industry.[158] Data for the production of polyether polyol and isocyanate is provided by American Chemistry Council 2006 data developed for submission to the U.S. LCI Database and elements of the SimaPro database. Soy polyol production is based on life cycle soybean oil production data developed for the U.S. Department of Agriculture (USDA),[159] updated to reflect a newer manufacturing process for the oil processing.

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[158] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

[159] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

Fillers include limestone and fly ash. Limestone data comes from the U.S. LCI Database. Fly ash, the mineral residue produced by burning coal, is captured from electricity-generating power plants' exhaust gases and collected for disposal or use. When used, this byproduct is assumed to be an environmentally “free” input material, although its transport to the production site is included in the BEES model. Data for all other additives are taken from elements of the SimaPro database.

Manufacturing

Energy Requirements and Emissions. The manufacturing process for UTT soy backed nylon carpet consists of forming the polyurethane backing, curing the backing, and adhering it to the nylon facing. Site data are used to quantify the energy inputs to the production process, which consist of purchased electricity (0.021 kWh/ft^2) and natural gas (0.23 MJ/ft^2). Data for all energy precombustion and use comes from the U.S. LCI Database.

Transportation. Transportation distances for shipment of the raw materials from the suppliers to the manufacturing plant are provided by UTT. The materials are transported by diesel truck, based on the U.S. LCI Database.

Transportation

Transport by diesel truck from the manufacturing plant in Dalton, Georgia to the building site is based on data from the U.S. LCI Database. The BEES user is free to adjust the default transportation distance.

Installation

The installation adhesive for the standard UTT carpet product is assumed to be the same traditional contact adhesive used to install the generic BEES carpet products. The other UTT carpet product is installed using a low-VOC adhesive . For both, the average application is assumed to require 0.65 kg adhesive/m^2 (0.13 lb/ft^2). About 3.5 % of the product is wasted during its installation.

Use

The lifetime of UTT broadloom carpet is assumed to be 11 years, consistent with the 11-year lives assumed for the other broadloom carpets in BEES, so it is replaced 4 times after the initial installation over the 50-year BEES use period. As with all BEES products, the life cycle environmental burdens from these replacements are included in the inventory data.

End of Life

At each replacement, it is assumed that 5 % of the used carpet is recycled, with the remaining 95 % going to a landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Boustead, I., Eco-profiles of the European Plastics Industry: POLYAMIDE 66 (NYLON 66) (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Sheehan, J. et al., *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus,* NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

Industry Contacts

Jim Pollack, Omnitech International (2005)

3.13.10 C&A Carpet

C&A is a manufacturer of modular tile and six-foot structured back carpeting for the commercial market. As part of Tandus, C&A works with sister brands Monterey and Crossley to provide customized floor covering solutions for its customers. The four C&A products listed below are included in BEES.

Table 3.100: C&A Products Included in BEES

Product Line	***Style***
ER3 RS Modular Tile	Habitat (nylon 6,6 with 80 % pre-consumer content)
ER3 RS Cushion Roll Goods	Intersection (nylon 6,6 with 90 % pre-consumer content)
Ethos RS Modular Tile	Topography (nylon 6,6 with 80 % pre-consumer content)
Ethos RS Cushion Roll Goods	Yosemite (nylon 6,6 with 80 % pre-consumer content)

Some of C&A's carpets are available as "climate neutral" products, meaning the greenhouse gases emitted over their life cycles are optionally offset or balanced. The BEES user may choose either the traditional or climate neutral versions of these products when selecting them for analysis.

The detailed environmental performance data for these products may be viewed by opening the following files under the File/Open menu item in the BEES software:

- ER3 RS Modular Tile: C3020X.DBF
- ER3 RS Cushion Roll Goods: C3020Y.DBF
- Ethos RS Modular Tile: C3020Z.DBF

- Ethos RS Cushion Roll Goods: C3020AA.DBF

Flow Diagram
The flow diagrams below show the major elements of the production of these products as they are currently modeled for BEES.

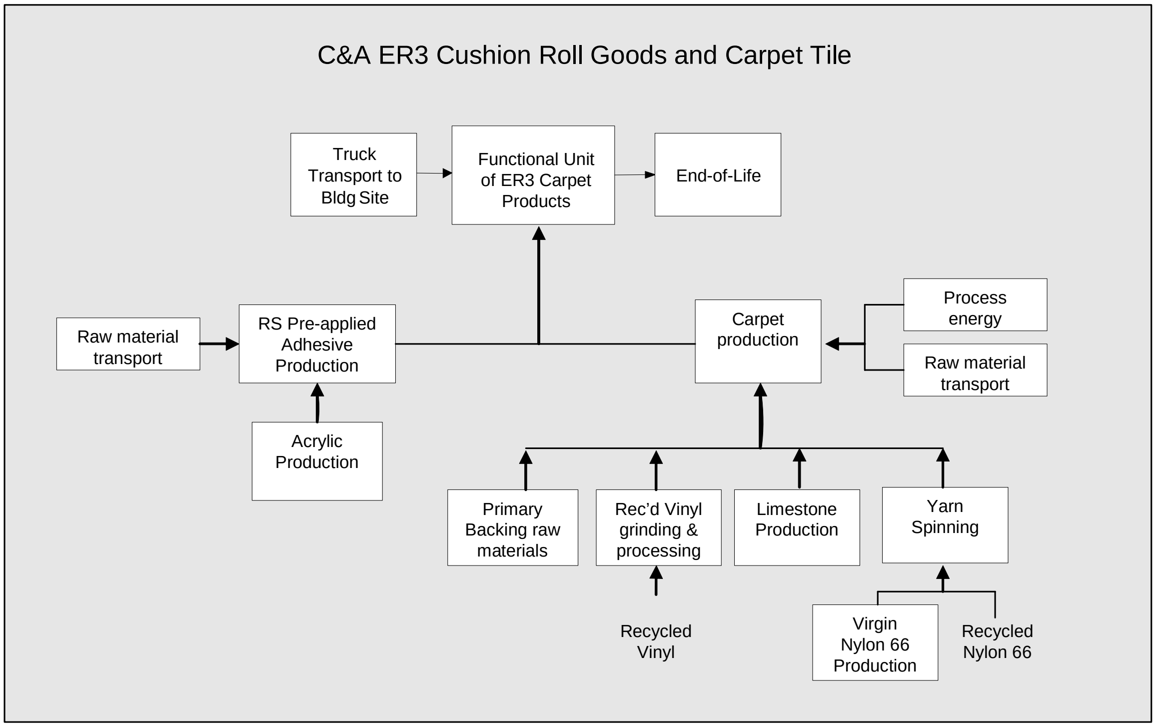

Figure 3.39: C&A ER3 Flooring Products System Boundaries

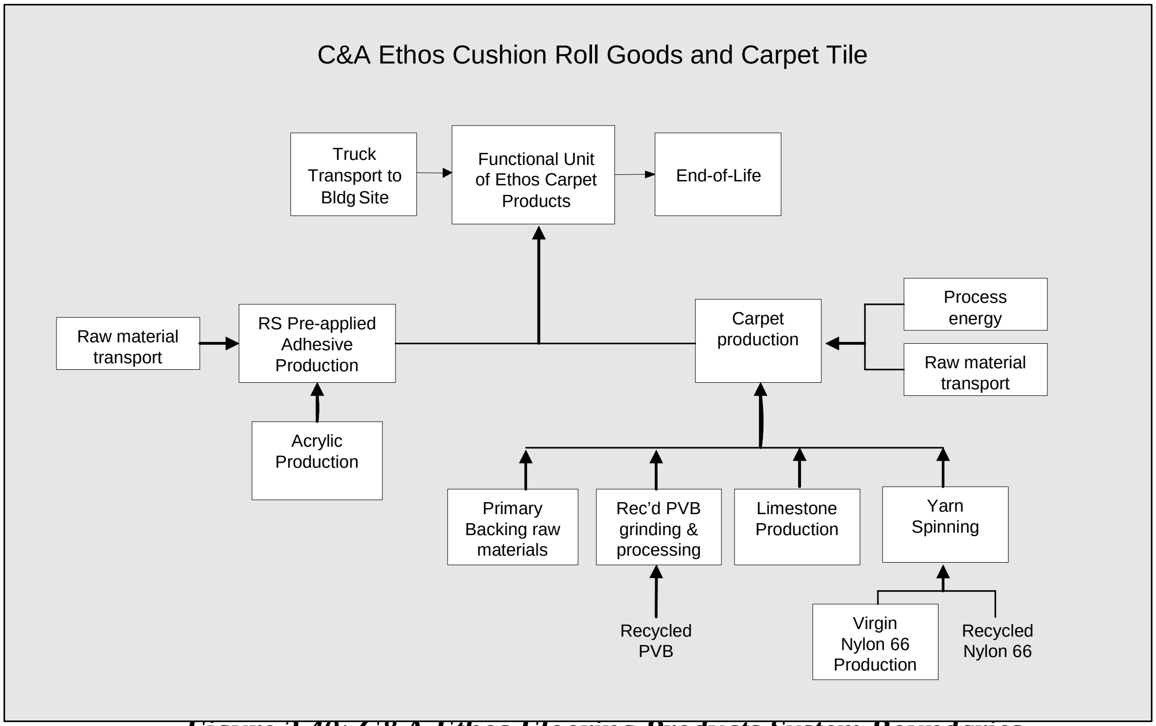

Figure 3.40: C&A Ethos Flooring Products System Boundaries

Raw Materials

The following tables present the constituents by mass percentage of the ER3 and Ethos products.

Table 3.101: C&A ER3 Flooring Constituents

Constituent	***ER3 Tile Mass Fraction***	***ER3 Cushion Roll Mass Fraction***
Nylon 6,6 Yarn	2 %	2 %
Post-industrial nylon 6,6	10 %	17 %
Primary backing	5 %	4 %
Recycled vinyl/Limestone (filler)	72 %	62 %
Other Additives (precoat, etc.)	11 %	15 %
Total:	**100 %**	**100 %**

Table 3.102: C&A Ethos Flooring Constituents

Constituent	***Ethos Tile Mass Fraction***	***Ethos Cushion Roll Mass Fraction***
Nylon 6,6 Yarn	3 %	3 %
Post-industrial nylon 6,6	11 %	11 %
Primary backing	4 %	4 %
Recycled PVB/ Limestone (filler)	65 %	65 %
Other Additives (precoat, etc.)	17 %	17 %
Total:	**100 %**	**100 %**

Yarn for the ER3 products consists primarily of post-industrial (PI) nylon 6,6. While producing the PI nylon 6,6 is not—and should not—be accounted for, spinning it into yarn plus its transportation to the manufacturing site is taken into account in the model. Data for the production of virgin nylon 6,6 comes from the European plastics industry.[160]

The secondary backing for ER3 products is made from recycled post consumer (PC) and PI vinyl backed carpet and waste. As with the PI nylon 6,6, no production data is included, with the exception of data for the material's processing into backing and transportation to the site.

The secondary backing for Ethos products is made from PC polyvinyl butyral (PVB) film recovered from windshield and safety glass recycling facilities. The transportation and processing of the PVB are accounted for in the model.

Data for materials in the primary backing and for other additives comes from the U.S. LCI Database and elements of the SimaPro database, which includes both North American and European data from the late 1990s and 2000s. Data for the limestone comes from the U.S. LCI Database.

Manufacturing

Energy Requirements. The manufacturing process for C&A's products consists of tufting the nylon yarn, applying the precoat compound, and joining the secondary backing. The energy to produce ER3 tile and the two Ethos products is comprised of 30 % electricity and 70 % natural gas. The ER3 cushion rolls require more energy to produce due to yarn dyeing processes; energy sources include electricity (27 %), natural gas (59 %), fuel oil (12 %), and biodiesel (2 %). The production and use of these energy sources come from the U.S. LCI Database, and biodiesel production data comes from a National Renewable Energy Laboratory (NREL) LCA study on biodiesel use in an urban bus.[161]

Transportation. Transportation distances for shipment of the raw materials from the suppliers to the manufacturing plant are provided by C&A. Most of the materials are transported exclusively by diesel truck, while some are transported by both diesel truck and rail. All forms of transportation are included in the model, and all data is based on the U.S. LCI Database.

Waste. Any waste generated during the manufacturing process is recycled back into other carpet products.

Transportation

The distance for transport by diesel truck from the C&A manufacturing plant in Dalton, Georgia to the building site is modeled as a variable in BEES. Transportation emissions allocated to each product depends on its overall mass, as given in the following Table.

Table 3.103: C&A Products' Mass and Density

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[160] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

[161] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

Product	***Mass per Applied Area in kg/m^2 (lb/ft^2)***	***Density in kg/m^3 (lb/ft^3)***
ER3 Modular Tile	4.4 (0.90)	674.4 (42.1)
ER3 Cushion Roll Goods	3.7 (0.76)	586.3 (36.6)
Ethos Modular Tile	3.9 (0.80)	619.9 (38.7)
Ethos Cushion Roll Goods	3.1 (0.63)	488.6 (30.5)

Installation

C&A products are produced with RS pre-applied adhesive, which provides a "peel and stick" installation system. It simplifies installation, reduces VOC and odors associated with the use of wet adhesives, and does not require an air-out period. According to C&A, carpet waste of less than 3 % is generated during installation. Scraps are typically kept at the building site for future repairs.

Use

C&A's roll products are replaced after 25 years. The modular tile products are replaced after 15 years. As with all BEES products, life cycle environmental burdens from these replacements are included in the inventory data.

End of Life

All C&A products are 100 % recyclable in their in-house closed-loop recycling process.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Boustead, I., Eco-profiles of the European Plastics Industry: POLYAMIDE 66 (NYLON 66) (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Sheehan, J. et al., *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus*, NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

Industry Contacts

Lynn Preston, Tandus (June 2006)

3.13.11 Interface Carpet

Based in Atlanta, Georgia, Interface is active in the global commercial interiors market, offering modular and broadloom carpets, fabrics, interior architectural products, and specialty chemicals. Nine Interface carpet products are included in BEES. They are listed below, together with the names of the BEES files containing their detailed environmental performance data.

Bentley Prince Street Division:

- UPC Recycled Nylon Carpet Tile (C3020VV.DBF)
- UPC Recycled Nylon Carpet Tile With Cool Carpet (C3020WW.DBF)
- Scan Recycled Nylon Broadloom Carpet (C3020TT.DBF)
- Scan Recycled Nylon Broadloom Carpet With Cool Carpet (C3020UU.DBF)
- Capri Recycled Nylon Broadloom Carpet (C3020RR.DBF)
- Capri Recycled Nylon Broadloom Carpet With Cool Carpet (C3020SS.DBF)

InterfaceFLOR (IFC) Division:

- Entropy Recycled Nylon And Vinyl Carpet Tile With Cool Carpet (C3020XX.DBF)
- Sabi Recycled Nylon And Vinyl Carpet Tile With Cool Carpet (C3020QQ.DBF)
- Transformation Recycled Nylon And Vinyl Carpet Tile With Cool Carpet (C3020CC.DBF)

Some of Interface's products are "climate neutral" under its Cool Carpet program. Climate neutral refers to products whose greenhouse gas (GHG) emissions over their life cycles are offset or balanced. The GHGs of IFC carpets under the Cool Carpet program are offset by 16.1 kg (35.4 lb) CO_2-equivalents/yd^2, while Bentley Prince Street products' GHGs are offset by 22.0 kg (48.4 lb) CO_2-equivalents/yd^2. These values are based upon internal Interface LCAs. Because these values are greater than those in the life cycle inventories compiled for BEES, the BEES Global Warming Potential results for Cool Carpets are set to zero. Entropy, Sabi, and Transformation carpet tiles are always Cool Carpets, while for the other Interface products offered in BEES, the customer has the choice of purchasing the Cool Carpet option for an additional cost per square unit. All these options are offered in BEES.

Flow Diagram

The flow diagram below shows the major elements of the production of these products as they are currently modeled for BEES.

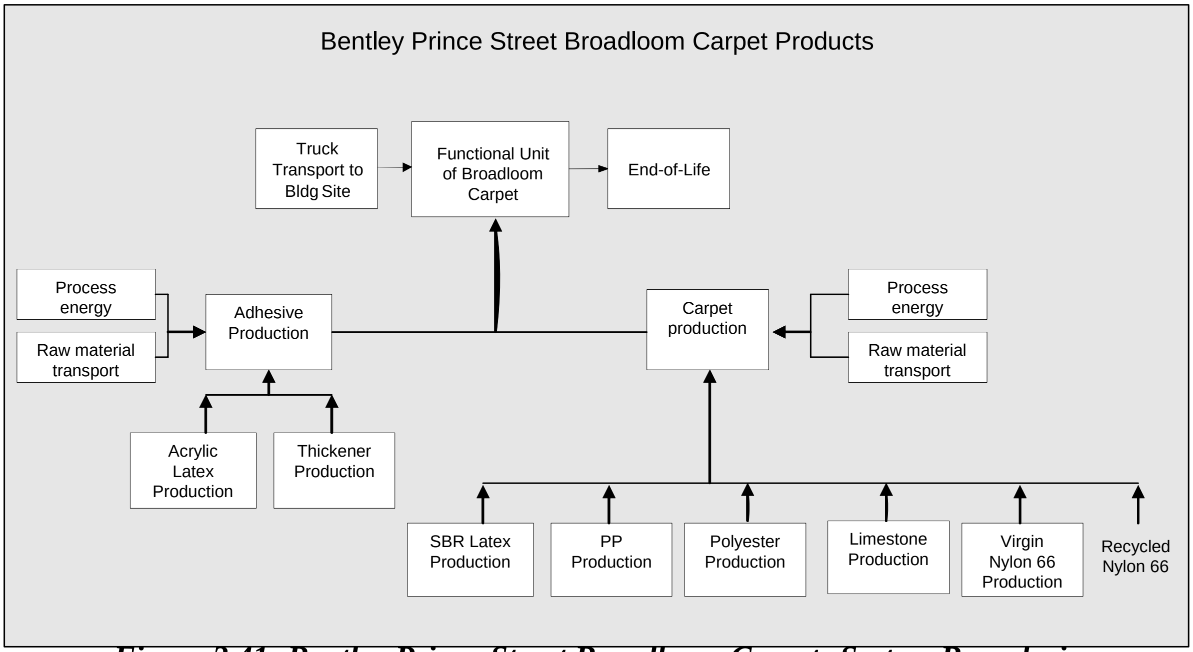

Figure 3.41: Bentley Prince Street Broadloom Carpets System Boundaries

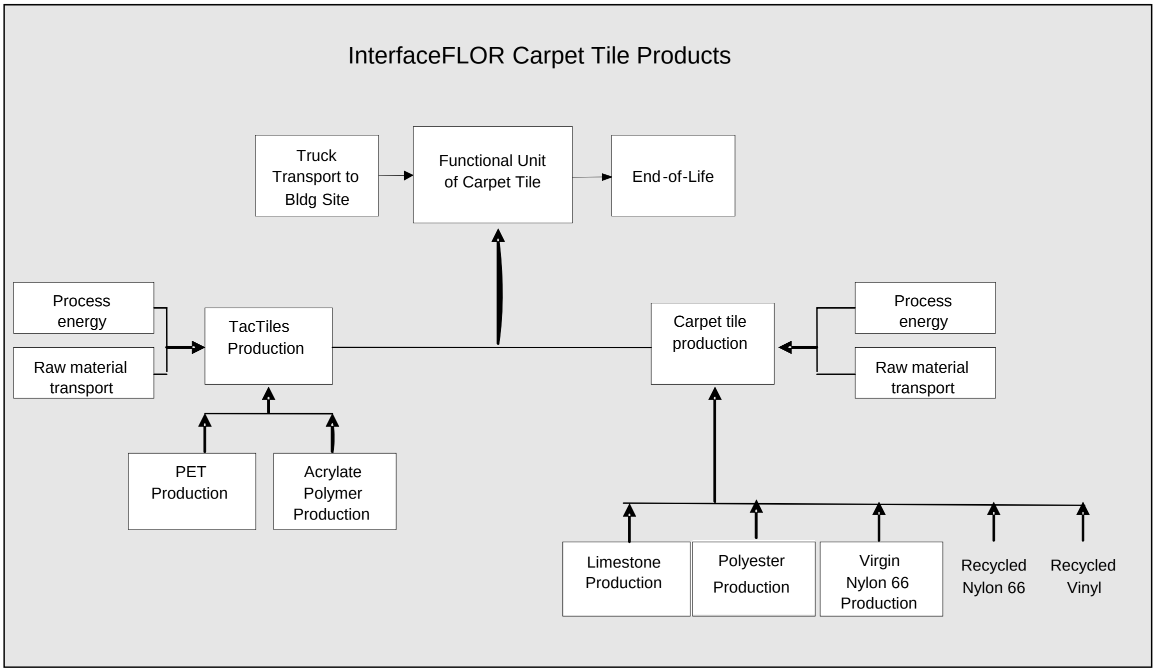

Figure 3.42: InterfaceFLOR Carpet Tiles System Boundaries

Raw Materials

Interface's two carpet divisions produce like mixes of materials, as shown in the tables below.

Table 3.104: Bentley Prince Street Commercial Carpet Constituents

Constituent	*UPC Mass Fraction (%)*	*Scan Mass Fraction (%)*	*Capri Mass Fraction (%)*
Virgin Nylon 6,6	34	34	30
Recycled Nylon 6,6 (pre-consumer)	6	6	10
Polypropylene or Polyester primary backing	5	5	5
SBR Latex backing	11	11	11
Limestone	31	31	31
Other Additives	13	13	13

Table 3.105: InterfaceFLOR Commercial Carpet Constituents

Constituent	*Entropy Mass Fraction (%)*	*Sabi Mass Fraction (%)*	*Transformation Mass Fraction (%)*
Virgin Nylon 6,6	9	5	6
Recycled Nylon 6,6 (pre-consumer)	5	5	6
Polyester primary backing	2	2	2
Recycled vinyl backing (pre-consumer)	22	23	23
Recycled vinyl backing (post-consumer)	39	41	40
Limestone (filler)	14	15	14
Other Additives	9	9	9

Data for nylon resin, polyamide 6,6, comes from publicly-available data from the European plastics industry.[162] Interface provided the energy required to spin the nylon into yarn (approximately 1.7 MJ/kg yarn). The nylon 6,6 and vinyl used in these carpet products have significant recycled content. These recycled materials carry no environmental burdens from the production of the virgin materials. However, they do carry impacts from transport after leaving the waste stream and subsequent processing. For example, the electricity used to grind down post-industrial and post-consumer material to a usable size is assigned to the recycled materials. This data is provided by Interface.

For the broadloom applications, the nylon yarn is back-coated with styrene butadiene rubber (SBR) to provide stability. Both styrene and butadiene production data come from the most recent APME data sets.[163,164] For the carpet tiles, ethylene vinyl acetate (EVA) is used to bind the nylon to the primary substrate. Data representing this process comes from public and site-specific data in the SimaPro database. Data for polypropylene, polyester (polyethylene terephthalate, or PET), and the limestone filler comes from the U.S. LCI Database.

Manufacturing

Energy Requirements and Emissions. The manufacturing process for the UPC, Scan, and Capri carpets essentially consists of weaving the nylon yarn, applying the precoat compound, and joining the yarn to the backing. This process requires both purchased electricity and natural gas. The production of a ft^2 of UPC, Scan, or Capri carpet requires approximately 0.24 MJ (0.07 kWh) of electricity and 2.1 MJ (0.58 kWh) from natural gas.

The manufacturing process for Entropy, Sabi, and Transformation carpet tile products consists of tufting the nylon yarn, applying the EVA adhesive, and joining the yarn to the backing. Producing 0.09 m^2 (1 ft^2) of each of these carpet tiles requires approximately 0.59 MJ (0.16

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[162] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

[163] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

[164] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

kWh) of electricity and 0.40 MJ (0.11 kWh) from natural gas. All energy production and consumption data come from the U.S. LCI Database.

Waste. A small amount of manufacturing waste, as reported by Interface, is included in each of its BEES carpet products.

Transportation. Manufacturer-reported transportation distances for shipment of the raw materials from the suppliers to the Interface plants are accounted for through diesel truck modeling based on the U.S. LCI Database.

Transportation

The transportation distance for diesel trucking from the Interface manufacturing plant in Georgia or California to the building site is modeled as a variable in BEES. The quantity of transportation emissions allocated to each product depends on the overall mass of the product, as given in the Table below.

Table 3.106: Interface Carpet Density

Product	***Mass*** kg/m^2 (lb/ft^2)	***Density*** kg/m^3 (lb/ft^3)
Scan	2.6 (0.53)	343 (21.4)
UPC	2.6 (0.53)	343 (21.4)
Capri	2.4 (0.49)	318 (19.9)
Entropy	4.4 (0.90)	616 (38.5)
Sabi	4.2 (0.86)	608 (38.0)
Transformation	4.3 (0.88)	602 (37.6)

Installation

The Interface carpet products evaluated by BEES are installed using a contact adhesive. The low-VOC TacTiles material, consisting of PET and acrylate polymer, is a tape that is applied between IFC carpet tiles at installation. A low-VOC glue is used for Bentley Prince Street installations. The following installation waste percentages are incorporated into the BEES models: UPC and Scan, 3 %; Capri, 5 %; and Entropy, Sabi, and Transformation, 1 %.

Use

With lifetimes of 15 years, the Entropy, Sabi, UPC, and Transformation carpet tiles are replaced 3 times over the 50-year BEES use period. The broadloom carpets, Scan and Capri, have 11-year lives, requiring 4 replacements over the use period. As with all BEES products, life cycle environmental burdens from these replacements are included in the inventory data.

End of Life

According to the manufacturer, at end of life, the Entropy, Sabi, and Transformation carpet tiles are recycled in a closed loop process, avoiding disposal in a landfill. At end of life for Capri, UPC, and Scan products, an average of 12.5 % is reclaimed.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 7.0 LCA Software*. 2005. The Netherlands.

Boustead, I., Eco-profiles of the European Plastics Industry: POLYAMIDE 66 (NYLON 66) (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Boustead, I., Eco-profiles of the European Plastics Industry: STYRENE (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Boustead, I., Eco-profiles of the European Plastics Industry: BUTADIENE (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Industry Contacts

John Jewell and Paul Firth, Interface (July 2006)

3.13.12 J&J Industries Carpet

J&J Industries is a privately-held manufacturer of commercial carpet, primarily for corporate interiors but also for healthcare, retail, education, and government facilities. The company provided data on one of its 0.8 kg (28 oz) products: Certificate with Styrene Butadiene Resin (SBR) Backing. The detailed environmental performance data for this product may be viewed by opening the file C3020DD.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product as it is currently modeled for BEES.

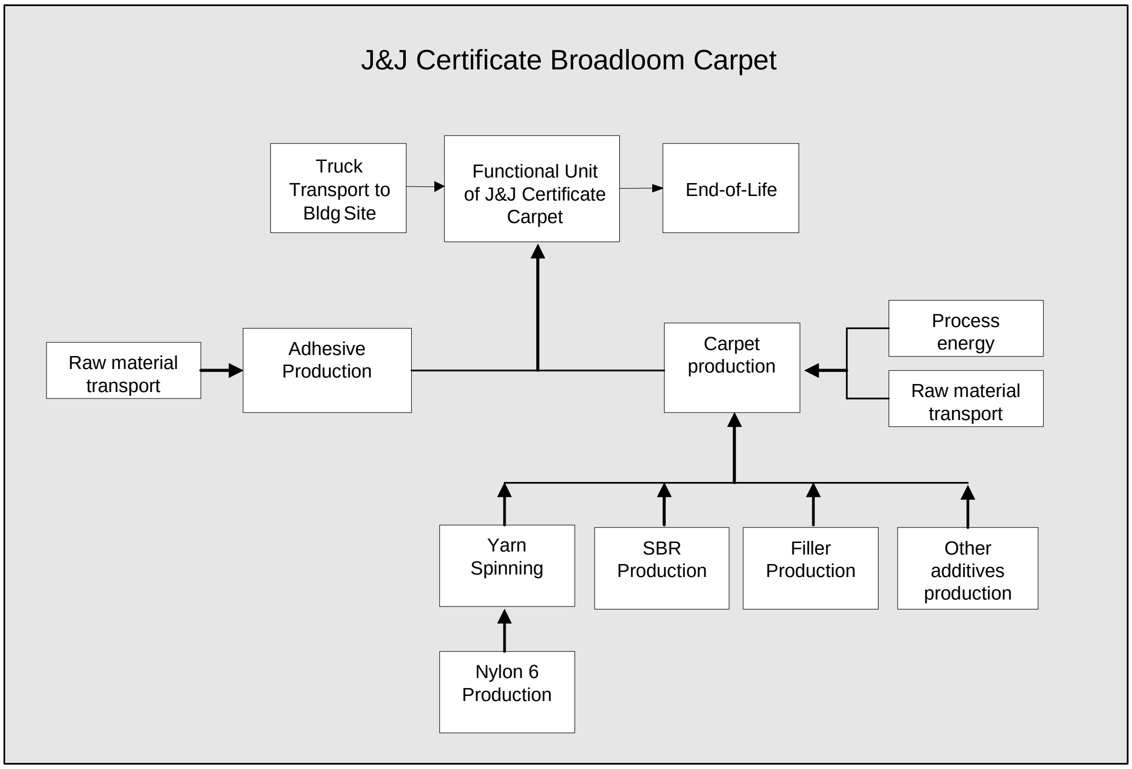

Figure 3.43: J&J Certificate Broadloom Carpet System Boundaries

Raw Materials

The following Table presents the constituents of the J&J product and their relative quantities.

Table 3.107: J&J Certificate Broadloom Carpet Constituents

Constituent	*Mass Fraction*
Yarn (Nylon 6)	32 %
Styrene Butadiene Resin (SBR)	10 %
Limestone	41 %
Other Additives	16 %

The yarn consists of Nylon 6, which is produced from the polymerization of caprolactam and whose BEES data comes from public data provided by the European plastics industry.[165] The SBR used in the carpet comes from European plastics data on styrene[166] and butadiene.[167] Limestone filler production data comes from the U.S. LCI Database.

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[165] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

[166] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

[167] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Manufacturing

Energy Requirements and Emissions. Certificate's manufacturing process consists of tufting the nylon yarn and joining the yarn to the backing. This process uses purchased electricity, natural gas, and other fossil fuels. The production of one unit of carpet (0.09 m^2, or 1 ft^2) requires 1.2 MJ (0.34 kWh) of electricity, 1.58 MJ (0.439 kWh) of natural gas, and less than 0.03 MJ (0.01 kWh) of other fossil fuels. Energy production and combustion data are modeled based on the U.S. LCI Database.

Transportation. Transportation distances for shipment of the raw materials from the suppliers to the manufacturing plant are provided by J&J. The materials are transported by diesel truck, based on the U.S. LCI Database.

Transportation

The distance for diesel truck transport from the J&J manufacturing plant in Dalton, Georgia to the building site is modeled as a variable in BEES, and transportation burdens are based on data from the U.S. LCI Database.

Installation

Certificate broadloom carpet is assumed to be installed using a low-VOC adhesive. The average application is assumed to require 0.03 kg (0.07 lb) of adhesive per unit of carpet (0.09 m^2, or 1 ft^2). On average, 7 % of the carpet and 5 % of the adhesive are lost during installation.

Use

The lifetime of the carpet is assumed to be 11 years, consistent with lives for other broadloom carpets in BEES, and meaning it is replaced 4 times after initial installation over the 50-year BEES use period. As with all BEES products, life cycle environmental burdens from these replacements are included in the inventory data.

End of Life

At end of life, it is assumed that Certificate is sent to the landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Boustead, I., Eco-profiles of the European Plastics Industry: POLYAMIDE 6 (NYLON 6) (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Boustead, I., Eco-profiles of the European Plastics Industry: POLYAMIDE 66 (NYLON 66) (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Boustead, I., Eco-profiles of the European Plastics Industry: BUTADIENE (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Industry Contacts

Howard Elder, J&J Industries (2002)

3.13.13 Mohawk Carpet

Mohawk Industries is the second-largest manufacturer of commercial and residential carpets and rugs in the United States and one of the largest carpet manufacturers in the world. Mohawk is involved in all aspects of carpet and rug production, from raw materials development to advanced tufting, weaving, and finishing. The company provided data on two broadloom carpets: Regents Row, a woven commercial carpet, and Meritage, a tufted commercial carpet. The detailed environmental performance data for these products may be viewed by opening the following files under the File/Open menu item in the BEES software:

- C3020FF.DBF—Mohawk Regents Row
- C3020GG.DBF—Mohawk Meritage

Flow Diagram

The flow diagrams below show the major elements of the production of these products as they are currently modeled for BEES.

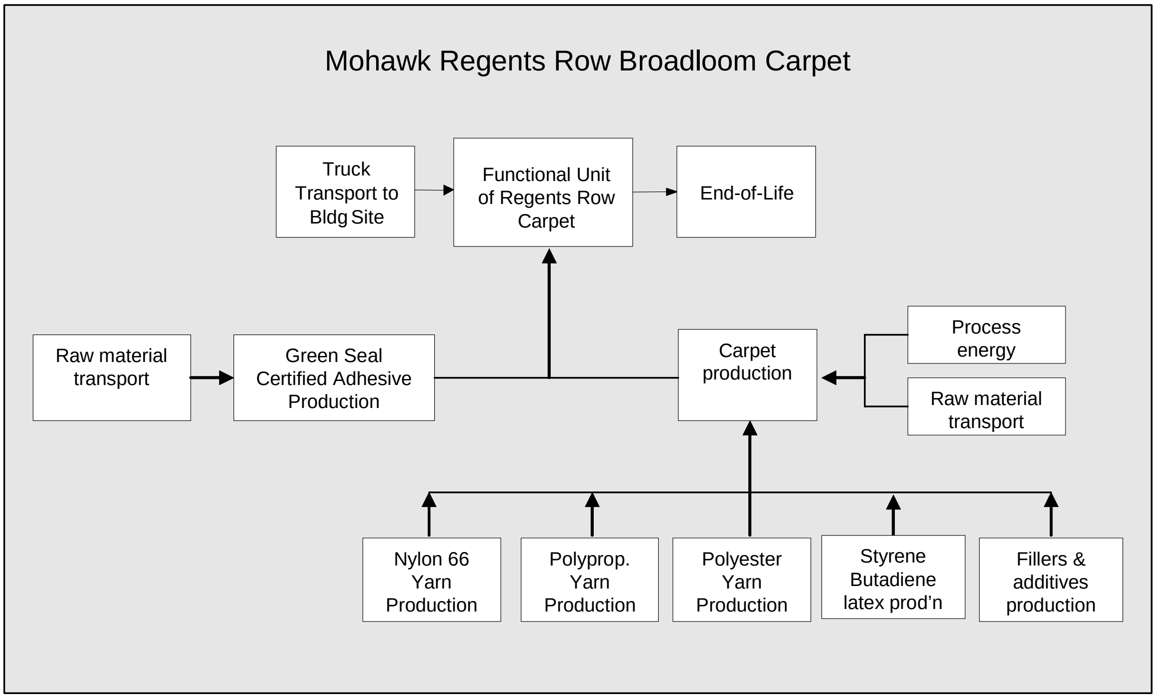

Figure 3.44: Mohawk Regents Row Broadloom Carpet System Boundaries

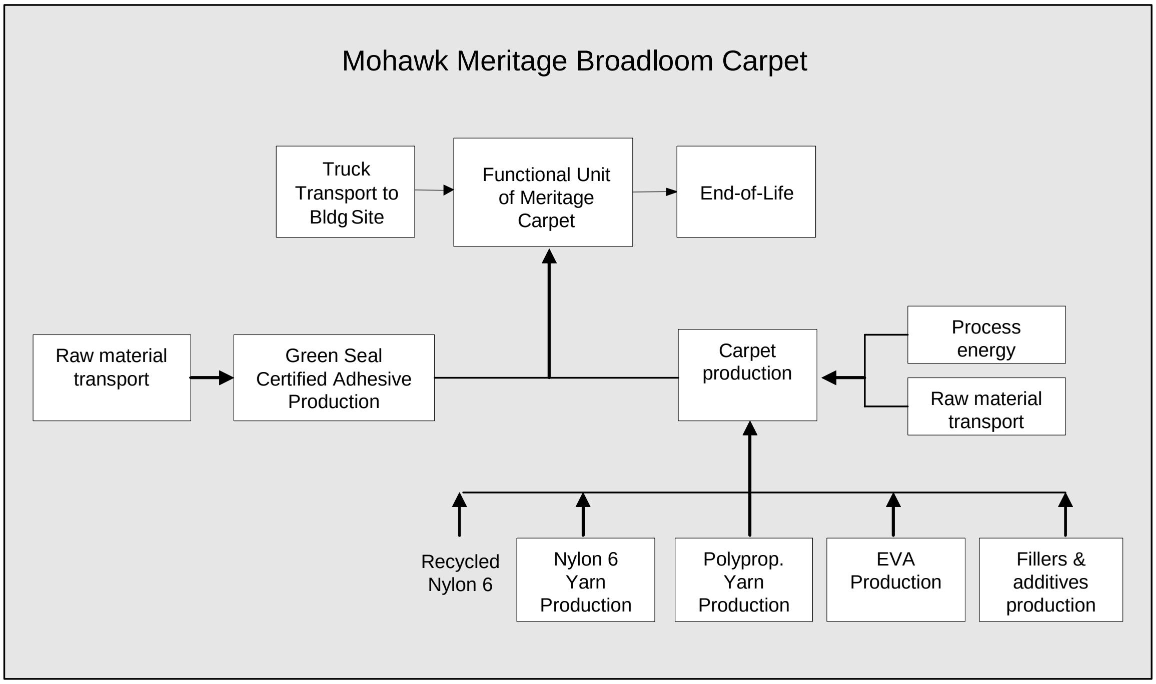

Figure 3.45: Mohawk Meritage Broadloom Carpet System Boundaries

Raw Materials

The two Mohawk carpets are produced from different materials and have different ratios of backing to yarn. The mixture of the main constituents of each carpet is listed in the Table below.

Table 3.108: Mohawk Broadloom Carpet Constituents

Constituent	*Regents Row Mass Fraction*	*Meritage Mass Fraction*
Yarn (nylon 6; 50 % recycled)	--	49 %
Yarn (nylon 6,6)	51 %	--
Backing	16 %	9 %
Precoat and other additives	33 %	42 %

The yarn for Regents Row carpet consists of woven nylon 6,6. Data for the production of virgin nylon 6,6 is publicly-available from the European plastics industry.[168] The yarn for Meritage carpet is 50/50 recycled-virgin nylon 6. The virgin nylon 6 is produced from the polymerization of caprolactam and is based on publicly-available European data.[169] While producing the recycled nylon 6 is not—and should not be—accounted for, spinning it into yarn plus its transportation to the manufacturing site are included in the BEES model.

The backing for the Regents Row carpet is a 50/50 mix of polypropylene and polyester fibers. The Meritage carpet only uses polypropylene for the backing material. Data for these backing materials comes from American Chemistry Council 2006 data developed for submission to the U.S. LCI Database.

Since the Regents Row carpet is woven, the nylon yarn is back-coated with styrene butadiene latex to provide stability. For the Meritage carpet, Ethylene Vinyl Acetate (EVA) is used to adhere the backing to the tufted nylon. Life cycle inventory data for styrene and butadiene are taken from European plastics data,[170] and EVA data are derived from elements of the SimaPro database. A majority of the “other additives” is limestone filler, whose data is based on the U.S. LCI Database. The remaining additives’ production data are based on the SimaPro database and U.S. LCI Database.

Manufacturing

Energy Requirements and Emissions. The manufacturing process for Mohawk Regents Row carpet consists of interlacing face yarns with backing yarns which are then coated with finish chemicals. This process requires both purchased electricity and natural gas. The production of each unit of Regents Row carpet (0.09 m^2, or 1 ft^2) requires 0.4 MJ (0.1 kWh) of electricity and 0.73 MJ (0.20 kWh) of natural gas. The manufacturing process for Meritage consists of tufting the nylon yarn into the backing foundation and coating the fabric with the EVA chemical system. This process requires 0.6 MJ (0.18 kWh) of electricity and 0.71 MJ (0.20 kWh) of natural gas

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[168] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

[169] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

[170] Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005) and Boustead, I.(Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

per unit. All energy production and combustion data is based on the U.S. LCI Database.

Transportation. Transportation distances for shipment of the raw materials by diesel truck from the suppliers to the manufacturing plant are provided by Mohawk. Diesel trucking burdens are based on the U.S. LCI Database.

Transportation

The transportation distance from the Mohawk manufacturing plant in South Carolina or Georgia to the building site is modeled as a variable in BEES. Both products are shipped by diesel truck. The quantity of transportation emissions allocated to each product depends on the overall mass of the product, as given in the Table below.

Table 3.109: Mohawk Carpet Density

Product	***Mass per Applied Area in kg/m^2 (lb/ft^2)***	***Density in kg/ m^3 (lb/ft^3)***
Regents Row	2.34 (0.47)	336.67 (22.27)
Meritage	2.41 (0.48)	346.67 (22.93)

Installation

Both Mohawk carpets are installed using a low-VOC adhesive. The average application requires about 0.04 kg (0.09 lb) of adhesive per unit of carpet (0.09 m^2, or 1 ft^2). For both carpets, approximately 5 % of the carpet and adhesive is wasted during installation; this is incorporated into the BEES product models.

Use

All BEES nylon broadloom carpets are assumed to have lifetimes of 11 years. Thus, both Mohawk broadloom carpets are assumed to be replaced four times over the 50-year BEES use period. As with all BEES products, life cycle environmental burdens from these replacements are included in the inventory data.

End of Life

At end of life, it is assumed that the Mohawk products are sent to the landfill.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Boustead, I., Eco-profiles of the European Plastics Industry: POLYAMIDE 66 (NYLON 66) (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Boustead, I., Eco-profiles of the European Plastics Industry: POLYAMIDE 6 (NYLON 6) (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Boustead, I., Eco-profiles of the European Plastics Industry: STYRENE (Association of

Plastics Manufacturers of Europe, March 2005) and Boustead, I., Eco-profiles of the European Plastics Industry: BUTADIENE (Association of Plastics Manufacturers of Europe, March 2005). Found at: www.plasticseurope.org.

Industry Contacts

Frank Endrenyi, Mohawk Industries (2002)

3.13.14 Natural Cork Flooring

Natural Cork is a U.S. supplier of cork flooring and wall coverings. It distributes products manufactured by Granorte, a Portuguese company that recycles cork waste from the production of cork bottle stoppers. The energy used to produce the cork tiles comes mainly from waste cork powder. Natural Cork provided data on two of its products: cork parquet tile and cork floating floor plank. The detailed environmental performance data for these products may be viewed by opening the following files under the File/Open menu item in the BEES software:

- Natural Cork Parquet Floor Tile —C3020HH.DBF
- Natural Cork Floating Floor Plank—C3020II.DBF

Flow Diagram

The flow diagrams below show the major elements of the production of these products as they are currently modeled for BEES.

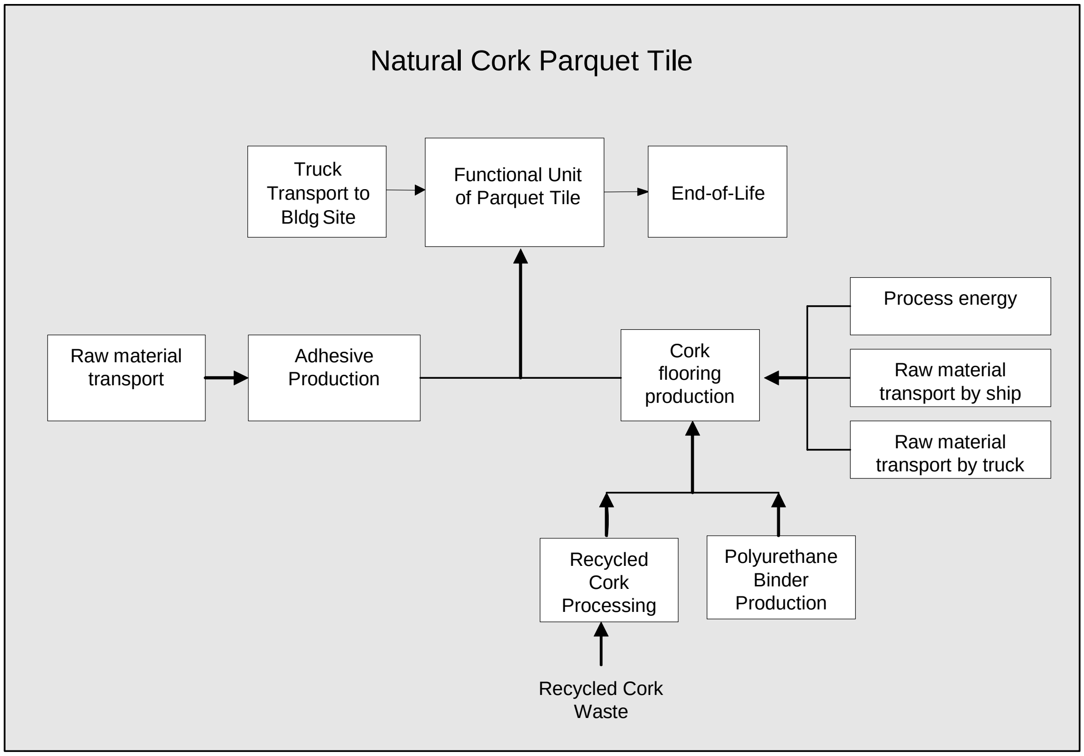

Figure 3.46: Natural Cork Parquet Floor Tile System Boundaries

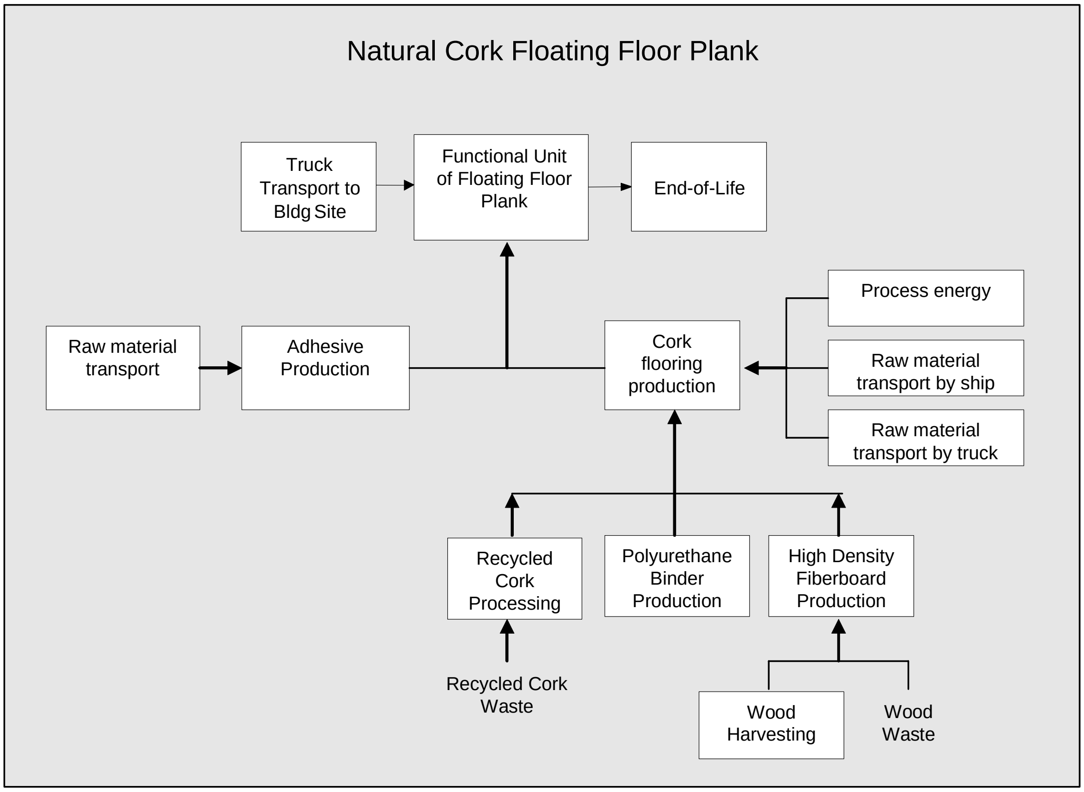

Figure 3.47: Natural Cork Floating Floor Plank System Boundaries

Raw Materials

Both Natural Cork floor products use a cork sheet made from a combination of recycled cork waste and urethane binder. The floating floor plank also includes a layer of High Density Fiberboard (HDF) cut into a tongue-and-groove pattern. The mixture of the main constituents of each floor product is listed in the Table below.

Table 3.110: Natural Cork Flooring Constituents

Constituent	***Parquet Floor Mass Fraction***	***Floating Floor Mass Fraction***
Recycled Cork Waste	93 %	58 %
Binder	7 %	3 %
High Density Fiberboard (HDF)	--	39 %

Since the cork constituent is a waste product, the environmental burdens from virgin production of the cork are not included. The energy used to grind the cork, however, is included, as is its transportation to the manufacturing facility. HDF is produced mostly from recovered wood waste – only 14 % of the wood going into HDF is harvested directly. In the absence of available data, HDF manufacturing is represented, by proxy, with oriented strand board (OSB) production data provided by the U.S. LCI Database and described in more detail under Generic Oriented Strand Board Sheathing.

The binder for Natural Cork flooring is a moisture-cured urethane, produced from a reaction between polyisocyanate and moisture present in the atmosphere. Isocyanate production data is based on publicly available plastics data in the U.S. LCI Database.

Manufacturing

Energy Requirements. The manufacturing processes for the two cork floor products are essentially the same. Cork waste is ground and blended with the urethane binder, then cured. For the floating floor plank, the HDF is sandwiched between two cork sheet layers and then cured.

Electricity and an on-site boiler are used to blend and cure both products. The boiler uses cork powder generated during the production process to produce steam and electricity. Manufacturing the parquet flooring requires about 0.8 MJ (0.02 kWh) of both thermal and electrical energy per unit produced (0.09 m^2, or 1 ft^2); the floating floor plank requires about 1 MJ (0.28 kWh) of electricity and 0.9 MJ (0.25 kWh) of thermal energy per unit. Water is also used in the production process, but it is recycled and recovered by the plant. Producing each unit of product generates about 1 kg (2.2 lb) of waste, 94 % of which is used to produce energy and 3 % of which is recycled. The recycled material is accounted for in the BEES life cycle inventory.

Transportation. Transportation distances for shipment of the raw materials from the suppliers to the manufacturing plant were provided by Natural Cork. The materials were transported by diesel truck, based on the U.S. LCI Database.

Transportation

The finished cork products are shipped first from the manufacturing facility in Portugal to the Natural Cork warehouse in Georgia–a distance of about 6 437 km (4 000 mi). Environmental burdens from this leg of the journey are built into the manufacturing portion of the BEES life-cycle inventory and are evaluated based on transport by ocean tanker using fuel oil. The transportation distance from the Natural Cork warehouse in Augusta, Georgia to the building site is modeled as a variable in BEES. Both products are shipped from Augusta by diesel truck; the quantity of transportation emissions allocated to each product depends on the overall mass of the product, as given in the Table below.

Table 3.111: Natural Cork Flooring Density

Product	***Mass per Applied Area in kg/m^2 (lb/ft^2)***	***Density in kg/ m^3 (lb/ft^3)***
Cork Parquet Tile	2.56 (0.51)	516.67 (34.18)
Cork Floating Floor	7.44 (1.48)	563.33 (37.26)

Installation

Natural Cork parquet tile is installed using a water-based contact adhesive. The average application requires about 0.009 kg (0.020 lb) of adhesive per unit of flooring (0.09 m^2, or 1 ft^2). The Natural Cork floating floor requires only a minimal amount of tongue-and-groove adhesive to bond the individual planks together. On average, 5 % of the adhesive is wasted during installation, but none of the flooring is lost.

Use

Based on information from Natural Cork, its flooring does not require replacement over the 50-year BEES use period.

End of Life

At end of life, the used flooring is sent to a landfill, since according to the manufacturer none is currently being recycled.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Industry Contacts

Phillipe Erramuzpe, Natural Cork (2002)

3.14 Chairs

3.14.1 Herman Miller Aeron Office Chair

Herman Miller is a worldwide producer of office furniture systems, seating, and accessories; filing and storage products for business, home office and healthcare environments; and residential furniture. The Herman Miller Aeron business chair consists of more than 50 different components and subassemblies from more than 15 direct suppliers. These components and subassemblies are constructed from four major materials: plastics, aluminum, steel, and foams/fabrics.

The detailed environmental performance data for this product can be viewed by opening the file E2020A.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

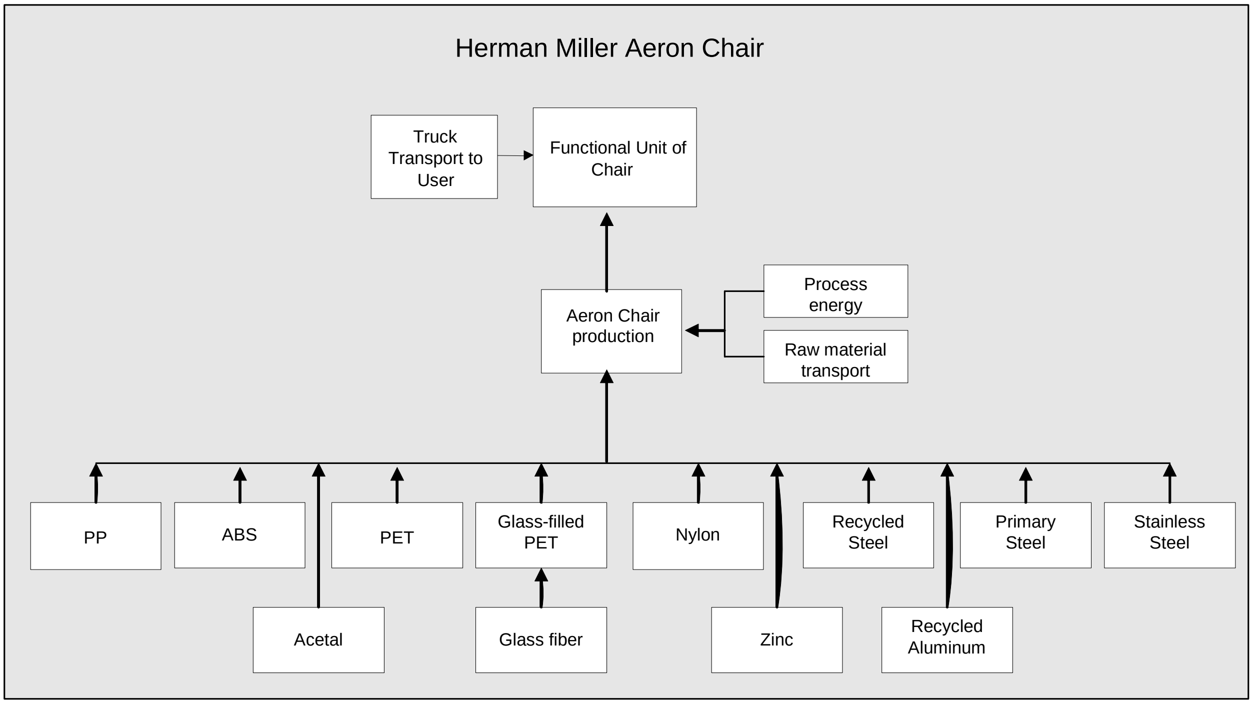

Figure 3.48: Herman Miller Aeron Chair System Boundaries

Raw Materials

Approximately 60 % of the Aeron chair, by mass fraction, is comprised of recycled materials including steel, polypropylene, glass-filled nylon, 30 % glass-filled PET, and aluminum. The mixture of all the chair constituents in terms of their mass fractions is provided in the Table below.

Table 3.112: Herman Miller Aeron Chair Major Constituents

Constituent	***Description***
Plastics	27 % for all plastics (24 % for seat and back frame assemblies, 9 % for knobs, levers, bushings, covers)
Aluminum	35 % for aluminum base, swing arms, seat links, arm yokes
Steel	23.5 % for tilt assembly, 2 % for nuts, bolts, other components
Foam/fabric (arm rests, lumbar supports)	Less than 4 %; Pellicle seat & back suspension system is a combination of synthetic fibers and elastomers
Composite subassemblies	3 % for 5 casters; 6.7 % for pneumatic cylinder; 6.2 % for moving components of tilt assembly

Of the plastics and metals in the Aeron chair that are nonrenewable, over two-thirds are made from recycled materials and can be further recycled at end of life.

Plastic components. Roughly one-fourth (27 %) of the Aeron chair, by mass fraction, is made up of various plastic resin materials including polypropylene, ABS, PET, nylon, and glass-filled nylons. The seat and back frame assemblies make up 23.6 % of the chair's weight. The seat and back frames are made of glass-filled PET, two thirds of which consists of post-industrial recycled materials. The plastic in the Pellicle suspension system (approximately 2 % of the chair weight) can be removed for replacement or for recycling of the seat and back frames. The remaining plastic components are various knobs, levers, bushings, and covers.

According to the manufacturer, these single-material plastic components used in the Aeron chair are identified with International Organisation for Standardization (ISO) recycling symbols and ASTM, International material designations to help channel them into the recycling stream.

Data for production of the plastic components comes from American Chemistry Council 2006 data developed for submission to the U.S. LCI Database.

Aluminum. Roughly 35 % of the Aeron chair is made from aluminum. Major components include the base, swing arms, seat links, and arm yokes. Aluminum components from the Aeron chair at the end of its life can be segregated and entered back into the recycling stream to be made into the same or other components, so they can be considered part of a closed-loop recycling system.

All aluminum components are made from 100 % post-consumer recycled aluminum, for which production data is found in the U.S. LCI Database.

Steel. The tilt assembly, approximately 23.5 % of the chair's weight, is largely made up of steel stampings and screw-machined components. These steel components represent 74 % of the tilt, by mass fraction, or 17.3 % of the mass of the chair. From 7 % to 50 % of the steel components in the tilt are made from recycled materials. The remaining steel materials (less than 2 % of the chair) are nuts, bolts, and other components that require the high strength properties of steel.

Production of primary and secondary steel is based on LCI data submitted by the American Iron and Steel Institute (AISI) and the International Iron and Steel Institute (IISI), which represents late 1990s worldwide steel production.

Foam/Fabric. The armrests and lumbar supports are the only Aeron chair components made from foams or fabrics. The Pellicle seat and back suspension system is a combination of synthetic fibers and elastomers and comprises a small percentage of the chair. Fabric scraps from Herman Miller's production facilities are recycled into automobile headliners and other similar components. Foam scraps are recycled into carpet padding. Data on synthetic fibers and elastomers comes from elements of the U.S. LCI Database and the SimaPro database.

Composite Subassemblies. The Aeron chair has three composite subassemblies of multiple material types. They consist of five casters, a pneumatic cylinder, and the moving components of the tilt assembly. The pneumatic cylinder can be returned to the manufacturer for disassembly and recycling. All material production data is based on elements of the U.S. LCI Database and the SimaPro database.

Manufacturing

Energy requirements and emissions from chair assembly are included in the model but not shared to protect company-specific confidential data. The energy used for processes that form materials into chair parts (plastic extrusion, steel rolling and stamping, etc.) is included in the product data for the raw materials acquisition life cycle stage.

Transportation

Packaging materials for the Herman Miller Aeron chair include corrugated paper and a polyethylene plastic bag to protect the product from soiling and dust. Each of these materials is part of a closed-loop recycling system. As such, they are not included in the system boundaries. On larger shipments within North America, disposable packaging can be eliminated through use of reusable shipping blankets.

Transportation of the chair by heavy-duty truck to the building is modeled as a variable of the BEES system. Data on diesel trucking is based on the U.S. LCI Database.

Use

The plastics in the chair are low-VOC emitting and most painted parts are powder-coated. The small amounts of foam and fabric are insignificant contributors of VOC.

End of Life

The Herman Miller Aeron chair is designed to last at least 12.5 years under normal use conditions, so the chair is assumed to be replaced three times over the 50-year BEES use period. As with all BEES products, life cycle environmental burdens from these replacements are included in the inventory data.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

http://www.hermanmiller.com.

Industry Contacts

Gabe Wing, Herman Miller (2001)

3.14.2 Herman Miller Ambi and Generic Office Chairs

Herman Miller is a worldwide producer of office furniture systems, seating, and accessories; filing and storage products for business, home office. and healthcare environments; and residential furniture. The Herman Miller Ambi chair is typical of the industry average office chair, and is used in BEES to represent both itself and a generic office chair.

The detailed environmental performance data for both these products can be viewed by opening the file E2020B.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

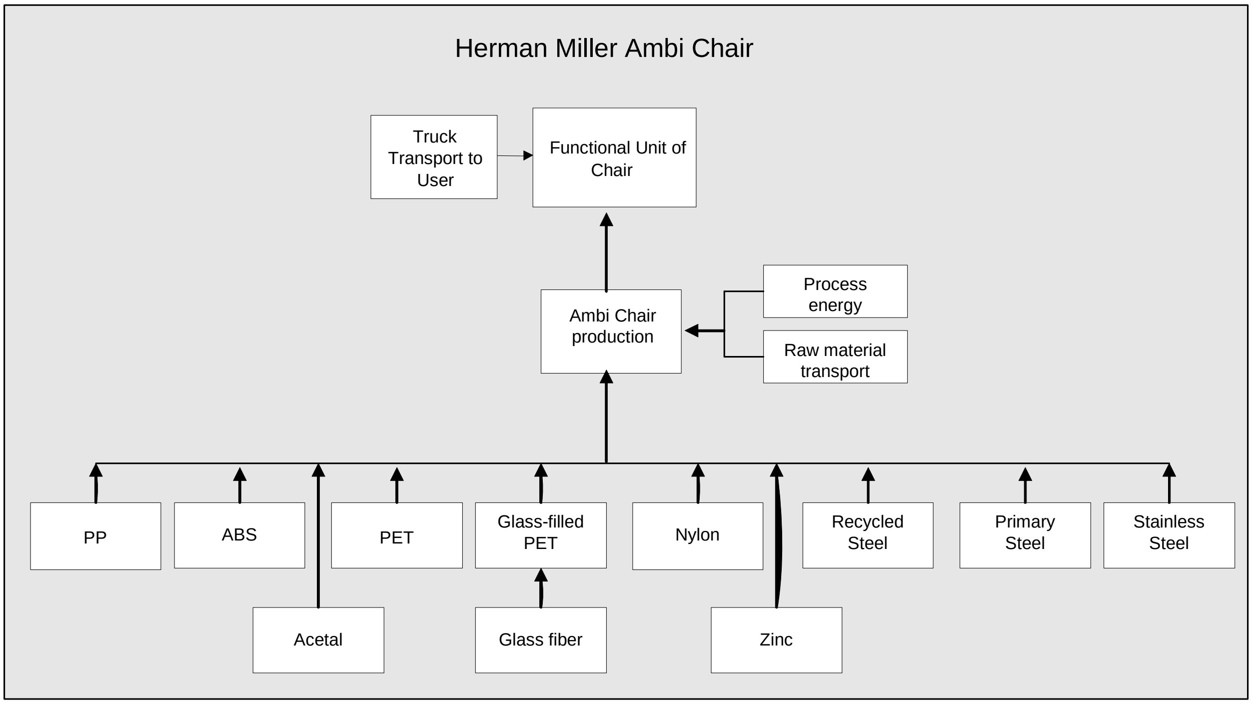

Figure 3.49: Herman Miller Ambi Chair System Boundaries

Raw Materials

The Herman Miller Ambi chair consists of more than 50 different components and subassemblies from more than 15 direct suppliers. The components and subassemblies are constructed from variations of three major materials: plastics, steel, and foams/fabrics. Approximately 20 % of the Ambi chair's weight is made up of recycled steel, polypropylene, nylon, and glass-filled nylon. The mixture of all the constituents in terms of their mass fractions is given in the Table below.

Table 3.113: Herman Miller Ambi Chair Major Constituents

Constituent	*Description*
Plastics (PP, PVC, nylon, glass-filled polymer)	33 % for all plastics (24 % for seat shells, 9 % for knobs, levers, bushings, covers)
Steel	63 % for tilt assembly and base; 2 % for nuts, bolts, other components
Foams/fabrics	Less than 4 %; included in open-loop recycling systems
Composite subassemblies	3 % for five casters; 6.7 % for pneumatic cylinder; 6.3 % for moving components of tilt assembly

Of the plastics and metals in the Ambi chair that are nonrenewable, over two-thirds are made from recycled materials and can be further recycled at end of life.

Plastic components. Roughly one-third of the Herman Miller Ambi chair, by weight, is made with polypropylene, PVC, nylon, and glass-filled nylons. The seat shells make up 24 % of the chair's weight. The seat shells, made of polypropylene, contain 10 % post-industrial recycled materials. The remaining plastic components are various knobs, levers, bushings, and covers. These single-material plastic components are identified with International Organisation for Standardization (ISO) recycling symbols and ASTM, International material designations to help channel them into the recycling stream. Data for each of these plastic components comes from American Chemistry Council 2006 data developed for submission to the U.S. LCI Database.

Steel. The tilt assembly and base, constituting approximately 63 % of the chair's weight, are largely made of steel stampings and screw-machined components. These steel components are 74 % of the tilt assembly by weight, or 50 % of the weight of the chair. The steel components in the tilt assembly are made from 28 % to 50 % recycled-content materials. The remaining steel materials (less than 2 % of the chair's mass) are nuts, bolts, and other components that require the high-strength properties of steel. The steel components of the Ambi chair can be segregated and entered into the recycling stream.

Production of primary and secondary steel is based on LCI data submitted by the American Iron and Steel Institute (AISI) and the International Iron and Steel Institute (IISI), which represents late 1990s worldwide steel production.

Foam/Fabric. Data on synthetic fibers and elastomers come from elements of the U.S. LCI Database and the SimaPro database. These materials are part of an open-loop system; they can be transformed into other products. For example, fabric scraps from Herman Miller's current production facilities are made into automobile headliners and other similar products. Foam scraps are used in carpet padding.

Composite Subassemblies. There are three composite subassemblies of multiple material types. They include five casters (3 % of the chair mass), a pneumatic cylinder (6.7 % of the chair mass), and the moving components of the tilt assembly (6.3 % of the chair mass). The pneumatic cylinder can be returned to the manufacturer for disassembly and recycling. All material production data is based on elements of the U.S. LCI Database and the SimaPro database.

Manufacturing

Energy requirements and emissions from chair assembly are included in the model but not shared to protect company-specific confidential data. The energy used for processes that form materials into chair parts (plastic extrusion, steel rolling and stamping, etc.) is included in the product data for the raw materials acquisition life cycle stage.

Transportation

Packaging materials for the Herman Miller Ambi chair include corrugated paper and a polyethylene plastic bag to protect the product from soiling and dust. Each of these materials is part of a closed-loop recycling system. As such, they are not included in the system boundaries. On larger shipments within North America, disposable packaging can be eliminated through use of reusable shipping blankets.

Transportation of the chair by heavy-duty truck to the building is modeled as a variable of the BEES system. Data on diesel trucking is based on the U.S. LCI Database.

Use

The chair is designed for easy maintenance, with many replaceable components. For BEES, however, no parts replacement is assumed; instead, the entire chair is simply replaced at end of life (see End of Life section below).

The plastics in the chair are low-VOC emitting and most painted parts are powder-coated. The small amounts of foam and fabric are insignificant contributors of VOC.

End of Life

The Herman Miller Ambi chair is designed to last at least 12.5 years under normal use conditions. Thus, the chair is assumed to be replaced three times over the 50-year BEES use period. As with all BEES products, life cycle environmental burdens from these replacements are included in the inventory data.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

http://www.hermanmiller.com

Industry Contacts

Gabe Wing, Herman Miller (2001)

3.15 Roadway Dust Control

3.15.1 Environmental Dust Control Dustlock

The roadway dust suppressant category includes products aimed at eliminating or reducing the spread of dust associated with gravel roads and other sources of high dust levels such as construction. Dustlock, produced by Environmental Dust Control, Inc. in Minnesota, is a biobased dust suppressant produced from by-products of the vegetable oil refining process. When applied, Dustlock penetrates into the bed of the material generating the dust and “bonds” to make a barrier that is naturally biodegradable. The bond keeps Dustlock in place, preventing the exposure of any material underneath. The manufacturer reports that Dustlock also reduces erosion of surface material (e.g., gravel) and the appearance of mud.

The functional unit for this category in BEES is dust control for 92.9 m^2 (1 000 ft^2) of surface area. One gal of Dustlock covers approximately 3.4 m^2 (37 ft^2), so 102 L (27 gal) of Dustlock are modeled for the BEES application.

The detailed environmental performance data for this product may be viewed by opening the file G2015B.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

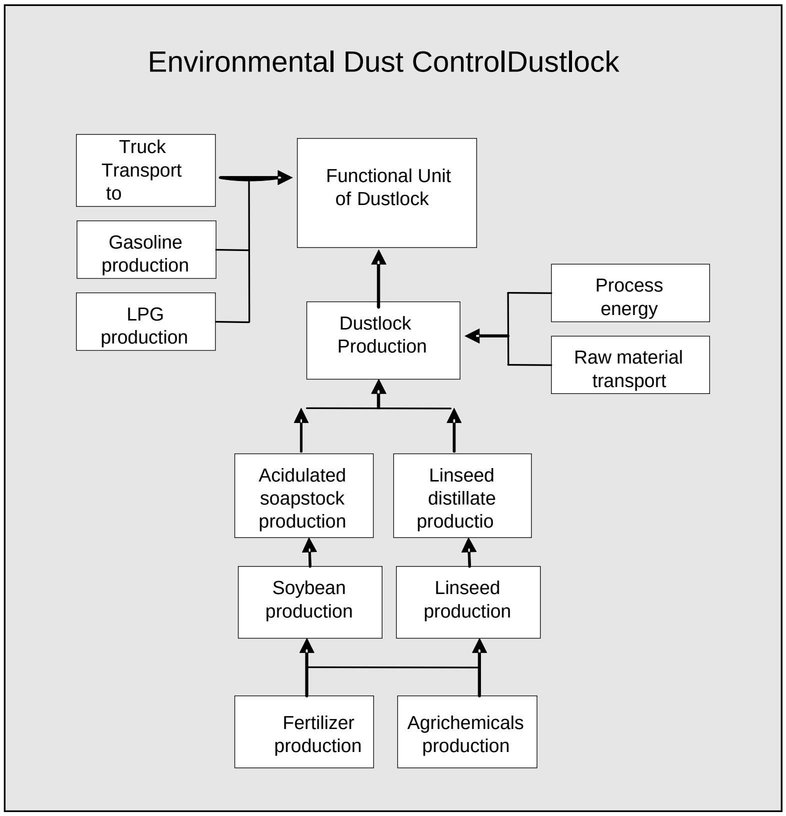

Figure 3.50: Dustlock System Boundaries

Raw Materials

Dustlock is comprised of acidulated soapstock and linseed distillate. The acidulated soapstock may be any combination of sunflower, canola, or soybean soapstock. Since BEES data for soybean production and processing is the most comprehensive, soybean-based soapstock is modeled for this product. Acidulated soapstock is a co-product of the soybean crushing process involved in biodiesel production; data for this process comes from biodiesel life cycle data developed for the U.S. Department of Agriculture that was used to compare petroleum-based diesel fuel to soy-based biodiesel.[171] The allocation among biodiesel and its coproducts is mass-based, with acidulated soapstock amounting to 0.1 % of the total output. Data for soybean production comes from the U.S. LCI Database.

Energy requirements and emissions for linseed oil production involve fuel oil and steam, and are allocated on an economic basis between linseed oil (87 %) and linseed cake (13 %). The cultivation of linseed is based on a modified version of wheat production data from the U.S. LCI Database.

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[171] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

Manufacturing

Energy Requirements and Emissions. Electric motors and pumps are used to blend the product and pump it in and out of tanks; these consume 1.5 J (4.3 E-4 kWh) per kg of Dustlock. Electricity is modeled using the U.S. average electric grid from the U.S. LCI Database.

Transportation. Raw materials are transported to the manufacturing site by diesel truck: soapstock travels 451 km (280 mi) and linseed oil 1086 km (675 mi). Diesel trucking is modeled using the U.S. LCI Database.

Transportation

Product transport to customers is assumed to average 805 km (500 mi) by diesel truck, and is modeled based on the U.S. LCI Database.

Installation

Dustlock requires heating before application when outside air or ground temperature is below 16 °C (60 °F) at night. For the BEES model, the heating is done with liquefied petroleum gas (LPG). Gasoline-powered equipment is used to spray the Dustlock™ onto the surface area. The energy requirements follow.

Table 3.114: Dustlock Installation Energy Requirements

Energy Carrier	***Quantity MJ/kg (kWh/lb)***
Liquid petroleum gas	0.14 (0.02)
Gasoline	0.004 (0.001)

Dustlock is applied at a rate of 3.4 m^2 (37 ft^2) per gal, or 102 L (27 gal) for a 92.9 m^2 (1 000 ft^2) application. At a density of 3.4 kg (7.5 lb) per gal, 93 kg (205 lb) of Dustlock are used for the application.

End of Life

No end of life burdens are modeled since the product is consumed during use.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Sheehan, J. et al., Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

Industry Contacts

Howard Hamilton (2005)

3.16 Parking Lot Paving

3.16.1 Generic Concrete Paving

Portland cement concrete, typically referred to as “concrete,” is a mixture of portland cement (a fine powder), water, fine aggregate such as sand or finely crushed rock, and coarse aggregate such as gravel or crushed rock. The semi-fluid mixture forms a rock-like material when it hardens. Fly ash—a waste material—may be substituted for a portion of the portland cement in the concrete mix.

Concrete is specified for different building elements by its compressive strength measured 28 days after casting. Concretes with greater compressive strengths generally contain more cementitious materials. For the BEES concrete paving alternatives, a compressive strength of at least 24 MPa (3 500 lb/in^2) is used. The concrete paving systems all consist of a 15 cm (6 in) layer of concrete poured over a 20 cm (8 in) base layer of crushed stone or compacted sand. Paving installed in regions that experience freezing conditions have intentionally entrained air to the volume of 4 % to 6 % to improve its durability in these conditions.

For 0.09 m^2 (1 ft^2) of concrete paving, the 15 cm (6 in) thick concrete layer weighs 32.9 kg (72.5 lb) and the 20 cm (8 in) thick crushed stone base layer weighs 33.3 kg (73.3 lb). Fly ash, a waste material that results from burning coal to produce electricity, can be substituted in equal quantities by mass for various proportions of the cement.

The detailed environmental performance data for three generic concrete paving alternatives may be viewed by opening the following files under the File/Open menu item in the BEES software:

- G2022A.DBF—100 % Portland Cement for Parking Lot Paving
- G2022B.DBF—15 % Fly Ash Cement for Parking Lot Paving
- G2022C.DBF—20 % Fly Ash Cement for Parking Lot Paving

Flow Diagram

The flow diagram below shows the major elements of the production of concrete paving for these products, as they are currently modeled for BEES.

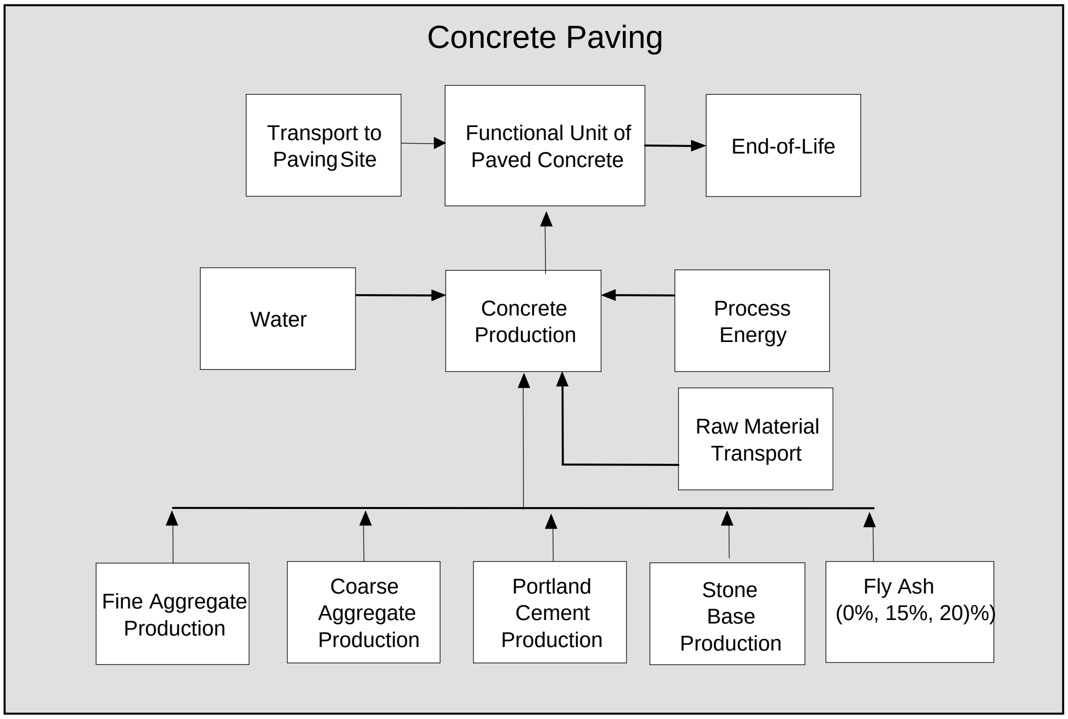

Figure 3.54: Concrete Paving System Boundaries

Raw Materials

The Table below shows concrete constituents and their quantities for the compressive strength of 24 MPa (3 500 lb/in^2).

Table 3.115: Concrete Constituents

Constituent	*Kg/m^3 (lb/ yd^3)*	*Mass Fraction*
Portland Cement and Fly Ash	265 (450)	12 %
Coarse Aggregate	1070 (1800)	42 %
Fine Aggregate	710 (1200)	38 %
Water	180 (300)	8 %

In LCA terms, fly ash is an environmental outflow of coal combustion, and an environmental inflow of concrete production. As such, this waste product is considered an environmentally "free" input material.[172] Transport of the fly ash to the ready mix plant, however, should be—and is—included in the BEES model.

A small amount of coarse aggregate and sand, assumed to be approximately 3 %, is recycled from unused returned concrete. Process water from concrete manufacturing (post-industrial) and in some cases post-consumer water also may be used as a component in concrete.

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[172] The environmental burdens associated with the production of waste materials are typically allocated to the intended product(s) of the process from which the waste results.

Manufacturing

Energy Requirements and Emissions. For concrete paving, about 20 % of the concrete is produced in central ready mix operations. Energy use in the batch plants includes electricity and fuel used for heating and mobile equipment.[173]

Table 3.116: Energy Requirements for Ready Mix Concrete Production

Energy Carrier	*MJ/m^3 (MBtu/yd^3)*	*MJ/kg (Btu/lb)*
Heavy Fuel Oil	124 (0.09)	0.05 (22)
Electricity	124 (0.09)	0.05 (22)
Total	**247 (0.179)**	**0.1 (43)**

Most concrete for paving applications (80 %) is produced in dry batch operations where the constituents are placed in a truck mixer. Concrete producers are located in all regions of the country since the product has to be placed within 1 h driving time from the production location. The trucks consume one gal of diesel fuel for every 5 km to 6 km (3 mi to 4 mi) traveled, and travel on average 64 km/h (40 mi/h) to reach the site. The fuel usage for mixing concrete in a truck mixer is estimated at 30 % of the total fuel used by mixer trucks.

Table 3.117: Energy Requirements for Dry Batch Concrete Production

Energy Carrier	*L/m^3 (gal/yd^3)*	*L/kg (gal/lb)*
Diesel Oil Total	7.07 (1.43)	0.00318 (0.00038)
Diesel Oil for Mixing (30 %)	2.12 (0.429)	0.00095 (0.00011)

Transportation. Concrete raw materials are transported to a plant where they are batched into either a plant mixer or a truck mixer. Round-trip distances by truck for the transport of the materials are assumed to be 97 km (60 mi) for portland cement and fly ash and 80 km (50 mi) for aggregate.

Waste. There is no manufacturing waste for either of the concrete manufacturing processes.

Transportation

The distance for transportation of concrete paving materials by heavy-duty truck to the building site is modeled as a variable of the BEES system.

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[173] Nisbet, M., et al. "Environmental Life Cycle Inventory of Portland Cement Concrete." *PCA R&D Serial No. 2137a*(Skokie, IL: Portland Cement Association, 2002).

Installation

The energy required for site preparation and placement of crushed stone is 7.5 MJ/m^2 (663 Btu/ft^2) of paving. The energy required for concrete placement is included in the energy requirements for the mixer truck that transports the concrete to the site.

About 3 % to 5 % of the total production of paving concrete is unused at the job site and returned to the concrete plant. Some of this material is recycled back into the product, and supplementary products also are developed. In some cases, the returned concrete is washed into pits and the settled solids are reused for other purposes or diverted to landfills. Landfill usage is minimized due to cost. For the purpose of this generic model of concrete paving, it is most representative of current practice to assume that 75 % of the leftover concrete is recycled back into the product as aggregate and 25 % is reused for other purposes. Industry practice varies based on local regulations, plant space, and company policy.

Installation of concrete paving *on roadways* requires heavy equipment using heavy fuel at 0.7 MJ (0.19 kWh) of fuel per ft^2 of paving; however, use of heavy equipment for installation may not be required for applications such as parking areas and sidewalks. Paving of larger parking areas like a mall area (generally totaling greater than 929 m^2, or 10 000 ft^2) requires some power-driven equipment with screeds[174] and ride-on finishing machines. The fuel used is some combination of diesel and gasoline, although only diesel fuel is assumed for modeling purposes. A rough estimate of fuel usage is about 20 % of that used for road paving. Smaller area placements (totaling less than 929 m^2, or 10 000 ft^2) are done manually with hand tools.

As noted above, unused concrete is usually returned to the concrete plant. About 1 % waste is generated on site as poured waste or spillage. This concrete is not returned to the mixer truck but is collected and hauled to the landfill with other construction debris.

Use

The design life for concrete pavement is typically 30 years, although longer life designs are now being promoted. Maintenance requirements are not intensive relative to life-cycle energy and other environmental burdens.

End of Life

At end of life, concrete parking lot paving is typically overlaid rather than replaced if the land is going to remain in use as a parking lot. The concrete is generally removed if the land is going to be used for a different purpose.

If the concrete paving is removed, the material can be crushed and reused on site or transported for use in another fill application. The decision to send crushed concrete to a landfill is a project decision. It is most representative of current practice to assume that removed concrete is managed by crushing and reusing or recycling in some manner other than landfilling.

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[174] Screeds are used to level poured concrete surfaces.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Nisbet, M., et al. “Environmental Life Cycle Inventory of Portland Cement Concrete.” *PCA R&D Serial No. 2137a*, (Skokie, IL: Portland Cement Association, 2002).

Industry Contacts

Colin Lobo, Ph.D., P.E, Vice President of Engineering, National Ready Mixed Concrete Association, September-October 2005.

3.16.2 Asphalt with GSB88 Seal-Bind Maintenance

The design of an asphalt parking lot pavement is dependent on the projected weight of traffic, the soil conditions at the site, and environmental conditions. Common asphalt parking lots consist of between 5 cm and 10 cm (2 in and 4 in) thick Hot-Mix Asphalt (HMA), which contains, on average, 15 % Recycled Asphalt Pavement (RAP). RAP is obtained from the millings of HMA surface lots or roadways and is typically hauled back to the HMA plant for reuse. The HMA pavement material is typically placed over a 15 cm (6 in) crushed aggregate base. In colder climates, additional fill material that insulates against frost-susceptible soils may be added below the base aggregate. The maintenance product assessed for this BEES paving alternative is GSB88 Emulsified Sealer-Binder produced by Asphalt Systems, Inc. of Salt Lake City, Utah. GSB88 Emulsified Sealer-Binder is a high-resin-content emulsifier made from naturally occurring asphalt and is applied to base asphalt every four years to prevent oxidation and cracking.

For the BEES asphalt parking lot model, a 0.09 m^2 (1 ft^2) surface with 8 cm (3 in) thick paving is studied. The amount of material used is 16.4 kg (36.2 lb) of HMA, 30.6 kg (67.5 lb) of crushed stone, and 12 installments of the GSB88 sealer-binder, at 0.374 kg (0.82 lb) each, over 50 years.

The detailed environmental performance data for this product system may be viewed by opening the file G2022D.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product system as it is currently modeled for BEES.

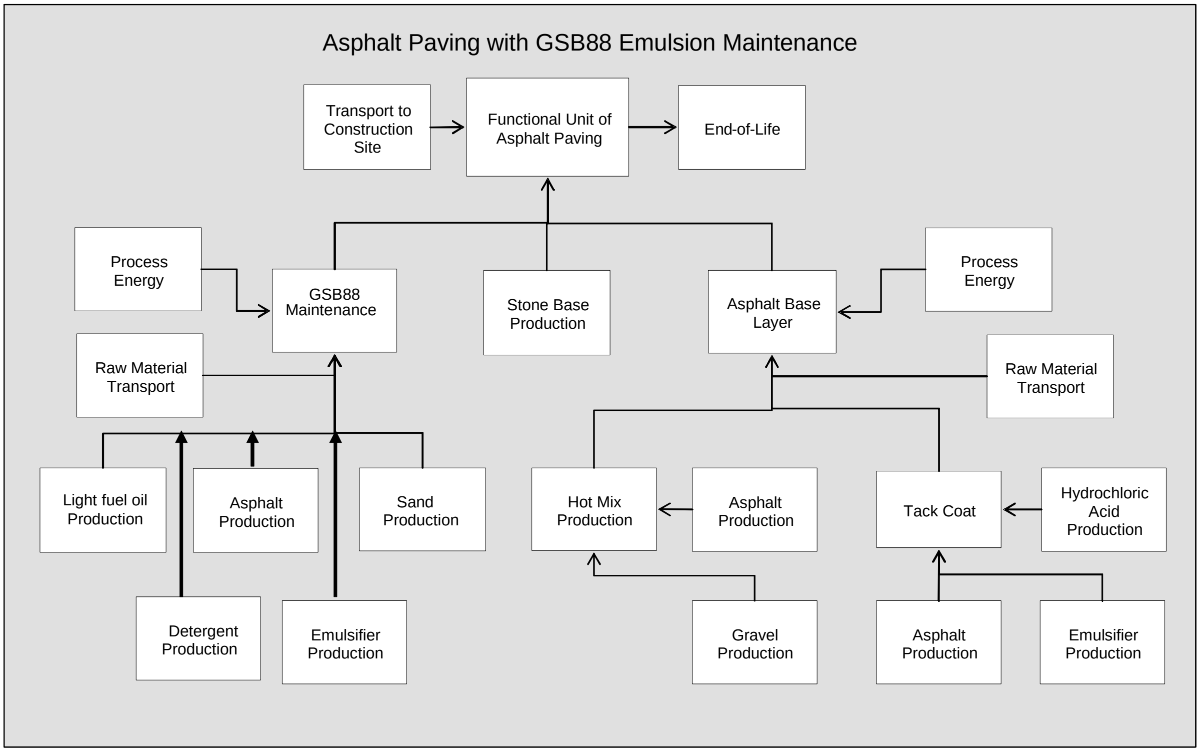

Figure 3.52: Asphalt Paving with GSB88 Emulsified Sealer-Binder Maintenance System Boundaries

Raw Materials

The composition of asphalt paving is shown in the Table below, and the production of its raw materials is based on data from both the U.S. LCI Database and the SimaPro database. The 15 % RAP in HMA reduces virgin asphalt binder requirements (by approximately 1 %) and reduces crushed stone (aggregate) amounts by approximately 14 %. The emulsifier is composed of asphalt with water and a small amount of surfactant.

Table 3.118: Hot Mix Asphalt Constituents

Constituent	*Mass Fraction (layer)*	*Mass Fraction (components)*
Hot Mix Asphalt	**99.5 %**	--
Gravel		81 %
Asphalt binder		4 %
RAP		15 %
Tack Coat	**0.5 %**	--
Asphalt		66 %
Water		33 %
Emulsifier		1.1 %
HCl		0.2 %

Raw materials used in the GSB88 sealer-binder include water, asphalt, sand, light fuel oil, detergent, emulsifier, and hydrochloric acid (HCl).[175] These materials, too, are based on data from the U.S. LCI Database and the SimaPro database.

Manufacturing

Energy Requirements and Emissions. The energy requirements for HMA production are provided in the Table below, and represent a weighted average of requirements for production in counterflow drum (85 %) and batch mix (15 %) plants.

Table 3.119: Energy Requirements for Hot Mix Asphalt Production

Energy Carrier	*MJ/kg (Btu/lb)*
Diesel	0.017 (7.3)
Natural Gas	0.29 (124.7)
Total	**0.307 (132)**

Emissions from the production of the upstream, or raw, materials and energy carriers are from the U.S. LCI Database. Emissions associated with the manufacture of asphalt are based on U.S. EPA AP-42 emission factors. The primary emissions from HMA production are particulates (PM) and volatile organic compounds (VOC); these are averaged on a weighted basis between counterflow drum (85 %) and batch mix (15 %) production technologies, as shown below.

Table 3.120: Emissions from Hot Mix Asphalt Production

Production Process	*PM g/kg (lb/ton)*	*VOC g/kg (lb/ton)*
Counterflow Drum	0.07 (0.14)	0.016 (0.032)
Batch Mix	0.0225 (0.45)	0.0041 (0.0082)
Weighted average	**0.0629 (0.1258)**	**0.0143 (0.02843)**

Transportation. Transport of the HMA raw materials to the production site is accomplished by trucking, over an average distance of 48 km (30 mi).

Waste. The manufacturing process generates no waste materials as all materials are utilized in the HMA pavement.

Transportation

Transport of HMA by heavy-duty truck to the construction site is modeled as a variable of the BEES system.

Installation

New asphalt pavements are placed directly on graded and compacted aggregate base or subgrade. A truck carrying HMA paving material from the plant backs up to a paver and dumps

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[175] Detailed information on product composition is not provided to protect manufacturer confidentiality.

the material into a hopper or a material transfer vehicle, which agitates the asphalt mix to keep the aggregate from segregating and to help ensure a uniform temperature. The paver lays a smooth mat of material, then a series of compactors make the material more dense. These compactors may include vibratory or static steel wheel rollers or rubber tire rollers. If multiple layers are placed or the parking lot is overlaid, the pavement surface is cleaned (typically by brooming) and then a distributor truck puts down a tack coat. The energy requirements for installation of an asphalt parking lot are provided in the following Table, with all diesel data based on the U.S. LCI Database.

Table 3.121: Energy Requirements for Asphalt Pavement Installation

Installation Process	***Energy Carrier***	***MJ/ft^2***
Site Preparation and Stone Base Placement	Diesel Equipment	0.7
Asphalt Binder Course Installation	Diesel Equipment	0.96
Asphalt Wearing Course Installation	Diesel Equipment	0.48
	Total	**2.14**

Use

Asphalt parking lot pavement is assumed to have a useful life of at least 50 years with application of GSB88 sealer-binder maintenance every 4 years. The energy required for each maintenance application is provided in the following Table.

Table 3.122: Energy Requirements for GSB88 Sealer-Binder Maintenance

Maintenance Process	***Energy Carrier***	***MJ/ft^2***
GSB88 Sealer-Binder Application	Diesel Equipment	9.45 E-4

End of Life

At end of life, asphalt paving is typically overlaid rather than replaced if the land is going to remain in use as a parking lot. The HMA is generally removed and recycled, however, if the land is going to be used for a different purpose. For BEES, the product is removed at end of life.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

U.S. Environmental Protection Agency, "Hot Mix Asphalt Plants," Volume I: Section 11.1, *AP-42: Compilation of Air Pollutant Emission Factors*, (Washington, DC: U.S. Environmental Protection Agency, April 2004). Found at: http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s01.pdf.

Industry Contacts

Howard Marks, Director of Regulatory Affairs, National Asphalt Paving Association (2005)
Mr. Gail Porritt, Asphalt Systems, Inc. (2002)

3.16.3 Generic Asphalt with Traditional Maintenance

The design of an asphalt parking lot pavement is dependent on the projected weight of traffic, the soil conditions at the site, and environmental conditions. Common asphalt parking lots consist of between 5 cm and 10 cm (2 in and 4 in) thick Hot-Mix Asphalt (HMA), which contains, on average, 15 % Recycled Asphalt Pavement (RAP). RAP is obtained from the millings of HMA surface lots or roadways and is typically hauled back to the HMA plant for reuse. The HMA pavement material is typically placed over a 15 cm (6 in) crushed aggregate base. In colder climates, additional fill material that insulates against frost-susceptible soils may be added below the base aggregate. Maintenance of asphalt parking lots, over 50 years, typically involves a 3.8 cm (1.5 in) HMA overlay with tack coat at year 15 followed by a 3.8 cm (1.5 in) mill and HMA overlay with tack coat every subsequent 15 years. Each maintenance coat contains, on average, 15 % RAP.

For the BEES asphalt parking lot model, a 0.09 m^2 (1 ft^2) surface with 8 cm (3 in) thick paving is studied. The amounts of materials used are 16.4 kg (36.2 lb) of HMA, 30.6 kg (67.5 lb) of crushed stone, and 3 installments of the HMA maintenance at 7.7 kg (17.0 lb) each.

The detailed environmental performance data for this product system may be viewed by opening the file G2022E.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product system as it is currently modeled for BEES.

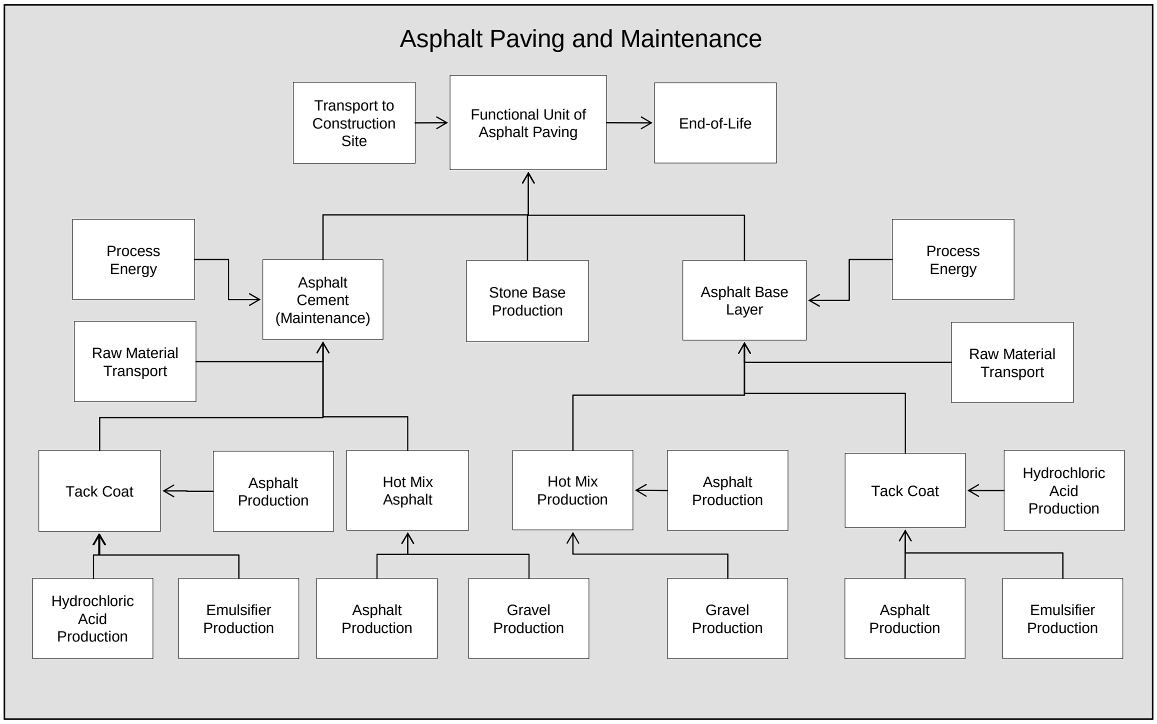

Figure 3.53: Asphalt Paving with Traditional Maintenance System Boundaries

Raw Materials

The composition of asphalt paving is shown in the Table below. The production of the raw materials required for both the pavement and its maintenance is based on data from both the U.S. LCI Database and the SimaPro database. The 15 % RAP in HMA reduces virgin asphalt binder use (by approximately 1 %) and reduces crushed stone (aggregate) amounts by approximately 14 %. The emulsifier is composed of asphalt with water and a small amount of surfactant.

Table 3.123: Hot Mix Asphalt Constituents

Constituent	*Mass Fraction (layer)*	*Mass Fraction (components)*
Hot Mix Asphalt	**99.5 %**	--
Gravel		81 %
Asphalt binder		4 %
RAP		15 %
Tack Coat	**0.5 %**	--
Asphalt		66 %
Water		33 %
Emulsifier		1.1 %
HCl		0.2 %

Manufacturing

Energy Requirements and Emissions. The energy requirements for HMA production are provided in the Table below, and represent a weighted average of requirements for production in counterflow drum (85 %) and batch mix (15 %) plants.

Table 3.124: Energy Requirements for Hot Mix Asphalt Production

Energy Carrier	*MJ/kg (Btu/lb)*
Diesel	0.017 (7.3)
Natural Gas	0.29 (124.7)
Total	**0.307 (132)**

Emissions from the production of the upstream (raw) materials and energy carriers are from the U.S. LCI Database. Emissions associated with the manufacture of asphalt are based on U.S. EPA AP-42 emission factors. The primary emissions from HMA production are particulates (PM) and volatile organic compounds (VOC); these are averaged on a weighted basis between counterflow drum (85 %) and batch mix (15 %) production technologies, as shown below.

Table 3.125: Emissions from Hot Mix Asphalt Production

Production Process	*PM g/kg (lb/ton)*	*VOC g/kg (lb/ton)*
Counterflow Drum	0.07 (0.14)	0.016 (0.032)
Batch Mix	0.0225 (0.45)	0.0041 (0.0082)
Weighted average	**0.0629 (0.1258)**	**0.0143 (0.02843)**

Transportation. Transport of the HMA raw materials to the production site is accomplished by trucking, over an average distance of 48 km (30 mi).

Waste. The manufacturing process generates no waste materials as all materials are utilized in the HMA pavement.

Transportation

Transport of HMA to the construction site by heavy-duty truck is modeled as a variable of the BEES system.

Installation

New asphalt pavements are placed directly on graded and compacted aggregate base or subgrade. A truck carrying HMA paving material from the plant backs up to a paver and dumps the material into a hopper or a material transfer vehicle, which agitates the asphalt mix to keep the aggregate from segregating and to help ensure a uniform temperature. The paver lays a smooth mat of material, then a series of compactors make the material more dense. These compactors may include vibratory or static steel wheel rollers or rubber tire rollers. If multiple layers are placed or the parking lot is overlaid, the pavement surface is cleaned (typically by brooming) and then a distributor truck puts down a tack coat. The energy requirements for installation of an asphalt parking lot are provided in the following Table, with all diesel data based on the U.S. LCI Database.

Table 3.126: Energy Requirements for Asphalt Paving Installation

Installation Process	*Energy Carrier*	*MJ/ft^2*
Site Preparation and Stone Base Placement	Diesel equipment	0.7
Asphalt Binder Course Installation	Diesel equipment	0.96
Asphalt Wearing Course Installation	Diesel equipment	0.48
	Total	**2.14**

Use

The asphalt parking lot pavement is assumed to have a useful life of greater than 50 years with maintenance performed every 15 years. The maintenance of the parking lot with HMA is called resurfacing. The surface is cleaned and all unnecessary debris is removed. A tack coat is then applied by a distributor truck. Hot asphalt is then applied and compacted. The energy required for resurfacing is provided in the following Table.

Table 3.127: Energy Requirements for Asphalt Resurfacing

Maintenance Process	*Energy Carrier*	*MJ/ft^2*
Asphalt Resurfacing	Diesel equipment	0.72

After the initial resurfacing at year 15, all subsequent resurfacings begin with removal of 3.8 cm (1.5 in) of existing material, followed by an HMA overlay with tack coat containing, on average, 15 % RAP. The 3.8 cm (1.5 in) of milled material is returned to the HMA manufacturing process as RAP.

End of Life

At end of life, the product is typically overlaid rather than replaced if the land is going to remain in use as a parking lot. However, the HMA is generally removed and recycled if the land is going to be used for a different purpose.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

U.S. Environmental Protection Agency, “Hot Mix Asphalt Plants,” Volume I: Section 11.1, *AP-42: Compilation of Air Pollutant Emission Factors*, (Washington, DC: U.S. Environmental Protection Agency, April 2004). Found at: http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s01.pdf.

Industry Contacts

Howard Marks, Director of Regulatory Affairs, National Asphalt Paving Association (2005)

3.16.4 Lafarge Cement Concrete Paving

See documentation on all BEES Lafarge concrete products under Lafarge North America Products.

3.17 Fertilizers

3.17.1 Perdue MicroStart 60 Fertilizer

Perdue AgriRecycle’s MicroStart 60™ is a slow-release nitrogen fertilizer consisting almost entirely of chicken litter, a byproduct of the poultry industry. Its Nitrogen-Phosphorus-Potassium (NPK) ratio is 4-2-3.

For the BEES system, the functional unit for fertilizers is applying 10 kg (22 lb) nitrogen per acre for a period of ten years. A typical application of MicroStart 60™ is 318 kg (700 lb) per acre. As the nitrogen in one application is released over a period of three years, fertilizer use per acre, per year, is 106 kg (233 lb). To achieve a 10 kg (22 lb) nitrogen per acre requirement, however, this amount is scaled up to 245 kg (540 lb) of fertilizer per acre per year.[176]

The detailed environmental performance data for this product may be viewed by opening the file G2060A.DBF under the File/Open menu item in the BEES software.

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[176] While this may not be the manufacturer’s suggested rate of use for this product, an adjustment was made to enable comparison of BEES fertilizers on a functionally equivalent performance basis.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

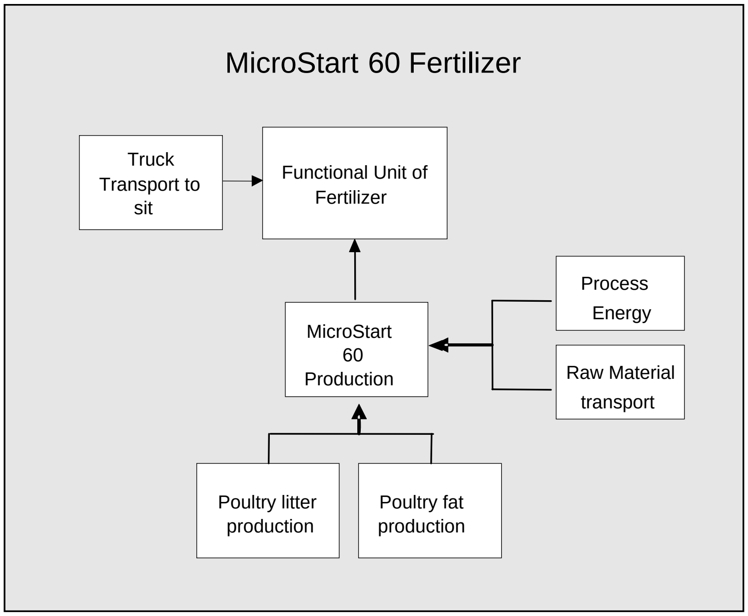

Figure 3.54: MicroStart 60™ Fertilizer System Boundaries

Raw Materials

Microstart 60 is composed of raw poultry litter and poultry fat, in the proportions shown in the Table below.

Table 3.128: Microstart 60 Constituents

Constituent	*Mass Fraction (%)*
Raw poultry litter	99.9
Poultry fat	0.1

The raw poultry litter is a byproduct of the poultry industry and would otherwise be a waste product. Therefore, any impacts associated with its production, such as chicken farming and poultry production, are allocated to the production of the poultry, not the litter. Wastewater generation from poultry production processes is accounted for in the context of poultry fat production; poultry fat accounts for 0.1 % of the inputs to these processes.[177]

Manufacturing

Energy Requirements and Emissions. Electricity and #2 diesel oil for a generator are among the energy requirements for manufacturing. Steam is generated from a 74.6 kW (100 hp) boiler, for palletizing and heating the finished product, for use of a scrubber, and for dust control. Approximately 472 MJ (131 kWh) and 0.04 m^3 (10 gal) of diesel are required to produce one ton

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[177] World Bank Group, "Meat Processing and Rendering," (World Bank, July 1998). Found at: http://lnweb18.worldbank.org/essd/essd.nsf/GlobalView/PPAH/$File/65_meat.pdf.

(2 000 lb) of fertilizer. Electricity is modeled using the U.S. average electric grid from the U.S. LCI Database. Diesel fuel production data comes from the U.S. LCI Database, as does a portion of the data used to represent its combustion in a boiler. Data for some of the diesel emissions is provided directly by Perdue AgriRecycle, and is included in the BEES model as follows.

Table 3.129: Microstart 60 Manufacturing Emissions

Air Emission	***g/kg (lb/ton)***
Nitrogen Oxides	1.24 (2.48)
Carbon Dioxide	1.61 (3.21)
Sulfur Dioxide	1.61 (3.21)
Particulates (unspecified)	1.23 (2.45)
Ammonia	0.48 (0.95)

Transportation. The raw litter is transported an average of 120 km (75 mi) and the poultry fat 161 km (100 mi) to Perdue AgriRecycle's facility.

Water Effluents. About 10 tanker loads of water effluents per week are generated from manufacturing Microstart 60™. However, this water is beneficially applied on land for irrigation, so is not modeled as a wastewater or as specific water effluents.

Transportation

Truck and rail are both used to ship Microstart 60™ to customers located across the United States. The transportation distance is modeled as a variable of the BEES system, with burdens shared equally by truck and rail.

Installation

Any burdens that may arise from on-site application of fertilizer are not accounted for in BEES.

Use

The nitrogen in the fertilizer is released over a three-year period. Microstart 60™ is fully biodegradable.

End of Life

There are no end of life burdens for this product since it is fully consumed during use, eliminating the need for waste management.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

World Bank Group, "Meat Processing and Rendering," Pollution Prevention and Abatement Handbook (World Bank, July 1998). Found at: http://lnweb18.worldbank.org/essd/essd.nsf/GlobalView/PPAH/$File/65_meat.pdf.

Industry Contacts

Joe Koch, Perdue AgriRecycle (2005)

3.17.2 Four All Seasons Fertilizer

Four All Seasons is a fertilizer composed of corn products, soybean products, and animal by-products with a Nitrogen-Phosphorus-Potassium (NPK) ratio of 10-1-1. According to the manufacturer, it can be used as a substitute for certain petroleum-based fertilizers: for every two applications of the petroleum-based product, only one application of Four All Seasons is necessary.

For the BEES system, the functional unit for fertilizers is applying 10 kg (22 lb) nitrogen per acre for a period of ten years. A typical application of Four All Seasons is approximately 489 kg per hectare (436 lb per acre). Since nitrogen continues to be released in the second year, fertilizer use per acre, per year, is 132 kg (290 lb), assuming the application lasts 1.5 years. To achieve a 10 kg (22 lb) nitrogen per acre requirement, however, this amount is scaled down to 100 kg (220 lb) of fertilizer per acre per year.[178]

The detailed environmental performance data for this product may be viewed by opening the file G2060B.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

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[178] While this may not be the manufacturer's suggested rate of use for this product, an adjustment was made to enable comparison of BEES fertilizers on a functionally equivalent performance basis.

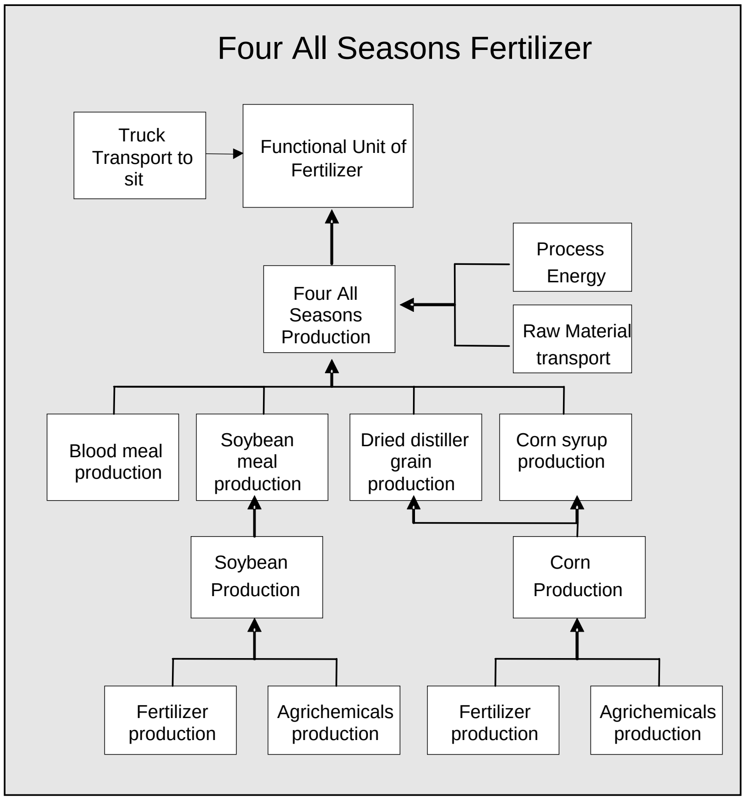

Figure 3.55: Four All Seasons Fertilizer System Boundaries

Raw Materials

Four All Seasons is composed of several animal- and vegetable-based products and byproducts.

Animal blood meal. Production of animal blood meal is based on European data for slaughterhouse residue production.[179]

Dry distiller grain. Production of this product constituent is based on the dry milling process, in which the grain is a coproduct of ethanol. Various sources are used to generate data for the dry milling process.[180]

Corn syrup. This constituent is based on wet milling processes, and modeled with data from several sources.[181]

Soybean meal. Data for this product constituent is based on data from the National Renewable

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[179] Nielsen, H., 2.-0 LCA Consultants, July 2003. Found at: http://www.lcafood.dk.

[180] Graboski, Michael S., (National Corn Growers Association, August 2002); Shapouri, H., "The 2001 Net Energy Balance of Corn-Ethanol" (U.S. Department of Agriculture, 2004); U.S. Environmental Protection Agency, “Grain Elevators and Processes,” Volume I: Section 9.9.1, *AP-42: Compilation of Air Pollutant Emission Factors* (Washington, DC: US Environmental Protection Agency, May 2003). Found at: http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s0909-1.pdf.

[181] Galitsky, C., Worrell, E., and Ruth, M., LBNL-52307 (Ernest Orlando Lawrence Berkeley National Laboratory, July 2003); U.S. Environmental Protection Agency, “Corn Wet Milling,” Volume I: Section 9.9.7, *AP-42: Compilation of Air Pollutant Emission Factors* (Washington, DC: US Environmental Protection Agency, January 1995). Found at: http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s09-7.pdf.

Energy Laboratory's (NREL's) LCA study of biodiesel use in an urban bus.[182]

Manufacturing

Energy Requirements and Emissions. Electricity and steam are used to produce Four All Seasons fertilizer. Four All Seasons provided site data for the amount of each in dollars per ton of fertilizer produced. The Table below translates this data into energy requirements for the production process. Natural gas is assumed to produce the steam.

Table 3.130: Four All Seasons Energy Requirements

Energy Carrier	*Quantity per kg*
Electricity[183]	0.065 MJ (0.018 kWh)
Steam[184]	0.1 kg (0.2 lb)

Transportation. The corn products are transported approximately 16 km (10 mi) to the Four All Seasons facility, and the soybean and blood meal products are transported approximately 97 km (60 mi) to the facility.

Solid Waste. Any solid wastes from manufacturing are reused in the system, so no wastes need to be modeled.

Transportation

A truck is assumed to transport the fertilizer to point of use, and the distance it travels is modeled as a variable in the BEES system.

Installation

Any burdens that may arise from on-site application of fertilizer are not accounted for in BEES.

Use

The nitrogen in the fertilizer is assumed to be released over a 1.5 year period. Four All Seasons fertilizer is fully biodegradable.

End of Life

There are no end of life burdens for this product since it is fully consumed during use, eliminating the need for waste management.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005.

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[182] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

[183] U.S. Energy Information Administration, Iowa's 2002 average price of electricity. Found at: http://www.eia.doe.gov/cneaf/electricity. The 2002 price corresponds to the date for which the manufacturer supplied data.

[184] U.S. Energy Information Administration, Iowa's 2004 average price of industrial natural gas. Found at: http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_a_EPG0_PIN_DMcf_a.htm. The 2004 price corresponds to the date for which the manufacturer supplied data.

Golden, CO. Found at: http://www.nrel.gov/lci/database.
PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.
Graboski, Michael S., Fossil Energy Use in the Manufacture of Corn Ethanol (National Corn Growers Association, August 2002).
Shapouri, H., "The 2001 net energy Balance of Corn-Ethanol" (U.S. Department of Agriculture, 2004).
U.S. Environmental Protection Agency, "Grain Elevators and Processes," Volume I: Section 9.9.1, *AP-42: Compilation of Air Pollutant Emission Factors*, (Washington, DC: U.S. Environmental Protection Agency, May 2003). Found at: http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s0909-1.pdf.
Galitsky, C., Worrell, E., and Ruth, M., Energy efficiency improvement and cost saving opportunities for the corn wet milling industry, LBNL-52307 (Ernest Orlando Lawrence Berkeley National Laboratory, July 2003).
U.S. Environmental Protection Agency, "Corn Wet Milling," Volume I: Section 9.9.7, *AP-42: Compilation of Air Pollutant Emission Factors*, (Washington, DC: U.S. Environmental Protection Agency, January 1995). Found at: http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s09-7.pdf.
Sheehan, J. et al., Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

Industry Contacts

Delayne Johnson, Four All Seasons (2005)

3.18 Transformer Oil

3.18.1 Generic Mineral Transformer Oil

Mineral oil-based transformer oil can be made from either naphtha or paraffin. Since the naphthenic-based mineral oil carries a larger market share, it is used as the mineral oil base for the product in BEES.[185] The detailed environmental performance data for this product may be viewed by opening the file G4010B.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The figure below shows the elements of mineral oil-based transformer oil production.

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[185] 2001 telephone conversation with United Power Services, an independent transformer oil testing laboratory.

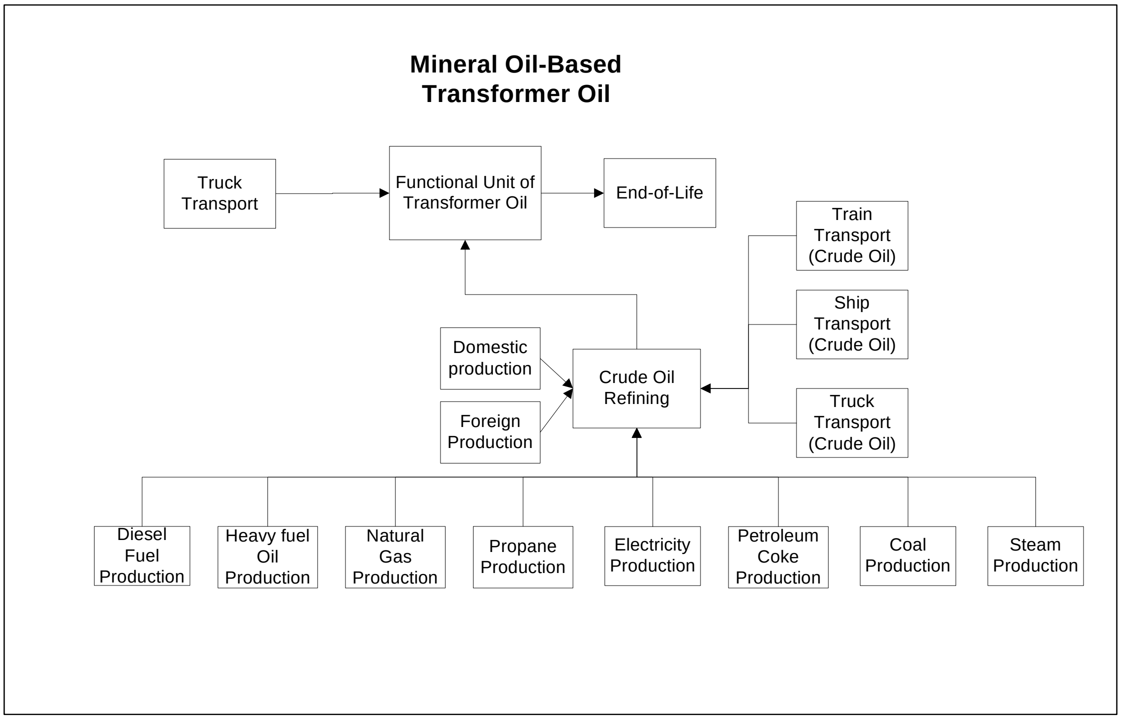

Figure 3.56: Mineral Oil-Based Transformer Oil System Boundaries

Raw Materials

Mineral-oil based transformer oil is composed of the materials listed in the Table below. The density of the oil is assumed to be 0.864 kg/L .[186]

Table 3.131. Mineral-Oil Based Transformer Oil Constituents

Constituent	*Mass (kg/kg oil)*
Naphtha	98 %
Pour-point depressives and other additives	2 %

The production of naphtha requires extraction of crude oil and crude oil refining; since naphtha is just one of many oil refinery products, only a portion of the inputs and outputs to these processes is allocated to naphtha production. Data for these inputs and outputs is based on the SimaPro and U.S. LCI Databases, as detailed below.

Crude Oil Extraction. This production component includes process flows associated with the extraction of crude oil from the ground. U.S. LCI Database data used to represent extraction from onshore and offshore wells range from the late 1990s to early 2000s.

Crude Oil Refining into Naphtha. Crude oil refining involves raw material and energy use as well as emissions. Crude oil refining is based on an average U.S. refinery. It is assumed that the material required by the refinery includes crude oil and other petroleum-based feedstocks, purchased energy inputs, and process catalysts.

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[186] .From http://www.shell-lubricants.com/Electrical/diala_hfx.html and http://www.camd.lsu.edu/msds/t/transformer_oil.htm.

Crude oil refineries draw much of their energy requirements from the crude oil stream in the form of still gas and catalyst coke as shown in the Table below. Additional energy requirements and process needs are fulfilled by the other inputs listed in the Table.[187]

Table 3.132. U.S. Average Refinery Energy Use

Energy Carrier	*Annual Quantity (MJ)*
Still Gas	1.52E+12
Catalyst Coke	5.14E+11
Natural Gas	7.66E+11
Coal	3.27E+09
Steam	3.8E+10
Electricity	1.43E+11
Propane (C3H8, kg)	6.21E+10
Diesel Oil (kg)	3.16E+09
Heavy Fuel Oil	6.13E+10
Coke	1.77E+10
Other	8.8E+09

The emissions and energy requirements associated with the production of these fuels are accounted for. Emissions are based on U.S. Environmental Protection Agency AP-42 emission factors.

Allocation. Crude oil refineries produce a number of different petroleum products from crude oil. The method for allocating total refinery energy use and total refinery emissions to the production of naphtha is complicated by the fact that the refinery product mix is variable, both among refineries and even with time for a given integrated refinery. The following method is used to allocate refinery flows to naphtha production:

1. Calculate the percentage of total refinery energy use by refinery process.
2. Calculate naphtha's share of each process's energy consumption.
3. For each refinery process, multiply the corresponding results from steps 1 and 2 to get the percentage of total refinery energy use allocated to naphtha refining

Manufacturing

Energy Requirements

After producing naphtha, pour-point depressives and other additives such as antioxidants are added to give the transformer oil the properties it needs. The specifics for these additives can not be reported because they are confidential, but their production data come from the SimaPro database. The assumed energy requirement for producing the transformer oil is given in the

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[187] Energy Information Administration, *Petroleum Supply Annual 1994*, Report No. DOE/EIA-0340(94)/1, May 1995.

Table below.[188]

Table 3.133. Energy Requirement for Mineral-Oil Based Transformer Oil Production

Requirement	***Quantity (per kg oil)***
Production Energy	1.6 MJ (0.44 kWh)

Transportation

Trucking is the mode of transport representing transportation from the transformer oil production plant to the transformer to be filled at the point of use. The transportation distance is modeled as a variable of the BEES system. Only trucking is modeled, and not pipeline transportation, since transformer oil is a specialty petroleum product with a tiny market as compared to other petroleum products. As a result, pipeline transportation burdens allocated to transformer oil are assumed to be insignificant.

Use

The amount of oil used in a transformer depends on the size of the transformer. A relatively small-sized (1 000 kV·A) transformer is assumed, which requires about 1.89 m^3 (500 gal) of fluid to cool. It is assumed that the use phase of the transformer oil lasts the lifetime of the transformer, approximately 30 years. Included in the modeling is the electricity required to recondition the oil when dissolved gas analysis tests indicate the need. Reconditioning is assumed to occur every five years.[189]

End of Life

With periodic reconditioning of transformer oil during the 30-year life of the transformer, the oil can be further reconditioned and reused in another transformer at end of life. This is assumed to be the case; none of the product is landfilled.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

3.18.2 Generic Silicone Transfer Oil

Silicone-based transformer fluid is a synthetic transformer oil composed primarily of dimethylsiloxane polymers, and follows a very different series of production steps than does mineral oil-based transformer oil. The detailed environmental performance data for this product may be viewed by opening the file G4010C.DBF under the File/Open menu item in the BEES

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[188] This data is based on confidential energy requirement data gathered for biobased transformer oil production (summer 2005). It is used in the absence of more representative manufacturing energy information for this product.

[189] Information on dissolved gas analysis testing can be found in the U.S. Bureau of Reclamation (USBR) website's Facilities Instructions Standards and Techniques (FIST) document, http://www.usbr.gov/power/data/fist_pub.html . Energy information on reconditioning was provided during telephone conversations with S.D. Myers, a transformer and transformer fluid contractor, November 2001.

software.

Flow Diagram

The figure below shows the elements of silicone transformer fluid production**.**

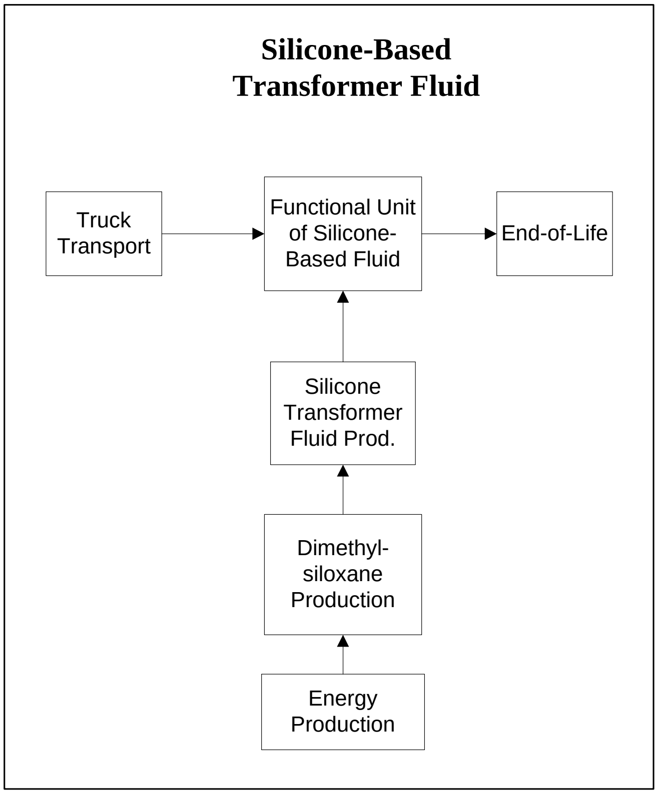

Figure 3.57. Silicone-Based Transformer Oil System Boundaries

Raw Materials

While silicone-based fluid is produced both in the United States and abroad, the only publicly-available data is European. European data is used to model the main component of the product, cyclical siloxane.[190]

Manufacturing

The production of dimethylsiloxane starts with the production of dimethylchlorosilane using chloromethane and silicon. Dimethylchlorosilane undergoes hydrolysis reactions to produce dimethylsilanediol, which undergoes another series of hydrolysis reactions to condense into cyclical siloxane. The average density of the fluid is assumed to be 0.9565 kg/L.[191]

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[190] Silicon production: JL Vignes, Données Industrielles, économiques, géographiques sur des produits chimiques (minéraux et organiques) Metaux et Matériaux, pp. 134, ed. 1994, Union des Physiciens; Dimethylchlorosilane production: "Silicones", Rhône-Poulenc département silicones, Techno-Nathan edition, Nouvelle Librairie, 1988; Dimethylsilanediol and cyclic siloxane production: Carette, Pouchol (RP Silicones), Techniques de l'ingénieur, vol. A 3475, p.3.

[191] From http://www.clearcoproducts.com/pdf/msds/specialty/MSDS-STO-50-Transformer-Oil.pdf and http://www.dowcorning.com/applications/product_finder/pf_details.asp?l1=008&pg=00000642&prod=01496204&type=PROD.

Transportation

Trucking is the mode of transport used to represent transportation from the transformer oil production plant to the transformer to be filled at point of use. The transportation distance is modeled as a variable of the BEES system.

Use

The amount of oil used in a transformer depends on the size of the transformer. A relatively small-sized (1 000 kV·A) transformer is assumed, which requires about 1.89 m^3 (500 gal) of fluid to cool. It is assumed that the use phase of the transformer oil lasts the lifetime of the transformer, approximately 30 years. Included in the modeling is the electricity required to recondition the oil when dissolved gas analysis tests indicate the need. Reconditioning is assumed to occur every five years.[192]

End of Life

With periodic reconditioning of silicone-based transformer oil during the 30-year life of the transformer, the oil is in good enough condition for half of it to be further reconditioned and reused in another transformer. The other half is sent back to the manufacturer for restructuring for production into other silicone-based products.[193] End-of-life options for transformer oil do not include waste disposal, as it is generally a well-maintained product and can be used in other applications. Therefore, none of the product is assumed to be landfilled.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

3.18.3 Cooper Envirotemp FR3

Envirotemp FR3 Dielectric Coolant is a soy oil-based transformer fluid. A relatively small-sized (1 000 kV·A) transformer is assumed for BEES, which requires about 1.89 m^3 (500 gal) of fluid to cool. The functional unit for Envirotemp FR3, as for all BEES transformer oils, is the use of 1.89 m^3 (500 gal) of transformer fluid to cool a 1 000 kV·A transformer for a period of 30 years.

The detailed environmental performance data for this product may be viewed by opening the file G4010D.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

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[192] Information on dissolved gas analysis testing can be found in the U.S. Bureau of Reclamation (USBR) website's Facilities Instructions Standards and Techniques (FIST) document, http://www.usbr.gov/power/data/fist_pub.html . Energy information on reconditioning was provided during telephone conversations with S.D. Myers, a transformer and transformer fluid contractor, November 2001.

[193] Information from Dow Corning, http://www.dowcorning.com, "Reuse, recycle, or disposal of transformer fluid," 2001.

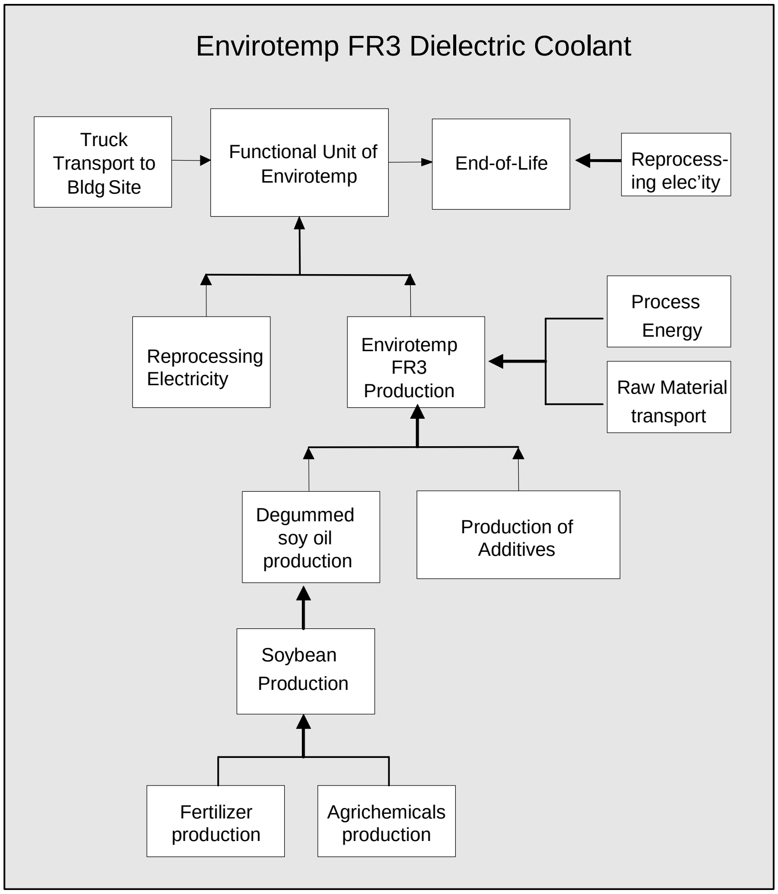

Figure 3.58: Envirotemp FR3 Dielectric Coolant System Boundaries

Raw Materials

The main constituent of Envirotemp FR3 is degummed soybean oil, and it contains small amounts of other additives, shown in the Table below.

Table 3.134: Envirotemp FR3 Constituents

Constituent	*Mass Fraction (%)*
Degummed soybean oil	95
Additives	5

Data for soybean production comes from the U.S. LCI Database. Production data for soybean oil comes from the National Renewable Energy Laboratory LCA study on biodiesel use in an urban bus,[194] in which degummed soy oil is modeled as the precursor to soy-based biodiesel. Additives used in Envirotemp FR3 include a blend of natural esters and methacrylate resins, phenol compounds, and coloring. These additives are not specified due to confidentiality concerns, but they are included in the model and life cycle data for their production comes from the general contents of the SimaPro LCA database.

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[194] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

Manufacturing

Energy Requirements and Emissions. Steam from natural gas and electricity are used to heat and blend a 22.71 m^3 (6 000 gal) batch of Envirotemp FR3. The Table below presents the quantities of each type of energy per gal of product (1 gal weighs 3.2 kg).

Table 3.135: Envirotemp FR3 Manufacturing Energy

Energy Carrier	***Quantity per gal***
Electricity	0.216 MJ (0.06 kWh)
Natural gas	4.43 MJ (4 200 Btu)

Electricity and natural gas are modeled using the U.S. average electric grid from the U.S. LCI Database.

Transportation. Soybean oil is assumed to be transported 322 km (200 mi) to the production site. Transportation of additives is assumed to cover 800 km (500 mi) by truck to the Envirotemp facility. Transportation data is based on the U.S. LCI Database.

Transportation

Heavy-duty truck transportation is used to represent transportation from the Envirotemp facility to the transformer to be filled at the point of use. The distance traveled is modeled as a variable of the BEES system.

Use

For BEES, Envirotemp FR3 Dielectric Fluid is used in a transformer with a capacity of 1.89 m^3 (500 gal). Any type of transformer oil needs to be reconditioned or reclaimed over the life of the transformer: transformer aging, thermal problems, or electrical problems can generate dissolved gas, which results in deterioration or contamination of the fluid. Included in the BEES use phase modeling is the electricity required to recondition the oil when dissolved gas analysis tests indicate the need. Reconditioning is assumed to occur every five years.[195] The transformer itself is assumed to have a lifetime of 30 years.

End of Life

At the end of the 30-year life of the transformer, Envirotemp FR3 is modeled the same as most all other transformer oils in BEES: at year 30, Envirotemp is assumed to be further reconditioned and reused in another transformer. Included in the end-of-life modeling is the electricity required to recondition the oil.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

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[195] Information on dissolved gas analysis testing can be found in the U.S. Bureau of Reclamation (USBR) website's Facilities Instructions Standards and Techniques (FIST) document, http://www.usbr.gov/power/data/fist/fist3-30. Energy information on reconditioning was provided during telephone conversations with S.D. Myers, a transformer and transformer fluid contractor, November 2001.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Sheehan, J. et al., *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus,* NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

Industry Contacts

Patrick McShane, Cooper Power Systems (February 2005)

3.18.4 ABB BIOTEMP

BIOTEMP, produced by ABB, Inc., is an insulating dielectric fluid used in transformers. BIOTEMP is made from various raw vegetable oils, depending on the most ideal market conditions at the time. The most common oils used in this product include sunflower, safflower, and soybean. BIOTEMP is modeled for BEES assuming use of sunflower oil.

A relatively small-sized (1 000 kV·A) transformer is assumed for BEES, which requires about 1.89 m^3 (500 gal) of fluid to cool. The functional unit for BIOTEMP, as for all BEES transformer oils, is the use of 1.89 m^3 (500 gal) of transformer fluid to cool a 1 000 kV·A transformer for a period of 30 years.

The detailed environmental performance data for this product may be viewed by opening the file G4010E.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

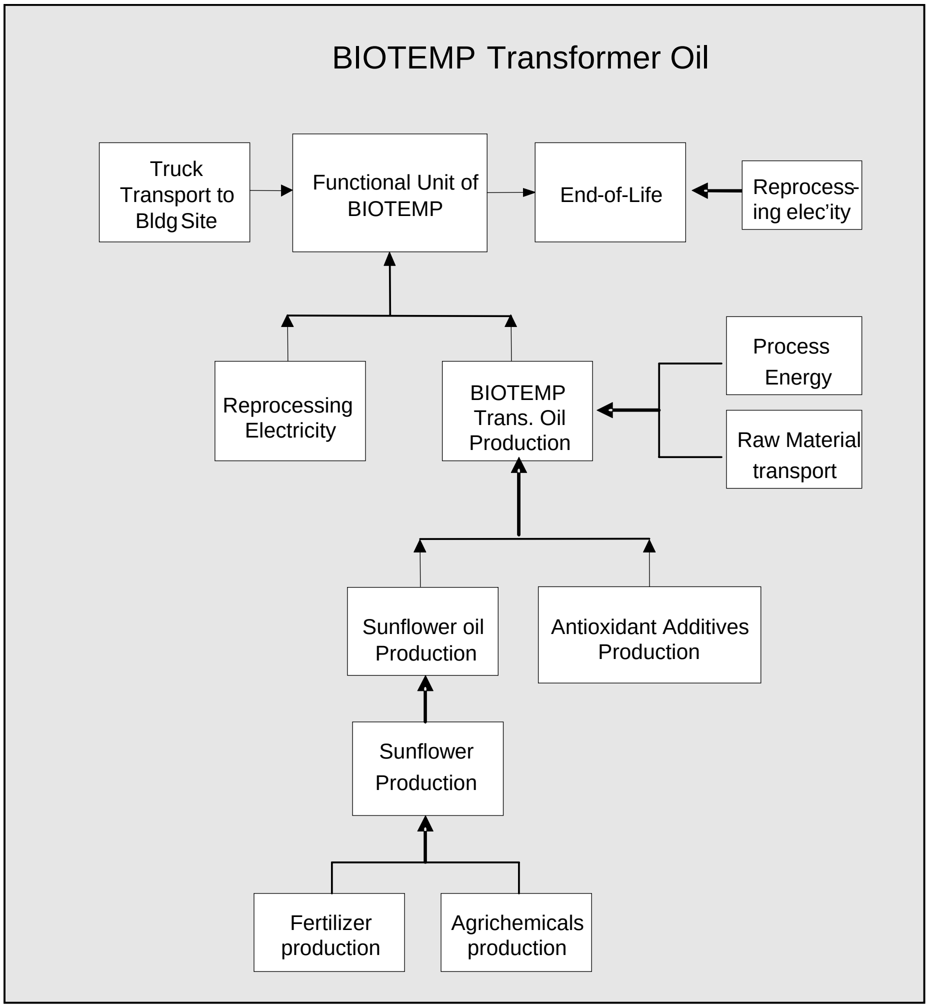

Figure 3.59: BIOTEMP Transformer Oil System Boundaries

Raw Materials

BIOTEMP consists of a high oleic vegetable oil, for BEES a sunflower-based oil, and a small quantity of antioxidant additives, in the proportions shown below.

Table 3.136: BIOTEMP Transformer Oil Constituents

Constituent	*Mass Fraction (%)*
High oleic sunflower oil	98.4
Antioxidant additives	1.6

Data on high oleic sunflower oil covers both sunflower production and production of the oil from sunflower seeds. Sunflower production is modeled as a U.S. average using data aggregated from various sources.[196]

Production of oil from sunflower seeds is modeled based on soybean crushing and crude oil production data, adjusted using mass balance information pertaining to sunflowers.[197]

The specific antioxidants are phenol- and amine- based, and are not further specified to protect manufacturer confidentiality. These are modeled, though, and the life cycle data for the production of phenol and amine as base materials in the additives comes from the general contents of the SimaPro LCA database.

Manufacturing

Energy Requirements and Emissions. At manufacturing, energy is used to heat and filter the raw vegetable oil, blend in the antioxidants, and run the blended compound through a vacuum process. The electricity required for these processes amounts to 1.8 MJ (0.5 kWh) per kilogram of product. Electricity is modeled using the U.S. average electric grid from the U.S. LCI Database.

Transportation. Truck transportation to the BIOTEMP facility for sunflower oil is assumed to cover 5 230 km (3 250 mi), and for the additives is assumed to cover 1 127 km (700 mi).

Waste. Manufacturing waste includes spent filter cartridges. Approximately 0.003 kg (0.007 lb) of spent cartridges result from 1 kg of BIOTEMP production; this is sent to a landfill.

Transportation

Heavy-duty trucking is used to represent transportation from the BIOTEMP production facility to the transformer to be filled at the point of use. The transportation distance is modeled as a variable of the BEES system.

Use

For BEES, BIOTEMP transformer oil is used in a transformer with a capacity of 1.89 m^3 (500 gal). Any type of transformer oil needs to be reconditioned or reclaimed over the life of the transformer: transformer aging, thermal problems, or electrical problems can generate dissolved gas, which results in deterioration or contamination of the fluid. Included in the BEES use phase modeling is the electricity required to recondition the oil when dissolved gas analysis tests indicate the need. Reconditioning is assumed to occur every five years.[198] The transformer itself

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[196] Schmierer, J. et al., SF-SV-04 (Sacramento Valley: University of California Cooperative Extension, 2004). Found at: http://www.agecon.ucdavis.edu/uploads/cost_return_articles/sunflowersv2004.pdf; National Sunflower Association, 2005. Found at: http://www.sunflowernsa.com/growers/default.asp?contentID=72; Thomas Jefferson Agricultural Institute, Columbia, MO, 2005. Found at: http://www.jeffersoninstitute.org/pubs/sunflower.shtml#Fertility; U.S. Geological Survey, "National Totals By Crop and Compound: Sunflower," . Found at: http://ca.water.usgs.gov/pnsp/crop/sunflower.html; Ontario Ministry of Agriculture, Food, and Rural Affairs, "Herbicide recommendations for sunflower," (November 2002). Found at: http://www.omafra.gov.on.ca/english/crops/pub75/12sunflo.htm.

[197] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

[198] Information on dissolved gas analysis testing can be found in the U.S. Bureau of Reclamation (USBR)

is assumed to have a lifetime of 30 years.

End of Life
At the end of the 30-year life of the transformer, BIOTEMP is modeled the same as most other transformer oils in BEES: at year 30, BIOTEMP is assumed to be further reconditioned and reused in another transformer, with reconditioning electricity included in the end-of-life modeling. BIOTEMP is 97 % to 99 % biodegradable.

References
Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Schmierer, J. et al., *Sample Costs to Produce Sunflowers for Seed in the Sacramento Valley,* SF-SV-04 (Sacramento Valley: University of California Cooperative Extension, 2004). Found at: http://www.agecon.ucdavis.edu/uploads/cost_return_articles/sunflowersv2004.pdf.

National Sunflower Association, 2005. Found at: http://www.sunflowernsa.com/growers/default.asp?contentID=72.

Thomas Jefferson Agricultural Institute, Columbia, MO, 2005. Found at: http://www.jeffersoninstitute.org/pubs/sunflower.shtml#Fertility.

U.S. Geological Survey, "National Totals By Crop and Compound: Sunflower," National Water Quality Assessment Pesticide National Synthesis Project. Found at: http://ca.water.usgs.gov/pnsp/crop/sunflower.html.

Ontario Ministry of Agriculture, Food, and Rural Affairs, "Herbicide recommendations for sunflower," Other Field Crops: Sunflowers: Introduction (November 2002). Found at: http://www.omafra.gov.on.ca/english/crops/pub75/12sunflo.htm.

Sheehan, J. et al., Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

Industry Contacts

Don Cherry, ABB, Inc. (March 2005)

3.18.5 Generic Biobased Transformer Oil

Biobased transformer oil is relatively new to the market. Results of independent tests on the performance of biobased transformer oil are comparable to results for other transformer oils, such as the mineral-based and silicone-based fluids in BEES.

Biobased transformer oil is produced from vegetable oil feedstock. The detailed environmental performance data for this product may be viewed by opening the file G4010F.DBF under the File/Open menu item in the BEES software.

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website's Facilities Instructions Standards and Techniques (FIST) document, http://www.usbr.gov/power/data/fist/fist3-30. Energy information on reconditioning was provided during telephone conversations with S.D. Myers, a transformer and transformer fluid contractor, November 2001.

Flow Diagram

The flow diagram in the figure below shows the elements of biobased transformer oil production, as it is currently modeled in BEES.

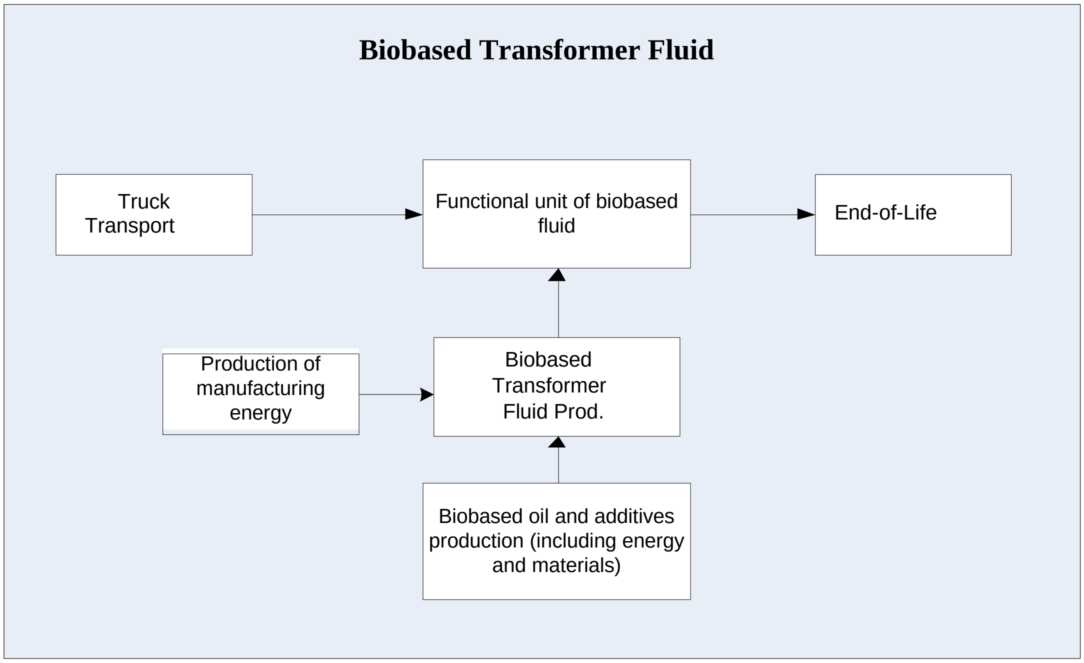

Figure 3.60: Generic Biobased Transformer Oil System Boundaries

Raw Materials

Generic biobased transformer oil is composed of the materials listed in the Table below.

Table 3.137. Generic Biobased Transformer Oil Constituents

Constituent	*Mass (kg/kg oil)*
Biobased oil (soybean and/or other vegetable oils)	96.5 %
Antioxidants and other additives	3.5 %

Production data for converting soybeans to oil[199] is updated with more recent U.S. LCI Database data on soybean growing and harvesting. While fertilizer and agrichemical use, and some energy use for farming equipment, are similar in amount to the older data, electricity use is different (slightly higher), as is natural gas use. There are also additional inputs represented by the new data, including lime.

Manufacturing

After producing biobased oil, antioxidants and other additives are added as enhancements. These

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[199] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

additives are confidential so could not be reported, but their production data come from the SimaPro database. The energy requirement for producing transformer oil is listed in the Table below.[200]

Table 3.138. Biobased Transformer Oil Manufacturing Energy

Requirement	*Quantity (per kg oil)*
Production Energy	1.6 MJ (0.44 kWh)

Transportation

Trucking is the mode of transport used to represent shipment of the product from the transformer oil production plant to the transformer to be filled at the point of use. The transportation distance is modeled as a variable of the BEES system.

Use

For BEES, generic biobased transformer oil is used in a transformer with a capacity of 1.89 m^3 (500 gal). Any type of transformer oil needs to be reconditioned or reclaimed over the life of the transformer: transformer aging, thermal problems, or electrical problems can generate dissolved gas, which results in deterioration or contamination of the fluid. Included in the BEES use phase modeling is the electricity required to recondition the oil when dissolved gas analysis tests indicate the need. Reconditioning is assumed to occur every five years.[201] The transformer itself is assumed to have a lifetime of 30 years.

End of Life

At the end of the 30-year life of the transformer, generic biobased transformer oil is modeled the same as most other transformer oils in BEES: at year 30, the product is assumed to be further reconditioned and reused in another transformer, with reconditioning electricity included in the end-of-life modeling.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

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[200] This data is based on confidential energy requirement data gathered from a biobased transformer oil producer (summer 2005).

[201] Information on dissolved gas analysis testing can be found in the U.S. Bureau of Reclamation (USBR) website's Facilities Instructions Standards and Techniques (FIST) document, http://www.usbr.gov/power/data/fist/fist3-30. Energy information on reconditioning was provided during telephone conversations with S.D. Myers, a transformer and transformer fluid contractor, November 2001.

3.19 Carpet Cleaners

3.19.1 Racine Industries HOST Dry Carpet Cleaning System

Racine Industries' HOST Dry Carpet Cleaning System uses a Green Seal®-certified, biobased cleaning compound. The HOST cleaning compound is a mixture of moisture, cleaning agents, and recycled organic fibers that work as tiny sponges to absorb dirt from the carpet. The compound is worked through the carpet with a brushing machine when working on large areas, or with a hand brush or one's fingers when working on spots. The soiled compound is then vacuumed, leaving a clean, dry carpet. The used product, being dry, does not require wastewater treatment; it can be composted. HOST is used to clean commercial and residential carpets, including those comprised of wool and other natural carpet fibers (it is also used to clean grout). Use of this dry system reduces water use and avoids the energy and time associated with use of dehumidifiers or air conditioners to dry carpets cleaned with wet systems. According to the manufacturer, the HOST System also removes mold, dust mites, and allergens and is manufactured in an EPA-registered facility (074202-WI-001).

For the BEES system, the function defined for carpet cleaning is cleaning 92.9 m^2 (1 000 ft^2) of carpet, which amounts to use of 4.25 kg (9.37 lb) of HOST.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

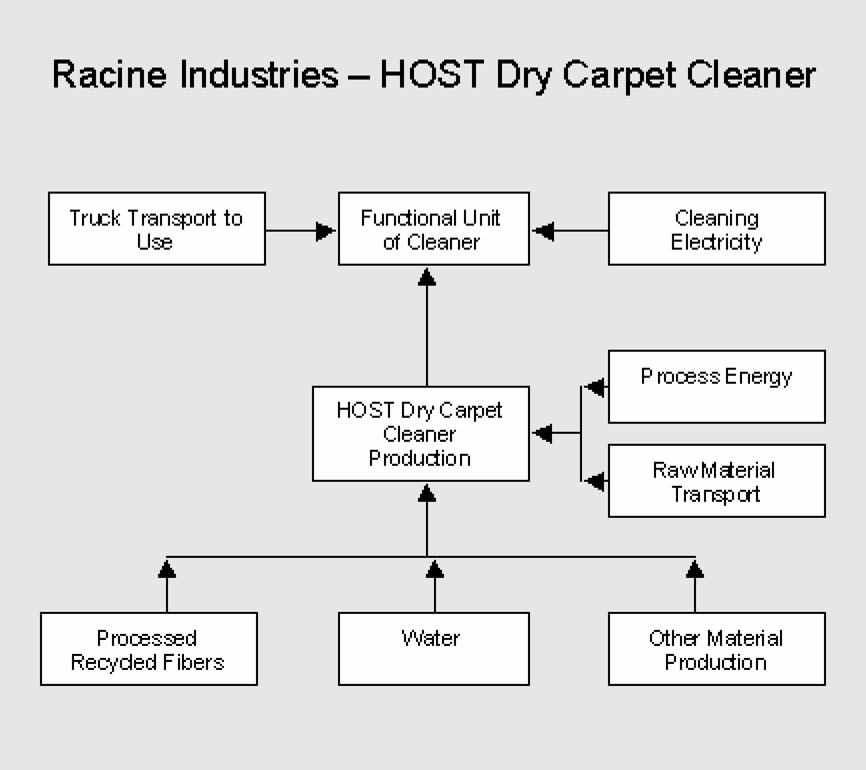

Figure 3.61: HOST Dry Carpet Cleaning System Boundaries

Raw Materials

HOST is made up of the materials shown in the Table below.

Table 3.139: HOST Dry Carpet Cleaning System Constituents

Constituent	*Mass Fraction (%)*
Water	63
Processed organic fiber	31
Other material inputs	6

Processed organic fiber. Processed organic fiber (POF) is comprised of 100 % pre-consumer waste from industrial processing. Because this fiber would otherwise be a waste material, no impacts from fiber production or fiber-based product production are accounted for. However, transportation of the fiber to the Racine plant, as well as energy requirements for manufacturing the fiber into usable material in HOST, are accounted for in BEES, as described below under Manufacturing.

Other material inputs

Emulsion Polymer. Production data for methyl methacrylate, used to represent the emulsion polymer, comes from publicly available European data.[202]

Citrus extract. For production purposes, this extract from citrus rind is considered a coproduct of orange production. It is assumed to comprise 0.5 % of the total mass of useful orange products, which include orange juice, cattle peel feed, and alcohol. Orange production data comes from a variety of sources.[203,204,205]

Other ingredients. Data for remaining ingredients comes from several sources, including a United Nations publication on fertilizer production,[206] elements of the U.S. LCI and SimaPro databases, engineering calculations, and a European life-cycle inventory containing late 1990s data on European detergent production.[207] A solvent is modeled as naphtha, whose production data comes from petroleum refining process data found in a National Renewable Energy Laboratory LCA study on biodiesel use in an urban bus,[208] in which petroleum-based diesel fuel is compared to biodiesel.

Manufacturing

Energy Requirements and Emissions. A total of 0.022 MJ (0.06 kWh) electricity is used in processing HOST, and covers the following processes:

- Blending the constituents
- Conveying and blending the liquid and POF
- Fill line packaging
- Lighting, controls, and ventilation associated with producing HOST

Electricity is modeled using the U.S. average grid, and data for electricity are from the U.S. LCI Database. Natural gas is required to process the organic fiber and amounts to 1.2 MJ (0.33 kWh) per kilogram of HOST. Data are from the U.S. LCI Database.

Processing Materials. A sanitizer is used to sanitize process equipment. Water is used to rinse the blending tank and to clean and sanitize the POF processing and conveyance system and filling line. Quantities of these ancillary materials are reported in the Table below.

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[202] Boustead, I., "Report 14: Polymethyl Methacrylate," (Association of Plastics Manufacturers of Europe, September 1997), pp. 27-29. Found at: http://www.apme.org.

[203] National Agricultural Statistics Service, 2005. Found at: http://www.nass.usda.gov:8080/QuickStats/index2.jsp.

[204] Reposa, J. Jr. and Pandit, A., "Inorganic Nitrogen, Phosphorus, and Sediment Losses from a Citrus Grove during Stormwater Runoff" (Melbourne, FL: Civil Engineering Program, Florida Institute of Technology). Found at: http://www.stormwaterauthority.org/assets/023PLreposacitrus.pdf.

[205] Extrapolation of data on agricultural production in the U.S. LCI Database.

[206] International Fertilizer Industry Association, "Part 1: the Fertilizer Industry's Manufacturing Processes and Environmental Issues," ISBN: 92-807-1640-9 (Paris: United Nations Environment Programme, 1998).

[207] Dall'Acqua, S., et al., Report #244 (St. Gallen: EMPA, 1999).

[208] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, #244 (St. Gallen: EMPA, 1999).

Table 3.140: HOST Processing Materials

Material	***Quantity per kg***
Sanitizer	0.015 g (0.0005 oz)
Water	0.0076 L (0.002 gal)

Solid Waste. Some waste is generated during processing, and includes quality assurance samples, filling line start-up waste, and plastic container waste, all of which amount to 0.003 kg (0.008 lb) per kg product. A portion of this waste is landfilled, while a portion is stored as samples.

Transportation. The transportation distance for all the, constituents besides organic fiber and sanitizer is approximately 80 km (50 mi). The fiber is transported about 563 km (350 mi) to the facility, and sanitizer is supplied locally (within 8 km, or 5 mi). All materials are transported by diesel truck, whose burdens are modeled based on data in the U.S. LCI Database.

Transportation

Product transport to the customer via diesel truck is a variable in BEES, and is modeled based on the U.S. LCI Database.

Use

A total of 4.25 kg (9.37 lb) of HOST are needed to clean 92.9 m^2 (1 000 ft^2) of carpet. HOST is distributed on the floor, brushed, and then vacuumed away. Electricity use associated with brushing the cleaner through the carpet and vacuuming is obtained by averaging the cleaning time based on use of the following three types of vacuum cleaners, for an overall average of 12.5 min per 92.9 m^2 (per 1 000 ft^2):[209]

- Upright Vacuum (from 30 cm to 61 cm in width, or from 12 in to 24 in)
- Large Area Push-Type Vacuum (66 cm to 91 cm, or 26 in to 36 in)
- Backpack Vacuum & Orifice Carpet Tool (30 cm to 61 cm, or 12 in to 24 in)

Assuming a 1 500 W (2.012 hp) motor and taking into account the first stage of brushing and the second stage of vacuuming, the electricity required to clean 92.9 m^2 (1 000 ft^2) is 135 MJ (37.6 kWh), or 32 MJ (8.8 kWh) per kilogram of HOST.[210] Electricity is modeled based on the U.S. average electric grid from the U.S. LCI Database.

End of Life

The contents of the vacuum filter bag or hopper are typically emptied into a waste bin for landfilling. The mass of the cleaner is accounted for in the landfill modeling for this product. While some residential and commercial consumers compost vacuum waste, this is not considered in the BEES product model.

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[209] International Sanitary Supply Associations (ISSA), “Cleaning Applications and Tasks,” The Official 358 Cleaning Times, 1999.

[210] This assumes the brushing stage uses the same quantity of energy as the vacuuming stage.

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Reposa, J. Jr. and Pandit, A., "Inorganic nitrogen, phosphorus, and sediment losses from a citrus grove during stormwater runoff” (Melbourne, FL: Civil Engineering Program, Florida Institute of Technology, date unknown). Found at: http://www.stormwaterauthority.org/assets/023PLreposacitrus.pdf.

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Industry Contacts

Deborah Lema (2006)

3.20 Floor Stripper

3.20.1 Nano Green Floor Stripper

Nano Green mastic remover and floor stripper are two applications in the Nano Green Sciences, Inc. line of janitorial and sanitation products. Nano Green is biobased and biodegradable. It is extracted and blended from U.S. Food and Drug Administration (FDA)-approved food stocks, principally corn, grains, soybeans, and potatoes, and, according the manufacturer, its cleaning capabilities have been shown to be as effective as those of almost any detergent, cleaner, or soap in the marketplace today.

Nano Green falls into two BEES product categories: mastic remover and floor stripper. For the BEES system, the function of mastic remover is removing 9.29 m^2 (100 ft^2) of mastic under vinyl or similar flooring over a period of 50 years. The function of floor stripper in BEES is removing three layers of wax and one layer of sealant from 9.29 m^2 (100 ft^2) of hardwood flooring.

The detailed environmental performance data for these products may be viewed by opening the file H1012A.DBF, for the floor stripper, and the file J1010B.DBF, for the mastic remover, under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of Nano Green as it is currently modeled for BEES.

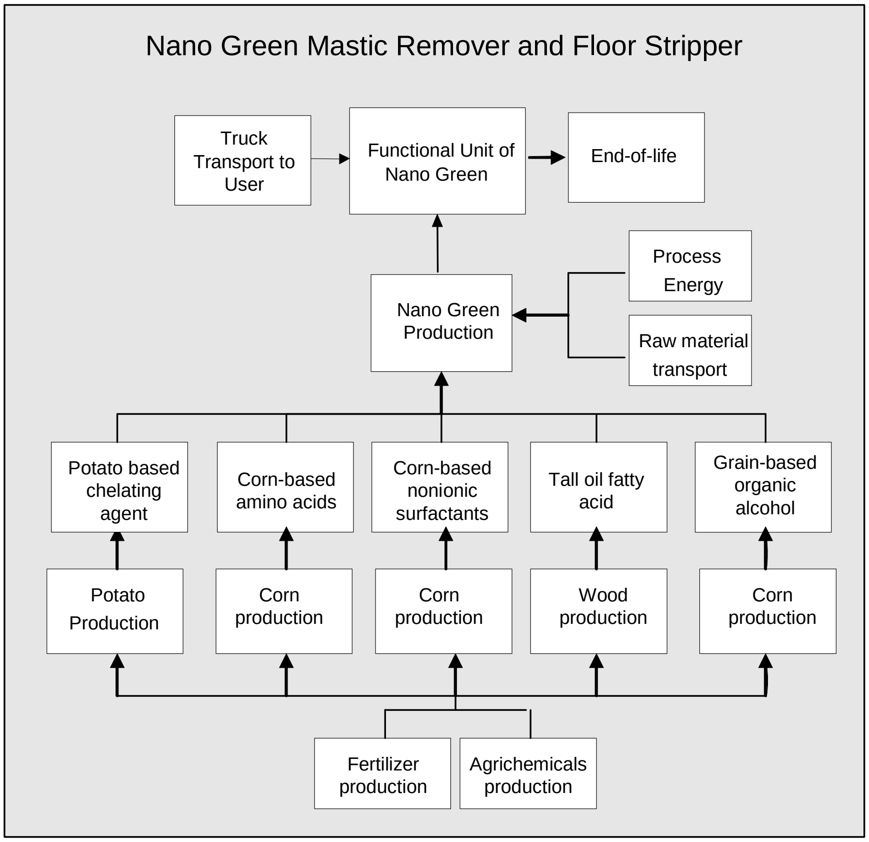

Figure 3.62: Nano Green System Boundaries

Raw Materials

The materials contained in Nano Green are listed in the Table below. Each is found on the FDA-approved Everything Added to Food in the United States (EAFUS) list.

Table 3.141: Nano Green Product Constituents

Constituent	*Mass Fraction (%)*
Corn-based amino acids	16
Corn-based nonionic surfactants	32
Tetracetic acid (potato based chelating agent)	16
Grain-based organic alcohol	16
Tall oil fatty acid	2

Corn-based amino acids. No data are available for the production of corn-based amino acids *per se;* corn starch is used as a surrogate since amino acids are often produced via fermentation, with corn starch as the raw material. Corn starch is assumed to be produced by the wet milling process, with ethanol and other coproducts allocated away. Data on wet milling comes from a study by Lawrence Berkeley National Laboratory.[211] Data on particulate matter emissions comes from the U.S. Environmental Protection Agency AP-42 emissions factors.[212] Corn growing and production data comes from the U.S. LCI Database.

Corn-based nonionic surfactant. Nano Green uses a corn-based nonionic surfactant; in the absence of available data on its production, anionic surfactants are used as a surrogate. Specifically, production data for palm kernel oil (PKO) and coconut oil (CNO) based alkyl polyglocosides (APG) from a European life cycle study of detergent surfactants production are averaged.[213] Since corn content is substantial, comprising 33 % and 36 % of the material requirements for APG-CNO and APG-PKO, respectively, these surfactants are judged to be viable surrogates.

Potato-based chelating agent. Potato starch is used as a surrogate for the tetracetic acid constituent, with data for its production coming from the Danish LCA food database.[214] Data for potato production comes from the U.S. LCI Database.

Grain-based organic alcohol. Corn ethanol is assumed to be the basis for the grain-based organic alcohol constituent. Ethanol production is modeled using an average of dry and wet milling operations.[215]

Tall oil fatty acid. Data for tall oil fatty acid is based mainly on data for tall oil alkyd, found in a Finnish LCA study on coated exterior wood cladding.[216] The tall oil fatty acid is modeled as comprising 95 % of the mass of inputs and outputs as it is a precursor to the alkyd.

Manufacturing

Energy Requirements and Emissions. Energy is used in Nano Green production primarily to blend the product using a 0.5 hp motor. Blending 3.785 m^3 (1 000 gal) for approximately four h amounts to 0.002 hp·h/gal. Electricity is modeled using the U.S. average electric grid from the U.S. LCI Database.

Transportation. All materials are transported by diesel truck approximately 805 km (500 mi) to

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[211] Galitsky, C., Worrell, E., and Ruth, M., LBNL-52307 (Ernest Orlando Lawrence Berkeley National Laboratory, July 2003).

[212] U.S. Environmental Protection Agency, "Corn Wet Milling," Volume I: Section 9.9.7, *AP-42: Compilation of Air Pollutant Emission Factors* (Washington, DC: US Environmental Protection Agency, January 1995). Found at: http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s09-7.pdf.

[213] Stalmans, H., et al., "European Life-Cycle Inventory for Detergent Surfactants Production," , Vol. 32, No. 2, 1995, pp. 84-109.

[214] Danish LCA Food Database, found at: http://www.lcafood.dk/processes/industry/potatoflourproduction.htm.

[215] Graboski, Michael S., (National Corn Growers Association, August 2002); Shapouri, H., "The 2001 Net Energy Balance of Corn-Ethanol" (U.S. Department of Agriculture, 2004); U.S. Environmental Protection Agency, "Grain Elevators and Processes," Volume I: Section 9.9.1, *AP-42: Compilation of Air Pollutant Emission Factors* (Washington, DC: US Environmental Protection Agency, May 2003). Found at: http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s0909-1.pdf. Wet milling data sources are cited under Corn-based Amino Acids.

[216] VTT Technical Research Centre of Finland, "Environmental Impact of Coated Exterior Wooden Cladding," 1999.

the manufacturing facility. Diesel trucking is modeled based on the U.S. LCI Database.

Transportation

Diesel trucking is used to transport the product from the Nano Green facility to the building site, and is modeled based on the U.S. LCI Database. The trucking distance is a variable in BEES.

Use

When Nano Green is used as a mastic remover, approximately 0.002 m^3 (0.5 gal) is needed to remove 18.6 m^2 (200 ft^2) of mastic from the floor. It is assumed that Nano Green is applied twice to remove mastic over a period of 50 years. The same amount of Nano Green is required to remove several layers of wax and sealant from 9.29 m^2 (100 ft^2) of hardwood flooring, but it is assumed that the floor is completely stripped only once over the 50 year BEES use period. Other data on use are not available.

End of Life

The mass of Nano Green at end of life is accounted for in the landfill modeling for this product.

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VTT Technical Research Centre of Finland, "Environmental Impact of Coated Exterior Wooden Cladding," 1999.

Industry Contacts

Alvin Bojar, Nano Green Sciences, Inc. (2005)

3.21 Glass Cleaner

3.21.1 Spartan Green Solutions Glass Cleaner

Spartan Chemical Company, Inc. Green Solutions Glass Cleaner is formulated to penetrate, emulsify, and remove dirt with minimal effort. Green Solutions contains no fragrances, dyes, or VOC. It is Green Seal-certified and it meets Green Seal's environmental standard for industrial and institutional cleaners based on its reduced human and aquatic toxicity and reduced smog production potential.

For the BEES system, 3.785 m^3 (1 000 gal) of ready-to-use glass cleaner is studied.[217] Green Solutions is produced in concentrated form and diluted at the point of use. For 3.785 m^3 (1 000 gal) of ready-to-use Green Solutions, 56 kg (120 lb) of concentrate is used. The detailed environmental performance data for this product may be viewed by opening the file H1013B.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

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[217] While it is unrealistic to assume a need for such a large quantity at a given time, this amount is used so that the environmental impacts for the product are large enough to be reported in the BEES results.

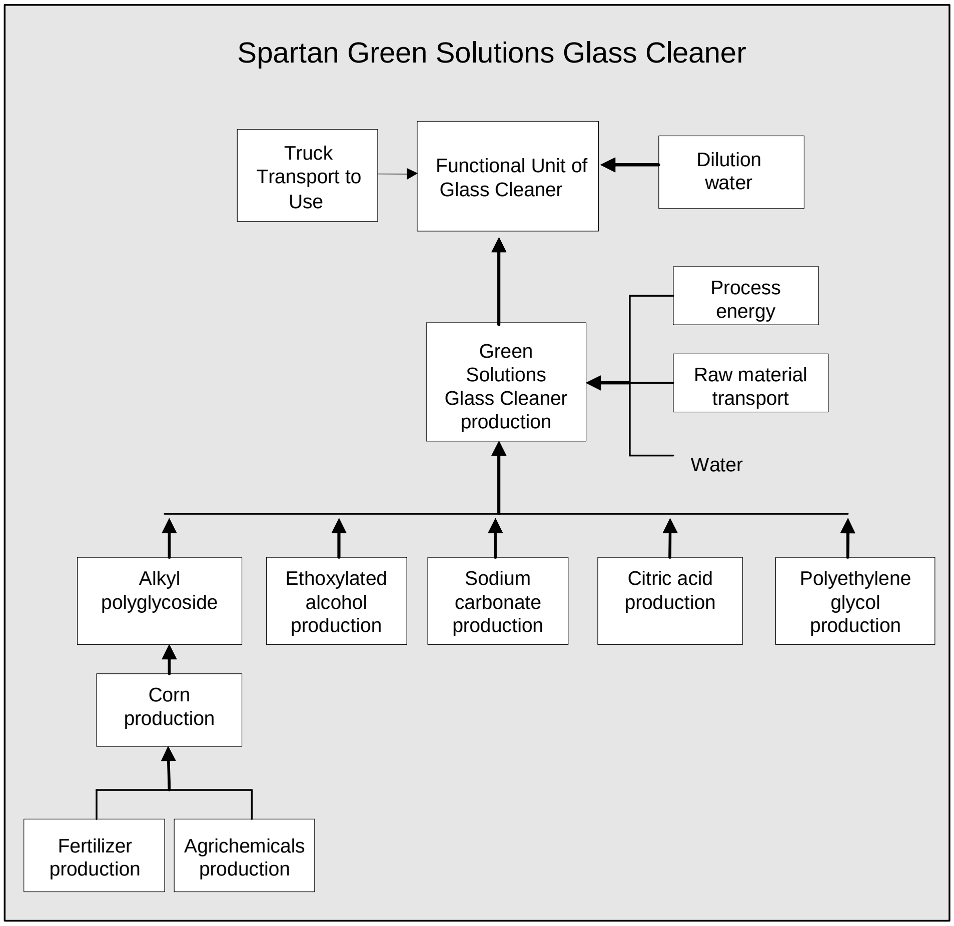

Figure 3.63: Green Solutions Glass Cleaner System Boundaries

Raw Materials

Green Solutions glass cleaner is comprised of the following materials.

Table 3.142: Green Solutions Glass Cleaner Constituents

Constituent	*Mass Fraction (%)*[218]
Water	94
Polyethylene glycol	1-5
Alkyl polyglycoside surfactant	1-5
Ethoxylated alcohol	1-5
Sodium carbonate	1-5
Citric acid	1-5

A portion of the alkyl polyglycoside surfactant is corn-based and assumed to be corn ethanol, for which production data is based on an average of wet- and dry-milling processes. Data for

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[218] Some mass fractions are presented as ranges to protect confidential information.

production of corn comes from the U.S. LCI Database. Process inputs and outputs for ethanol from dry milling come from two ethanol studies.[219,220] Wet milling data comes from a corn wet milling study addressing energy efficiency.[221] The U.S. Environmental Protection Agency AP-42 emissions factors provide air emissions data on wet and dry milling.[222,223]

Polyethylene glycol is assumed to be a copolymer of ethylene oxide and propylene oxide. Data for these substances comes from a source with late 1990s European production data[224] and from elements of the SimaPro and U.S. LCI Databases. An LCA study on detergents[225] provides the data for alcohol ethoxylate, which is used to produce the ethoxylated alcohol in the product.

The production of sodium carbonate is based on the U.S. LCI Database module for soda ash. Citric acid is not included in the model in the absence of available data. Overall, however, the small quantity of citric acid use is judged to contribute little to the raw materials burdens for the product.

Manufacturing

Energy Requirements and Emissions. Product manufacturing consists of a simple chemical blending operation requiring virtually no heat or pressure. Items in the formulation are drum or bulk storage materials that are added to the open top mixing vessel via an air-operated drum lift or air actuated valve. The batching water is used at ambient temperature so no heating is required. The quantity of electricity required to blend one gal is 0.0025 MJ (0.0007 kWh). Electricity is modeled using the U.S. average electric grid from the U.S. LCI Database.

Transportation. Materials are transported varying distances ranging from 14 km (9 mi) to 885 km (550 mi) to the plant. Materials are transported by diesel truck, which is modeled based on the U.S. LCI Database.

Transportation

All final product shipping occurs via diesel semi-truck to approximately 450 points of distribution around the country, averaging a distance of 1 207 km (750 mi) to the customer. This default transportation distance may be adjusted by the BEES user. Diesel trucking is modeled based on the U.S. LCI Database.

Use

According to user directions, two ounces of concentrated cleaner are used per gal of water, a

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[219] Graboski, Michael S., (National Corn Growers Association, August 2002).

[220] Shapouri, H., "The 2001 Net Energy Balance of Corn-Ethanol" (U.S. Department of Agriculture, 2004).

[221] Galitsky, C., Worrell, E., and Ruth, M., LBNL-52307 (Ernest Orlando Lawrence Berkeley National Laboratory, July 2003).

[222] U.S. Environmental Protection Agency, "Grain Elevators and Processes," Volume I: Section 9.9.1 (Washington, DC: US Environmental Protection Agency, May 2003). Found at: http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s0909-1.pdf.

[223] U.S. Environmental Protection Agency, "Corn Wet Milling," Volume I: Section 9.9.7 (Washington, DC: US Environmental Protection Agency, January 1995). Found at: http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s09-7.pdf.

[224] European Commission, "Reference Document on Best Available Techniques in the Large Volume Organic Chemical Industry" , February 2002.

[225] Dall'Acqua, S., et al. , Report #244 (St. Gallen: EMPA, 1999).

dilution ratio of 1:64. The density of Green Solutions glass cleaner is 3.8 kg (8.4 lb) per gal. As a result, 0.067 m^3 (17.6 gal) of water are used per kilogram of concentrate. For 3.785 m^3 (1 000 gallons) of ready to use glass cleaner, 56 kg (120 lb) of the concentrate are used. Other data on use, such as application rates and frequencies, are neither available nor uniform among users.

End of Life

No end-of-life modeling is required, since the product is fully consumed during use.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

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Dall'Acqua, S., et al., Life Cycle Inventories for the Production of Detergent Ingredients, Report #244 (St. Gallen: EMPA, 1999).

Industry Contacts

Bill Schalitz (2005)

3.22 Bath and Tile Cleaner

3.22.1 Spartan Green Solutions Restroom Cleaner

Spartan Chemical Company, Inc. Green Solutions Restroom Cleaner is a natural acid toilet, urinal, and shower room cleaner. It contains 8 % natural citric acid, a hard water scale remover that cleans soap scum, water spots, and light rust from toilet bowls, urinals, and shower room walls and floors. Green Solutions Restroom Cleaner is Green Seal-certified and it meets Green Seal's environmental standard for industrial and institutional cleaners.

For the BEES system, 3.8 L (1 gal) of ready-to-use cleaner is studied. The detailed environmental performance data for this product may be viewed by opening the file H1014A.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

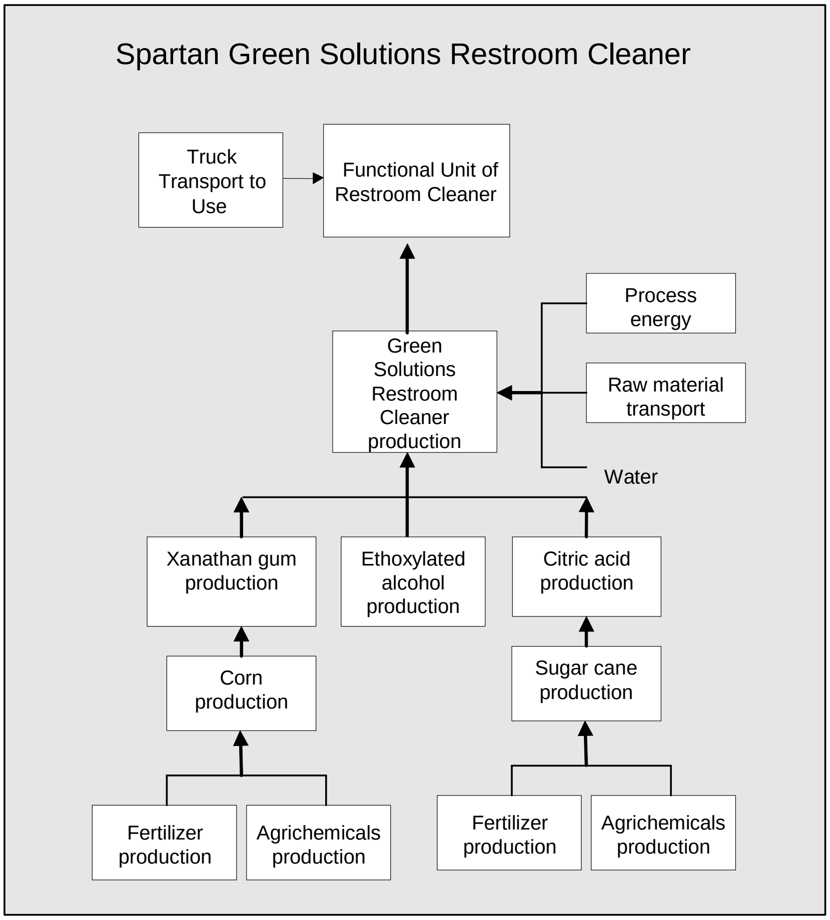

Figure 3.64: Green Solutions Restroom Cleaner System Boundaries

Raw Materials

Green Solutions Restroom Cleaner is comprised of the following materials.

Table 3.143: Green Solutions Restroom Cleaner Constituents

Constituent	Mass Fraction (%)
Water	91
Citric acid	8
Ethoxylated alcohol	0.1 to 1
Xanathan gum	0.1 to 1

In general, citric acid may be manufactured from several renewable natural resources: citrus fruits, pineapple waste, or crude sugars. The citric acid in this product is modeled as coming from molasses from sugar cane. Citric acid process data comes from a plant in the United States that produces approximately 10 million kg (22 million lb) of crystalline citric acid per year.[226] Both sugar cane production data and data representing molasses extraction from the sugar cane come from the U.S. Department of Agriculture Economic Research Service.[227,228]

An LCA study on detergents[229] provides the data for alcohol ethoxylate. Xanathan gum is a thickening agent produced naturally by bacteria. For BEES, xanathan gum is assumed to be corn sugar based, and as such, corn starch is used as the basis for the sweetener. Corn starch is produced by the wet milling process for which data comes from a Lawrence Berkeley National Laboratory study.[230] Data on particulate matter emissions from wet milling comes from the U.S. Environmental Protection Agency AP-42 emissions factors.[231] Corn growing and production data comes from the U.S. LCI Database.

Manufacturing

Energy Requirements and Emissions. Product manufacturing consists of a simple chemical blending operation with virtually no heat or pressure involved. Items in the formulation are drum or bulk storage materials that are added to the open top mixing vessel via an air-operated drum lift or air actuated valve. The batching water is used at ambient temperature so no heating is required. The quantity of electricity required to blend one gal of the product is 0.0025 MJ (0.0007 kWh). Electricity is modeled using the U.S. average electric grid from the U.S. LCI Database.

Transportation. Materials are transported varying distances to the plant, ranging from 14 km (9 mi) for the ethoxylated alcohol to 805 km (500 mi) for the xanathan gum. Materials are transported by diesel truck, which is modeled based on the U.S. LCI Database.

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[226] Petrides, Demetri(Intelligen, Inc.), 2001.

[227] U.S. Department of Agriculture Economic Research Service, : http://ers.usda.gov/Data/sdp/view.asp?f=specialty/89019/&arc=C; http://www.ers.usda.gov/briefing/sugar/data.htm.

[228] Resource Economics Division of the Economic Research Service(Washington, DC: U.S. Department of Agriculture, 1997).

[229] Dall'Acqua, S., et al. , Report #244 (St. Gallen: EMPA, 1999).

[230] Galitsky, C., Worrell, E., and Ruth, M., LBNL-52307 (Ernest Orlando Lawrence Berkeley National Laboratory, July 2003).

[231] U.S. Environmental Protection Agency, "Corn Wet Milling," Volume I: Section 9.9.7(Washington, DC: US Environmental Protection Agency, January 1995). Found at: http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s09-7.pdf.

Transportation

All final product shipping occurs via diesel semi-truck to approximately 450 points of distribution around the country, averaging a distance of 1 207 km (750 mi) to the customer. This default transportation distance may be adjusted by the BEES user. Diesel trucking is modeled based on the U.S. LCI Database.

Use

Green Solutions is VOC-free and can be used both "as is" and diluted. According to the manufacturer's customer use data, most of the time it is not diluted; when it is, a 1:10 dilution ratio is the average. For BEES, the product is assumed to be used in undiluted form. Other data on use, such as application rates and frequencies, are neither available nor uniform among users.

End of Life

No end-of-life modeling is required since the product is fully consumed during use.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

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Petrides, Demetri, Bioprocess Design (Intelligen, Inc.), 2001.

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U.S. Environmental Protection Agency, "Corn Wet Milling," Volume I: Section 9.9.7, AP-42: Compilation of Air Pollutant Emission Factors, (Washington, DC: U.S. Environmental Protection Agency, January 1995). Found at: http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s09-7.pdf

Industry Contacts

Bill Schalitz, Spartan Chemical Company, Inc. (2005)

3.23 Grease & Graffiti Remover

3.23.1 VertecBio Gold Graffiti Remover

VertecBio™ Gold is a corn and soybean derived solvent used to remove spray paint and ink from all types of surfaces. It is a light gold liquid with low volatility that is rinsed away with water.

For the BEES system, 3.8 L (1 gal) of VertecBio™ Gold is studied. The detailed environmental performance data for this product may be viewed by opening the file H1015C.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

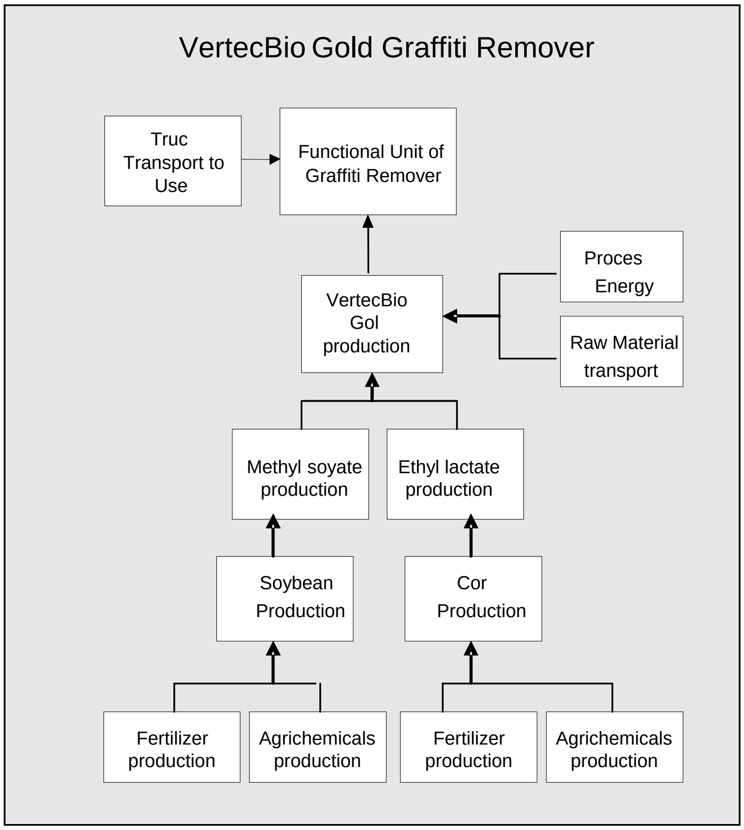

Figure 3.65: VertecBio™ Gold System Boundaries

Raw Materials

VertecBio™ Gold is primarily made up of the materials shown in the Table below.

Table 3.144: VertecBio™ Gold Graffiti Remover Constituents

Constituent	*Mass Fraction (%)*
Ethyl lactate	50
Methyl soyate	50

Data for the soybean-based input, methyl soyate, is based on soybean production data from the U.S. LCI Database. Data for both the production of soybean oil and the esterification process used to produce methyl soyate comes from a National Renewable Energy Laboratory LCA study on biodiesel use in an urban bus.[232] Information on ethyl lactate comes from the manufacturer,[233] elements of the U.S. LCI Database, a report by Lawrence Berkeley National Laboratory on corn wet milling,[234] and U,S. EPA AP-42 emissions factors.[235]

Manufacturing

Energy Requirements and Emissions. VertecBio™ Gold production involves mixing the components in batches. No heating of the components is required. Energy is used for pumping raw materials into a 3.78 m^3 (1 000 gal) vessel, mixing the components, and pumping the product out of the vessel. Actual energy requirements are not available; the pumps are assumed to require 1.5 kW (2 hp) for a duration of 1 h and the mixer is assumed to require 15 kW (20 hp) for a duration of 1 h, based on conversations with production facility personnel. Total energy use per 3.785 m^3 (1 000 gal) batch is calculated to be 59.1 MJ (16.4 kWh), or 0.06 MJ (0.02 kWh) per gal.

Transportation. The transportation distance for shipping the raw materials to the manufacturing plant by diesel truck is assumed to be 402 km (250 mi). Diesel trucking burdens are modeled based on the U.S. LCI Database.

Transportation

Product transport is assumed to cover 1 175 km (730 mi) by diesel truck, which is modeled based on the U.S. LCI Database.

Use

One gal of VertecBio™ Gold weighs 3.56 kg (7.85 lb), and it is fully biodegradable. No data on effluents from rinsing the product are available.

End of Life

No end-of-life modeling is required since the product is fully consumed during the use phase.

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[232] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

[233] Phone conversation with Rathin Datta, Vertec Biosolvents, September 20, 2004.

[234] Galitsky, C., Worrell, E., and Ruth, M., LBNL-52307 (Ernest Orlando Lawrence Berkeley National Laboratory, July 2003).

[235] U.S. Environmental Protection Agency, "Corn Wet Milling," Volume I: Section 9.9.7, *AP-42: Compilation of Air Pollutant Emission Factors*(Washington, DC: US Environmental Protection Agency, January 1995). Found at: http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s09-7.pdf

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Sheehan, J. et al., Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

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Industry Contacts

Vertec Biosolvents, Inc. (September 2004)

3.24 Adhesive and Mastic Remover

3.24.1 Frammar BEAN-e-doo Mastic Remover

BEAN-e-doo Mastic Remover is a soybean based product used to remove asbestos mastic, carpet mastic, and ceramic tile mastic. The user pulls up the flooring, pours BEAN-e-doo onto the surface, and after about one h, scrapes off the softened mastic. BEAN-e-doo has no odor and rinses away with water.

For the BEES system, the function of mastic remover is removing 9.29 m^2 (100 ft^2) of mastic under vinyl or similar flooring over a period of 50 years.

The detailed environmental performance data for this product may be viewed by opening the file J1010A.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

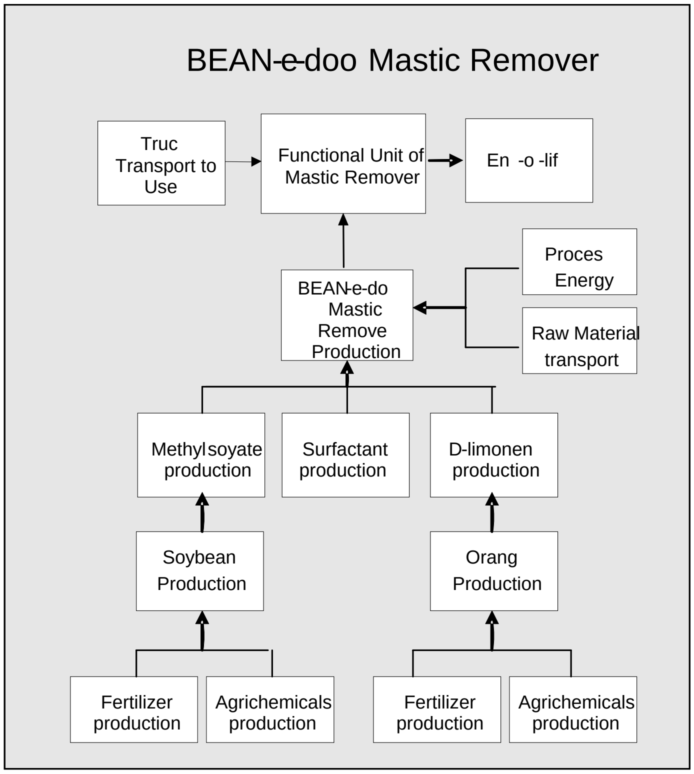

Figure 3.66: BEAN-e-doo Mastic Remover System Boundaries

Raw Materials

BEAN-e-doo is made up of the materials shown in the Table below.

Table 3.145: BEAN-e-doo Mastic Remover Constituents

Constituent	*Mass Fraction (%)*
Methyl soyate	85
Nonionic surfactants[236]	14
d-Limonene	1

Data for methyl soyate originates with soybean production data from the U.S. LCI Database. Data for the production of soybean oil and its further transformation into methyl soyate comes from a National Renewable Energy Laboratory LCA study on biodiesel use in an urban bus.[237] While data for production of the nonionic surfactant compounds in the product is unavailable, data for producing alcohol ethoxylate (AE) is used as a proxy.[238] D-Limonene is the major component of oil extracted from citrus rind; for production data purposes it is considered a coproduct of orange production. As such, it is assumed to comprise 0.5 % of the total mass of useful orange products, which include orange juice, cattle peel feed, and alcohol. Orange data comes from a variety of sources.[239,240,241]

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[236] Names of surfactants not released to protect the confidentiality of company data.

[237] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

[238] Dall'Acqua, S., et al., Report #244 (St. Gallen: EMPA, 1999).

[239] National Agricultural Statistics Service, 2005. Found at:

Manufacturing

Energy Requirements and Emissions. Manufacture of BEAN-e-doo consists of pumping the components together into a 1.14 m^3 (300 gal) container, then draining the container. Production energy is required for pumping, but no heating of the product is required. For each 3.8 L (1 gal) of product, 0.004 MJ (0.001 kWh) is the estimated energy requirement based on the size of the pump. Electricity is modeled using the U.S. average electric grid from the U.S. LCI Database. Approximately 0.04 m^3 (10 gal) of water is included in the model to account for rinsing the tank between several production batches.

Transportation. Methyl soyate is transported approximately 322 km (200 mi) to the BEAN-e-doo facility. D-limonene is transported approximately 1931 km (1 200 mi), and the surfactants are transported about 64 km (40 mi). All materials are assumed to be transported by diesel truck, which is modeled based on the U.S. LCI Database.

Transportation

Diesel trucking is the mode of product transport from the BEAN-e-doo facility to the customer. The transportation distance is, by default, 805 km (500 mi), but this distance can be adjusted by the BEES user. Diesel trucking is modeled based on the U.S. LCI Database.

Use

According to manufacturer instructions for vinyl mastic removal, one gal of BEAN-e-doo may be applied to up to 18.6 m^2 (200 ft^2) of flooring, so 0.002 m^3 (0.5 gal) is modeled for removing 9.29 m^2 (100 ft^2) of mastic. It is assumed that BEAN-e-doo is applied twice to remove mastic over a period of 50 years. Data on water requirements or potential effluents from rinsing the product are not available.

End of Life

After BEAN-e-doo has been applied and mastic removed, they are both assumed to be disposed of in a landfill. However, while they are disposed together, only the mass of the BEAN-e-doo is accounted for at end of life.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Sheehan, J. et al., Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

Dall'Acqua, S., et al., Life Cycle Inventories for the Production of Detergent Ingredients, Report #244 (St. Gallen: EMPA, 1999).

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http://www.nass.usda.gov:8080/QuickStats/index2.jsp.

[240] Reposa, J. Jr. and Pandit, A., "Inorganic nitrogen, phosphorus, and sediment losses from a citrus grove during stormwater runoff" (Melbourne, FL: Civil Engineering Program, Florida Institute of Technology). Found at: http://www.stormwaterauthority.org/assets/023PLreposacitrus.pdf.

[241] Extrapolation of data for agricultural products from the U.S. LCI Database.

National Agricultural Statistics Service, 2005. Found at: http://www.nass.usda.gov:8080/QuickStats/index2.jsp

Reposa, J. Jr. and Pandit, A., "Inorganic nitrogen, phosphorus, and sediment losses from a citrus grove during stormwater runoff" (Melbourne, FL: Civil Engineering Program, Florida Institute of Technology, date unknown). Found at: http://www.stormwaterauthority.org/assets/023PLreposacitrus.pdf.

Industry Contacts

Dan Brown, Franmar Chemical, Inc. (September 2004)

3.24.2 Nano Green Mastic Remover

See documentation on both Nano Green products under Floor Stripper.

4. BEES Tutorial

To select environmentally-preferred, cost-effective building products, follow three main steps:

1. Set your study parameters to customize key assumptions
2. Define the alternative building products for comparison. BEES results may be computed once alternatives are defined.
3. View the BEES results to compare the overall, environmental, and economic performance scores for your alternatives.

4.1 Setting Parameters

Select Analysis/Set Parameters from the BEES Main Menu to set your study parameters. A window listing these parameters appears, as shown in Figure 4.1. Move around this window by pressing the Tab key.

BEES uses importance weights to combine environmental and economic performance measures into a single performance score. If you prefer not to weight the environmental and economic performance measures, select the "no weighting" option. In this case, BEES will compute and display only disaggregated performance results.

Assuming you have chosen to weight BEES results, you are asked to enter your relative importance weights for environmental versus economic performance. These values must sum to 100. Enter a value between 0 and 100 for environmental performance reflecting your percentage weighting. For example, if environmental performance is all-important, enter a value of 100. The corresponding economic importance weight is automatically computed. Next you are asked to select your relative importance weights for the environmental impact categories included in the BEES environmental performance score: Global Warming, Acidification, Eutrophication, Fossil Fuel Depletion, Indoor Air Quality, Habitat Alteration, Water Intake, Criteria Air Pollutants, Smog, Ecological Toxicity, Ozone Depletion, and Human Health. You are presented with four sets of alternative weights. You may choose to define your own set of weights or to select a built-in weight set derived from an EPA Science Advisory Board study, judgments by a BEES Stakeholder Panel, or a set of equal weights.[242] Press View Weights to display the impact category weights for all four weight sets, as shown in Figure 4.2. If you select the user-defined weight set, you will be asked to enter weights for all impacts under analysis, as shown in Figure 4.3. These weights must sum to 100.

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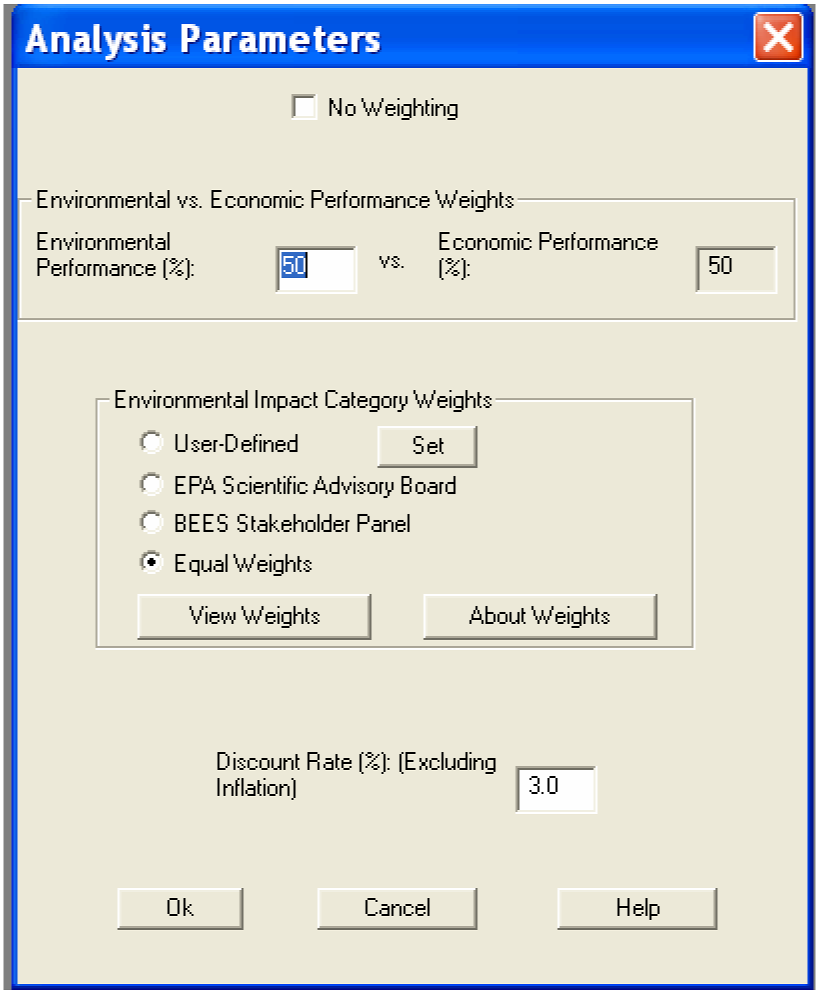
[242] So that the set of equal weights would appropriately sum to 100, individual weights have been rounded up or down. These arbitrary settings may be changed by using the user-defined weighting option.



☐ No Weighting

Environmental vs. Economic Performance Weights

Environmental Performance (%): 50 vs. Economic Performance (%): 50

Environmental Impact Category Weights

○ User-Defined

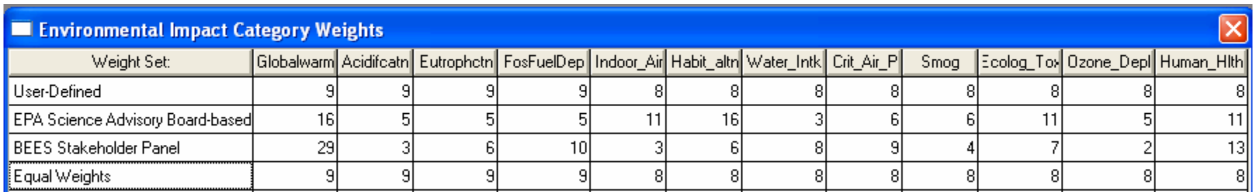
○ EPA Scientific Advisory Board

○ BEES Stakeholder Panel

● Equal Weights

Discount Rate (%): (Excluding Inflation) 3.0

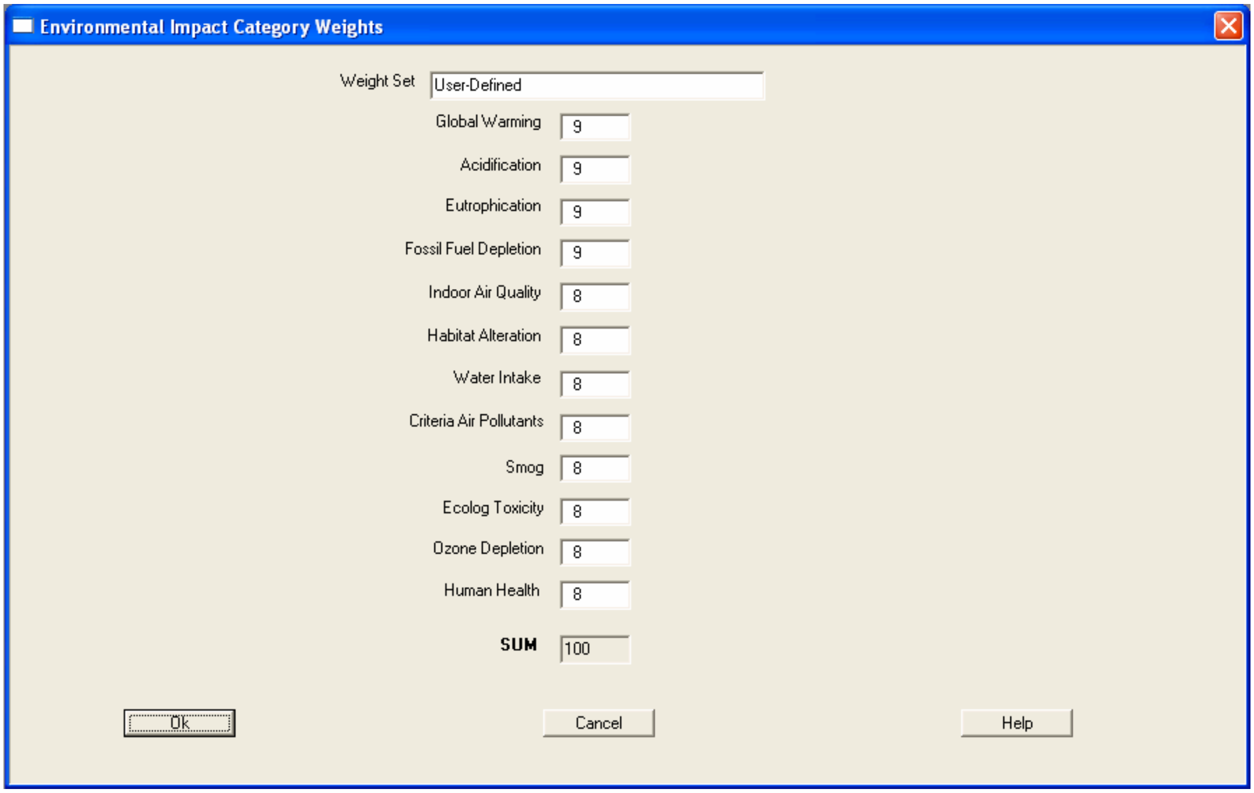
Figure 4.1 Setting Analysis Parameters



Environmental Impact Category Weights

Weight Set:	Globalwarm	Acidifcatn	Eutrophctn	FosFuelDep	Indoor_Air	Habit_altn	Water_Intk	Crit_Air_P	Smog	Ecolog_To	Ozone_Depl	Human_Hlth
User-Defined	9	9	9	9	8	8	8	8	8	8	8	8
EPA Science Advisory Board-based	16	5	5	5	11	16	3	6	6	11	5	11
BEES Stakeholder Panel	29	3	6	10	3	6	8	9	4	7	2	13
Equal Weights	9	9	9	9	8	8	8	8	8	8	8	8

Figure 4.2 Viewing Impact Category Weights



Weight Set	User-Defined
Global Warming	9
Acidification	9
Eutrophication	9
Fossil Fuel Depletion	9
Indoor Air Quality	8
Habitat Alteration	8
Water Intake	8
Criteria Air Pollutants	8
Smog	8
Ecolog Toxicity	8
Ozone Depletion	8
Human Health	8
SUM	100

Figure 4.3 Entering User-Defined Weights

Finally, enter the real (excluding inflation) discount rate for converting future building product costs to their equivalent present value. All future costs are converted to their equivalent present values when computing life-cycle costs. Life-cycle costs form the basis of the economic performance scores. The higher the discount rate, the less important to you are future building product costs such as repair and replacement costs. The maximum value allowed is 20 %. A discount rate of 20 % would value each dollar spent 50 years hence as only $0.0001 in present value terms. The 2006 rate mandated by the U.S. Office of Management and Budget for most Federal projects, 3.0 %, is provided as a default value.[243]

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[243] U.S. Office of Management and Budget (OMB) Circular A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, Washington, DC, October 27, 1992 and OMB Circular A-94, Appendix C, Washington, DC, January 2007

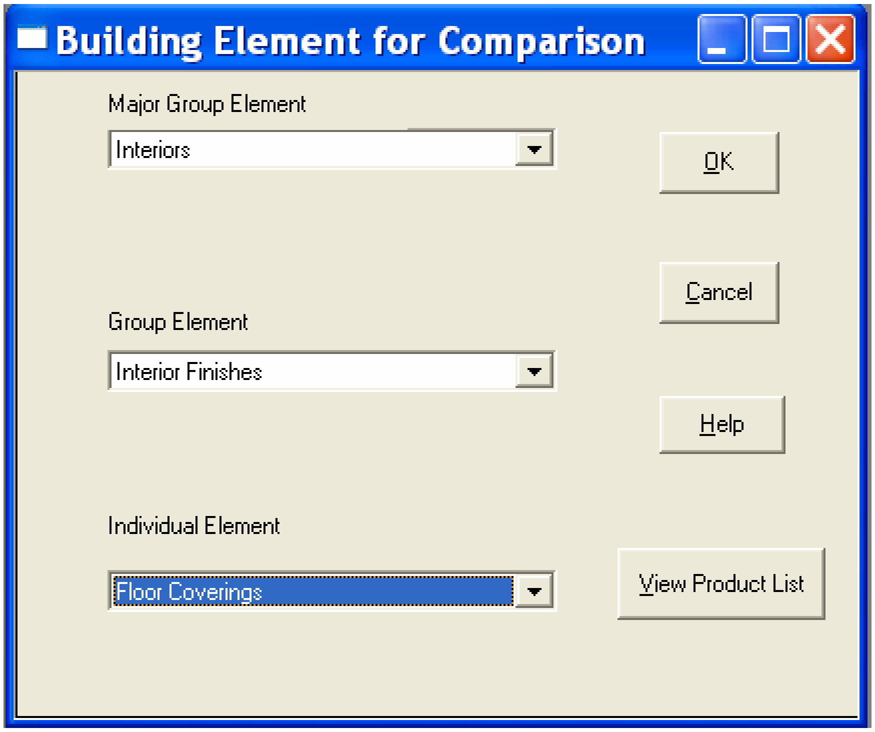

Figure 4.4 Selecting Building Element for BEES Analysis

4.2 Defining Alternatives

Select Analysis/Define Alternatives from the Main Menu to choose the building products you want to compare. A window appears as in Figure 4.4. Selecting alternatives is a two-step process.

1. Select the specific building element for which you want to compare alternatives. Building elements are organized using the hierarchical structure of the ASTM standard UNIFORMAT II classification system: by Major Group Element, Group Element, and Individual Element.[244] Click on the down arrows to display the complete lists of available choices at each level of the hierarchy. For a listing BEES products included in each building element, click View Product List.

   BEES 4.0 contains environmental and economic performance data for over 230 products across a wide range of building elements including beams, columns, roof sheathing, exterior wall finishes, wall insulation, framing, roof coverings, partitions, ceiling finishes, interior wall finishes, floor coverings, chairs, and parking lot paving. Press Ok to select the choice in view.

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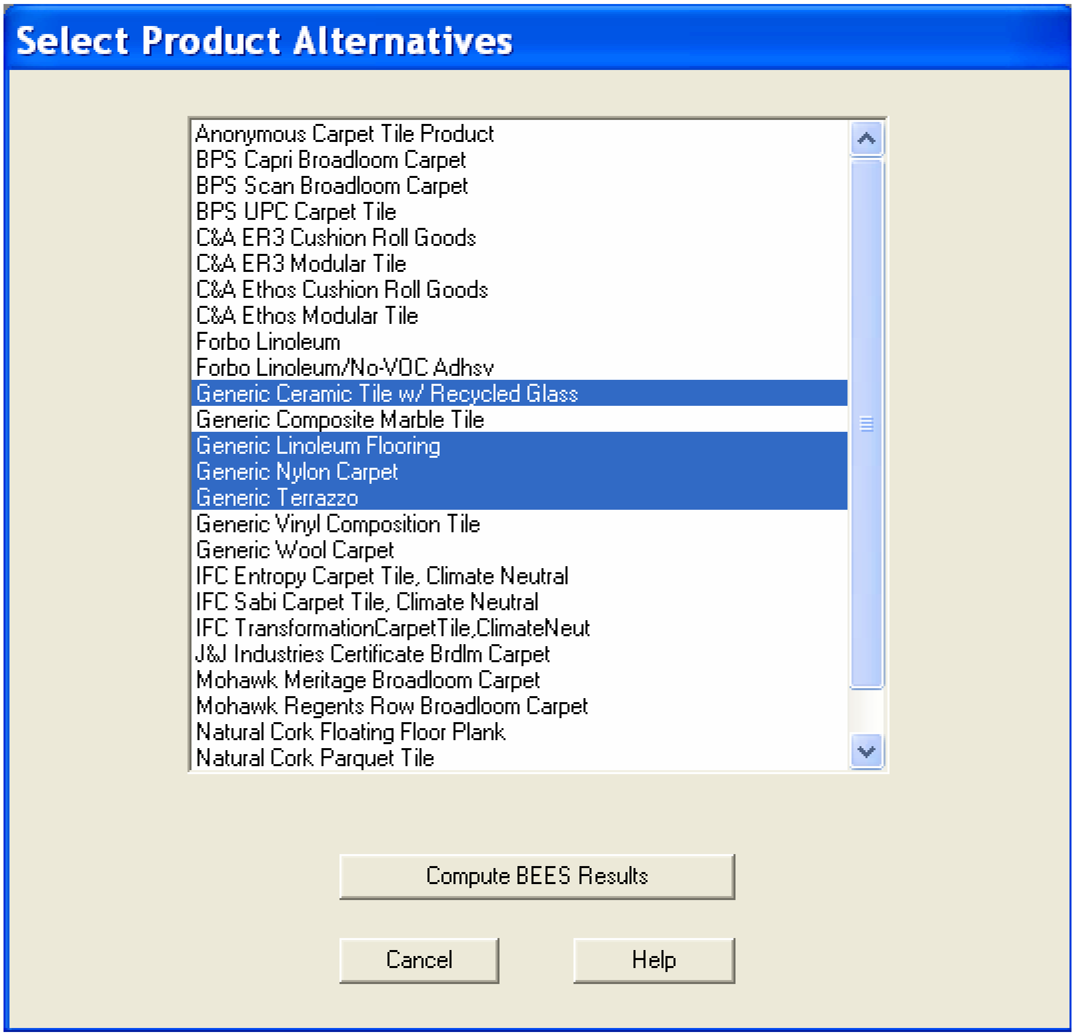
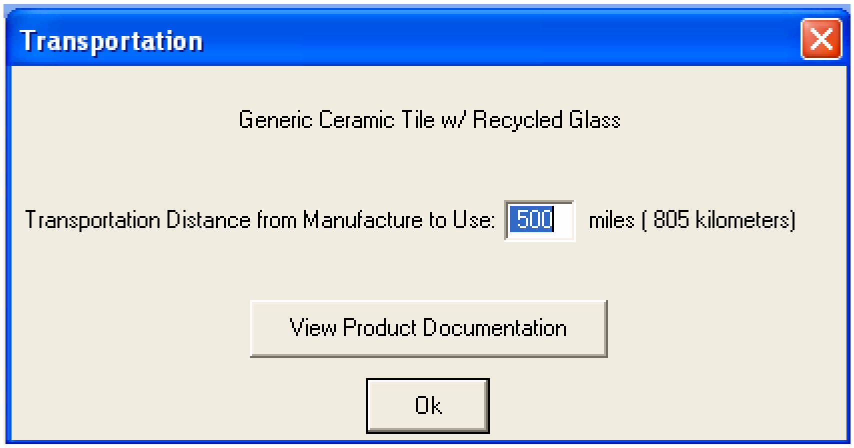
[244] ASTM International, *Standard Classification for Building Elements and Related Sitework--UNIFORMAT II,* ASTM Designation E1557-05, West Conshohocken, PA, 2005.



Anonymous Carpet Tile Product
BPS Capri Broadloom Carpet
BPS Scan Broadloom Carpet
BPS UPC Carpet Tile
C&A ER3 Cushion Roll Goods
C&A ER3 Modular Tile
C&A Ethos Cushion Roll Goods
C&A Ethos Modular Tile
Forbo Linoleum
Forbo Linoleum/No-VOC Adhsv
Generic Ceramic Tile w/ Recycled Glass
Generic Composite Marble Tile
Generic Linoleum Flooring
Generic Nylon Carpet
Generic Terrazzo
Generic Vinyl Composition Tile
Generic Wool Carpet
IFC Entropy Carpet Tile, Climate Neutral
IFC Sabi Carpet Tile, Climate Neutral
IFC TransformationCarpetTile,ClimateNeut
J&J Industries Certificate Brdlm Carpet
Mohawk Meritage Broadloom Carpet
Mohawk Regents Row Broadloom Carpet
Natural Cork Floating Floor Plank
Natural Cork Parquet Tile

Figure 4.5 Selecting Building Product Alternatives



Generic Ceramic Tile w/ Recycled Glass

Transportation Distance from Manufacture to Use: 500 miles (805 kilometers)

Figure 4.6 Setting Transportation Parameters

2. Once you have selected the building element, you are presented with a window of product alternatives available for BEES scoring, such as in Figure 4.5. Select an alternative with a mouse click. After selecting each alternative, you will be presented with a window, such as in Figure 4.6, asking for the distance required to transport the product from the manufacturing plant to your building site.[245] If the product is exclusively manufactured in another country (e.g., linoleum flooring), this setting should reflect the transportation distance from the U.S. distribution facility to your building site (transport *to* the distribution facility has already been built into the BEES data).

If you have already set your study parameters, press Compute BEES Results to compute and display the BEES environmental and economic performance results.

4.3 Viewing Results

Once you have set your study parameters, defined your product alternatives, and computed BEES results, BEES displays the window for selecting BEES reports illustrated in Figure 4.7. By default, the three summary graphs shown in Figures 4.8, 4.9, and 4.10 are selected for display or printing. Press Display to view the three graphs. For all BEES graphs, the larger the value, the *worse* the performance. Also, all BEES graphs are stacked bar graphs, meaning the height of each bar represents a summary performance score consisting of contributing scores represented as its stacked bars.

1. The Overall Performance Results graph displays the weighted environmental and economic performance scores and their sum, the overall performance score. If you chose not to weight, this graph is not available.
2. The Environmental Performance Results graph displays the weighted environmental impact category scores and their sum, the environmental performance score. Because this graph displays scores for unit quantities of individual building products that have been normalized (i.e., placed on a common scale) by reference to total U.S. impacts, they appear as very small numbers. For a primer on interpreting BEES environmental performance scores, refer to Appendix B. If you chose not to weight, this graph is not available.
3. The Economic Performance Results graph displays the first cost, discounted future costs and their sum, the life-cycle cost.

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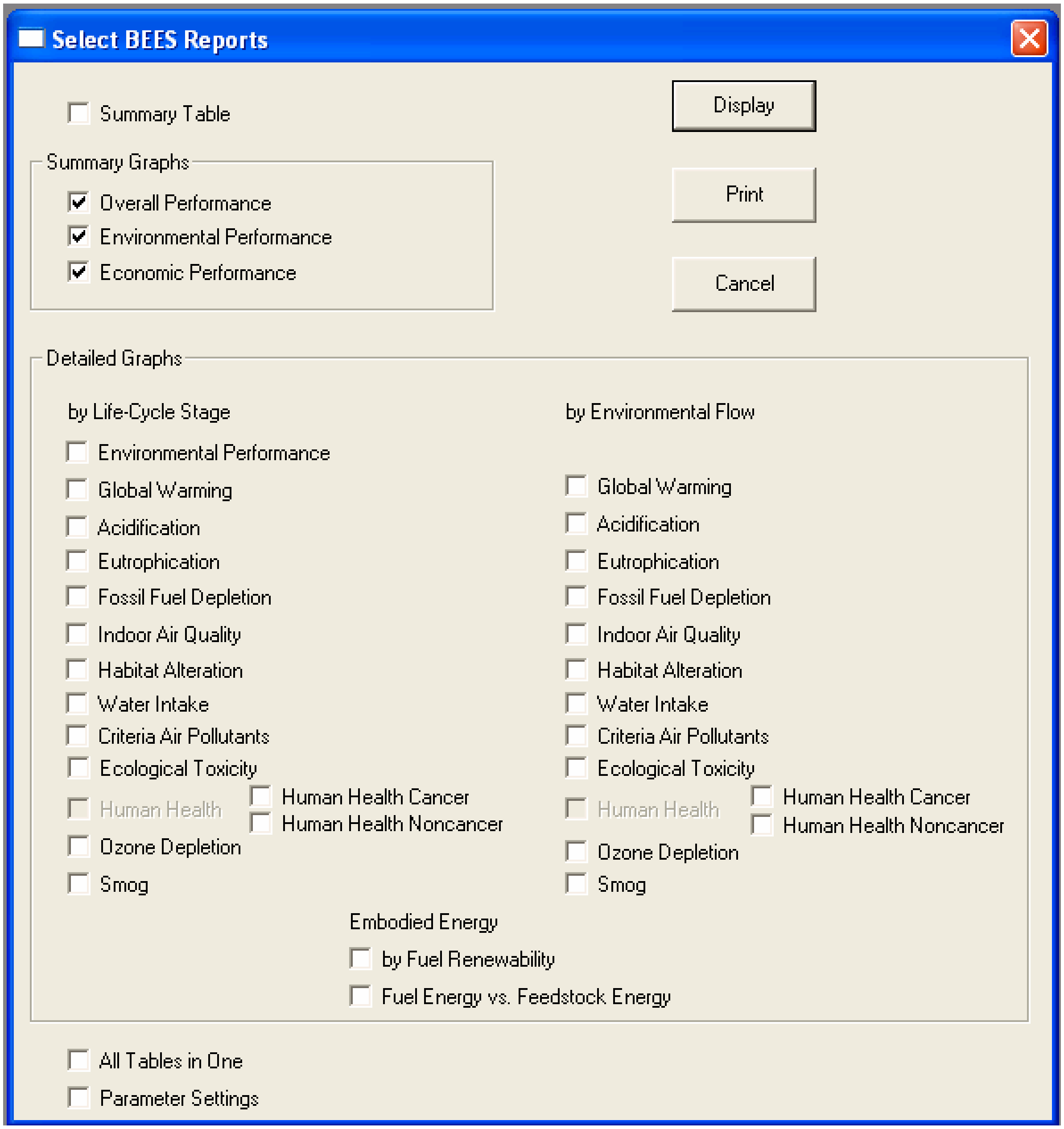
[245] If you have chosen the wall insulation or exterior wall finish elements, you will first be asked for parameter values so that the products' influence on heating and cooling energy use over the 50-year study period can be properly estimated. If you have chosen roof coverings and installation will be in a U.S. Sunbelt climate, you will be asked for parameter values that will permit accounting for 50-year heating and cooling energy use based on roof covering color.



☐ Summary Table

Summary Graphs
- ☑ Overall Performance
- ☑ Environmental Performance
- ☑ Economic Performance

Detailed Graphs

by Life-Cycle Stage
- ☐ Environmental Performance
- ☐ Global Warming
- ☐ Acidification
- ☐ Eutrophication
- ☐ Fossil Fuel Depletion
- ☐ Indoor Air Quality
- ☐ Habitat Alteration
- ☐ Water Intake
- ☐ Criteria Air Pollutants
- ☐ Ecological Toxicity
- ☐ Human Health
  - ☐ Human Health Cancer
  - ☐ Human Health Noncancer
- ☐ Ozone Depletion
- ☐ Smog

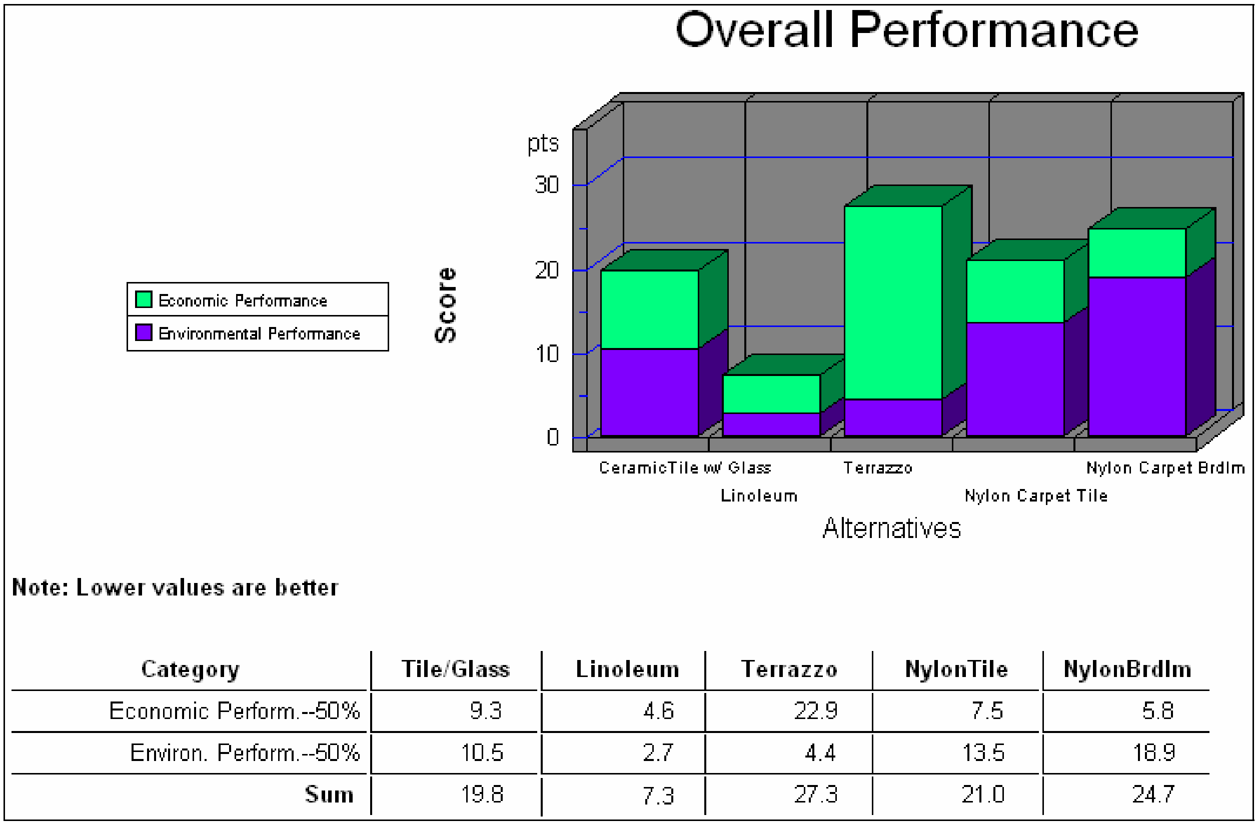
by Environmental Flow
- ☐ Global Warming
- ☐ Acidification
- ☐ Eutrophication
- ☐ Fossil Fuel Depletion
- ☐ Indoor Air Quality
- ☐ Habitat Alteration
- ☐ Water Intake
- ☐ Criteria Air Pollutants
- ☐ Ecological Toxicity
- ☐ Human Health
  - ☐ Human Health Cancer
  - ☐ Human Health Noncancer
- ☐ Ozone Depletion
- ☐ Smog

Embodied Energy
- ☐ by Fuel Renewability
- ☐ Fuel Energy vs. Feedstock Energy

☐ All Tables in One

☐ Parameter Settings

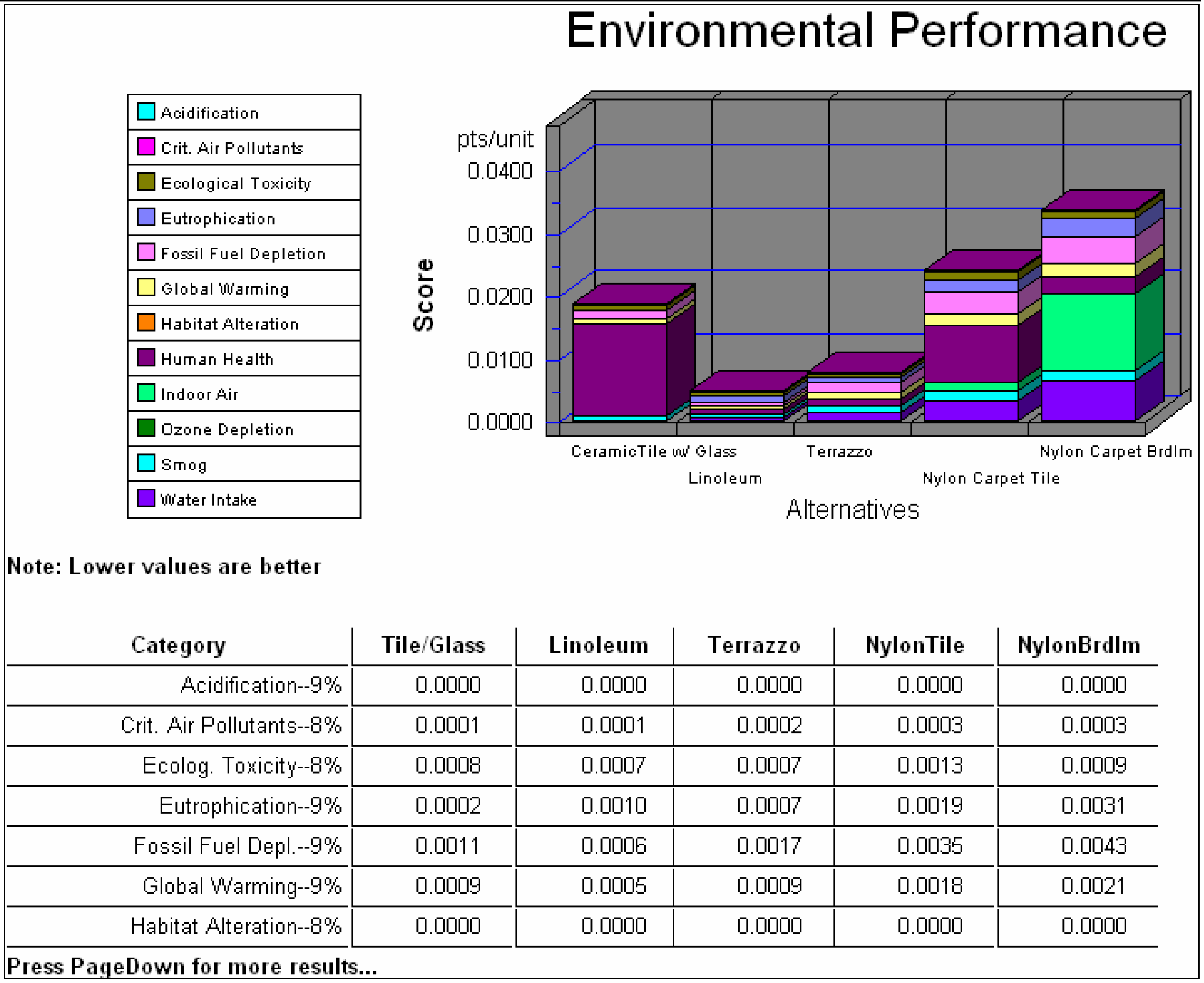
Figure 4.7 Selecting BEES Reports



Note: Lower values are better

Category	**Tile/Glass**	**Linoleum**	**Terrazzo**	**NylonTile**	**NylonBrdlm**
Economic Perform.--50%	9.3	4.6	22.9	7.5	5.8
Environ. Perform.--50%	10.5	2.7	4.4	13.5	18.9
Sum	19.8	7.3	27.3	21.0	24.7

Figure 4.8 Viewing BEES Overall Performance Results

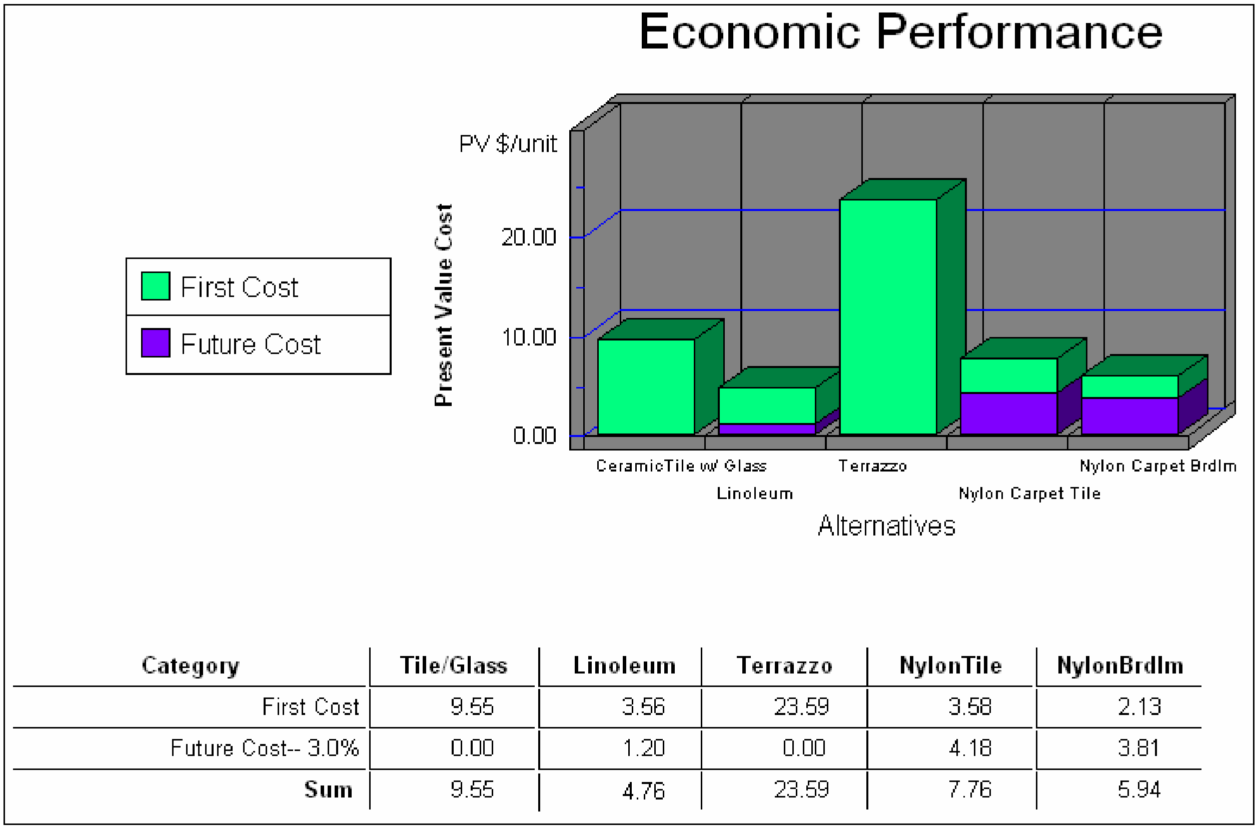


Note: Lower values are better

Category	Tile/Glass	Linoleum	Terrazzo	NylonTile	NylonBrdlm
Acidification--9%	0.0000	0.0000	0.0000	0.0000	0.0000
Crit. Air Pollutants--8%	0.0001	0.0001	0.0002	0.0003	0.0003
Ecolog. Toxicity--8%	0.0008	0.0007	0.0007	0.0013	0.0009
Eutrophication--9%	0.0002	0.0010	0.0007	0.0019	0.0031
Fossil Fuel Depl.--9%	0.0011	0.0006	0.0017	0.0035	0.0043
Global Warming--9%	0.0009	0.0005	0.0009	0.0018	0.0021
Habitat Alteration--8%	0.0000	0.0000	0.0000	0.0000	0.0000

Press PageDown for more results...

Figure 4.9 Viewing BEES Environmental Performance Results



Category	Tile/Glass	Linoleum	Terrazzo	NylonTile	NylonBrdlm
First Cost	9.55	3.56	23.59	3.58	2.13
Future Cost-- 3.0%	0.00	1.20	0.00	4.18	3.81
Sum	9.55	4.76	23.59	7.76	5.94

Figure 4.10 Viewing BEES Economic Performance Results

BEES results are derived by using the BEES model to combine environmental and economic performance data using your study parameters. The method is described in section 2. The detailed BEES environmental and economic performance data, documented in section 3, may be browsed by selecting File/Open from the Main Menu.

From the window for selecting BEES reports, you may choose to display a summary Table showing the derivation of summary scores, graphs depicting results by life-cycle stage and by contributing flow for each environmental impact category, graphs depicting embodied energy performance, and an *All Tables in One* report giving all the detailed results in a single tabular report. Figures 4.11 through 4.15 illustrate each of these options.[246]

Once you have displayed any BEES report, you may select additional reports for display by selecting Tools/Select Reports from the menu.[247] To compare BEES results based on different parameter settings, either select Tools/Change Parameters from the menu, or if the Summary Table is in focus, press the *Change Parameters* button. Change your parameters, and press Ok.

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[246] If you Set Analysis Parameters to use the BEES Stakeholder Panel weight set to interpret life-cycle impact assessment results, then impact-based results may be viewed separately for cancerous and noncancerous health effects. For compatibility with the other BEES 4.0 weighting schemes, however, these results are weighted and combined into a single Human Health impact for display of BEES Environmental Performance Scores. For more information on the BEES Stakeholder Panel weight set, see section 2.1.4.

[247] This feature is not available from the menu displayed with the BEES Summary Table.

You may now display reports based on your new parameters. Then you may find it convenient to view reports with different parameter settings side-by-side by selecting Window/Tile from the menu. Note that your parameter settings are displayed on the Table corresponding to each graph.

Embodied Energy

While the environmental impacts from energy consumption and combustion already are accounted for throughout the BEES results by environmental impact category, BEES reports embodied energy results for informational purposes. BEES classifies and reports total embodied energy in two ways: (1) by fuel and feedstock energy and (2) by fuel renewability.[248]

The first classification system uses the energy accounting categories of fuel energy and feedstock energy. Feedstock energy is the energy content of fuel resources extracted from the earth, while fuel energy is the amount of energy that is released when fuels are burned. When fuel resources such as petroleum and natural gas are used as material inputs (e.g., as feedstocks for the manufacture of polystyrene resin), then the energy value remains in the feedstock category. When extracted fuel resources are transformed into fuels and burned for energy, however, most of the feedstock energy is transformed into industrial process or transportation energy. This moves the quantity of combustion energy from the feedstock category into the fuel category. Because less than 100 % of the inherent energy value of extracted resources remains after fuel converting processes and combustion, a small amount of energy remains in the feedstock category. In general, biobased products and plastics will generate higher BEES feedstock energy values because there is potential energy "embodied" in the system. A rubber tire, for example, will have feedstock energy in the tire itself and fuel energy from its production. If, after use, the tire is then sent to a cement kiln to recover its energy as a method of "disposing" of the used tire, then that feedstock (potential) energy in the tire is converted to that amount of fuel to the cement kiln. In that case, the feedstock energy in the tire has been converted to fuel energy.

Total embodied energy is also classified and reported using the energy accounting categories of renewable energy and non-renewable energy. Energy derived from fossil fuels such as petroleum, natural gas, and coal is classified as non-renewable, while energy from all other sources (hydropower, wind, nuclear, geothermal, biomass) is classified as renewable.

4.4 Browsing Environmental and Economic Performance Data

The BEES environmental and economic performance data may be browsed by selecting File/Open from the Main Menu. Environmental data files are specific to products, while there is a single economic data file, LCCOSTS.DBF, with cost data for all products. Some environmental data files map to a product in more than one application, while the economic data typically vary for each application. Table 4.1 lists the products by environmental data file name (all with the .DBF extension) and by code number within the economic performance data file LCCOSTS.DBF.

The environmental performance data files are similarly structured. The first column in all these files, XPORT, shows the default transportation distance from manufacture to use (in mi). The

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[248] Embodied energy definitions documented by Four Elements, LLC.

second column lists a number of environmental flows. Flows marked "(r)" are raw materials inputs, "(a)" air emissions, "(ar)" radioactive air emissions, "(s)" releases to soil, "(w)" water effluents, "(wr)" radioactive water effluents, and "E" energy usage. All quantities are expressed in terms of the product's functional units, typically 0.09 m^2 (1 ft^2) of product service for 50 years.[249] The column labeled "Total" is the primary data column, giving total cradle-to-grave flow amounts. Next are columns giving flow amounts for each product component, followed by columns giving flow amounts for each life-cycle stage. The product component columns roughly sum to the total column, as do the life-cycle stage columns. The IAINDEX column is for internal BEES use.

The economic performance data file LCCOSTS.DBF lists for each cost the year of occurrence (counting from year 0) and amount (in constant 2006 dollars) per functional unit.

Warning: If you change any of the data in the environmental or economic performance data files, you will need to reinstall BEES to restore the original BEES data.

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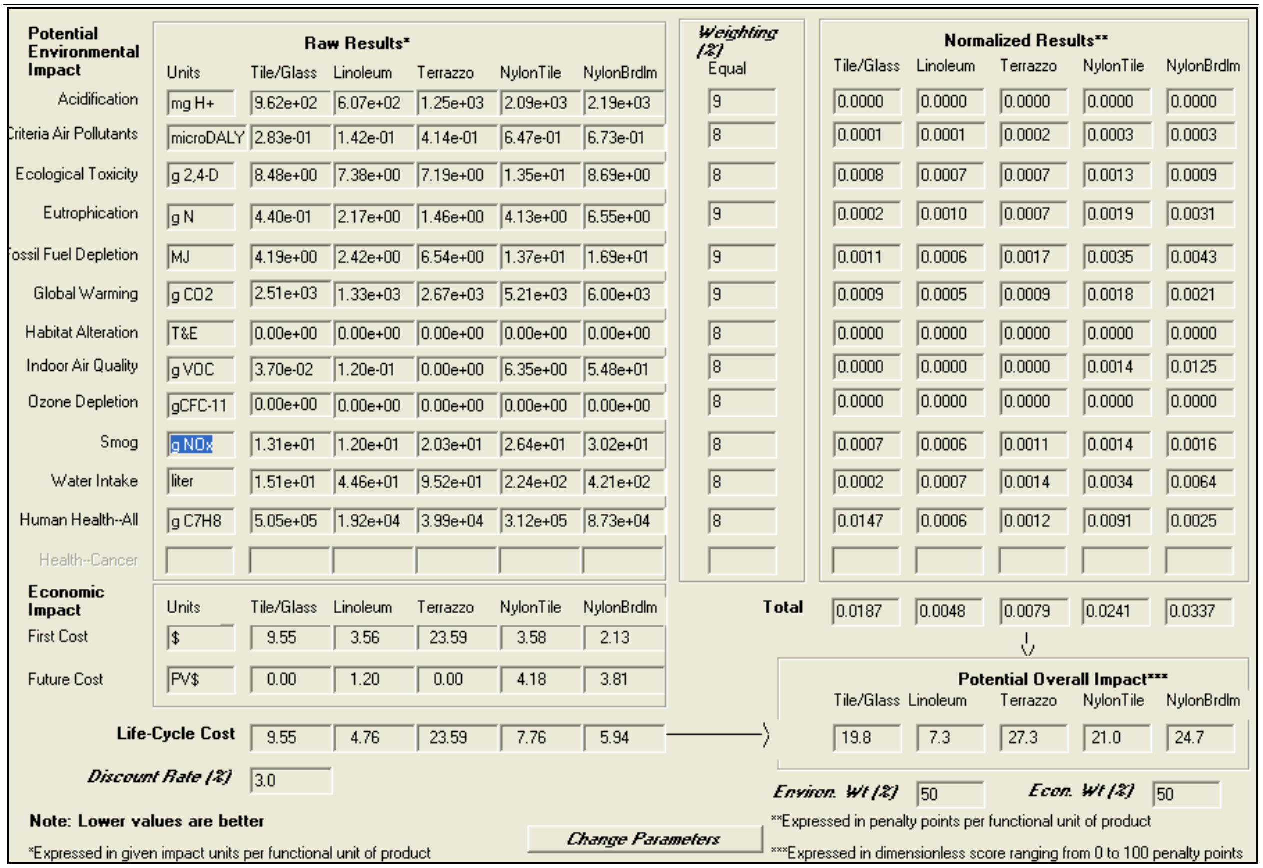
[249] The following BEES product categories have different functional units: Roof Coverings: covering 9.29 m^2 (1 square, or 100 ft^2) of roof surface for 50 years; Concrete Beams and Columns: 0.76 m^3 (1 yd^3) of product service for 50 years; Office Chairs: seating for 1 person for 50 years; Adhesive and Mastic Remover: removing 9.29 m^2 (100 ft^2) of mastic under vinyl or similar flooring over 50 years; Exterior Sealers and Coatings: sealing or coating 9.29 m^2 (100 ft^2) of exterior surface over 50 years ; Transformer Oils: cooling for one 1 000 kV·A transformer for 30 years; Fertilizer: fertilizing 0.40 ha (1 acre) for 10 years; Carpet Cleaners: cleaning 92.9 m^2 (1 000 ft^2) of carpet once; Floor Stripper: removing three layers of wax and one layer of sealant from 9.29 m^2 (100 ft^2) of hardwood flooring once; Roadway Dust Control: controlling dust from 92.9 m^2 (1 000 ft^2) of surface area once; Bath and Tile Cleaner: using 3.8 L (1 gal) of ready-to-use cleaner once; Glass Cleaners: using 3.785 m^3 (1 000 gal) of ready-to-use glass cleaner once; and Grease and Graffiti Remover: using 3.8 L (1 gal) of grease and graffiti remover once.



Potential Environmental Impact	Raw Results*						Weighting (%)	Normalized Results**				
	Units	Tile/Glass	Linoleum	Terrazzo	NylonTile	NylonBrdlm	Equal	Tile/Glass	Linoleum	Terrazzo	NylonTile	NylonBrdlm
Acidification	mg H+	9.62e+02	6.07e+02	1.25e+03	2.09e+03	2.19e+03	9	0.0000	0.0000	0.0000	0.0000	0.0000
Criteria Air Pollutants	microDALY	2.83e-01	1.42e-01	4.14e-01	6.47e-01	6.73e-01	8	0.0001	0.0001	0.0002	0.0003	0.0003
Ecological Toxicity	g 2,4-D	8.48e+00	7.38e+00	7.19e+00	1.35e+01	8.69e+00	8	0.0008	0.0007	0.0007	0.0013	0.0009
Eutrophication	g N	4.40e-01	2.17e+00	1.46e+00	4.13e+00	6.55e+00	9	0.0002	0.0010	0.0007	0.0019	0.0031
Fossil Fuel Depletion	MJ	4.19e+00	2.42e+00	6.54e+00	1.37e+01	1.69e+01	9	0.0011	0.0006	0.0017	0.0035	0.0043
Global Warming	g CO2	2.51e+03	1.33e+03	2.67e+03	5.21e+03	6.00e+03	9	0.0009	0.0005	0.0009	0.0018	0.0021
Habitat Alteration	T&E	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	8	0.0000	0.0000	0.0000	0.0000	0.0000
Indoor Air Quality	g VOC	3.70e-02	1.20e-01	0.00e+00	6.35e+00	5.48e+01	8	0.0000	0.0000	0.0000	0.0014	0.0125
Ozone Depletion	gCFC-11	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	8	0.0000	0.0000	0.0000	0.0000	0.0000
Smog	g NOx	1.31e+01	1.20e+01	2.03e+01	2.64e+01	3.02e+01	8	0.0007	0.0006	0.0011	0.0014	0.0016
Water Intake	liter	1.51e+01	4.46e+01	9.52e+01	2.24e+02	4.21e+02	8	0.0002	0.0007	0.0014	0.0034	0.0064
Human Health--All	g C7H8	5.05e+05	1.92e+04	3.99e+04	3.12e+05	8.73e+04	8	0.0147	0.0006	0.0012	0.0091	0.0025
Health--Cancer												
Total								0.0187	0.0048	0.0079	0.0241	0.0337

Economic Impact	Units	Tile/Glass	Linoleum	Terrazzo	NylonTile	NylonBrdlm
First Cost	$	9.55	3.56	23.59	3.58	2.13
Future Cost	PV$	0.00	1.20	0.00	4.18	3.81
Life-Cycle Cost		9.55	4.76	23.59	7.76	5.94

Discount Rate (%) 3.0

Potential Overall Impact***				
Tile/Glass	Linoleum	Terrazzo	NylonTile	NylonBrdlm
19.8	7.3	27.3	21.0	24.7

Environ. Wt (%) 50

Econ. Wt (%) 50

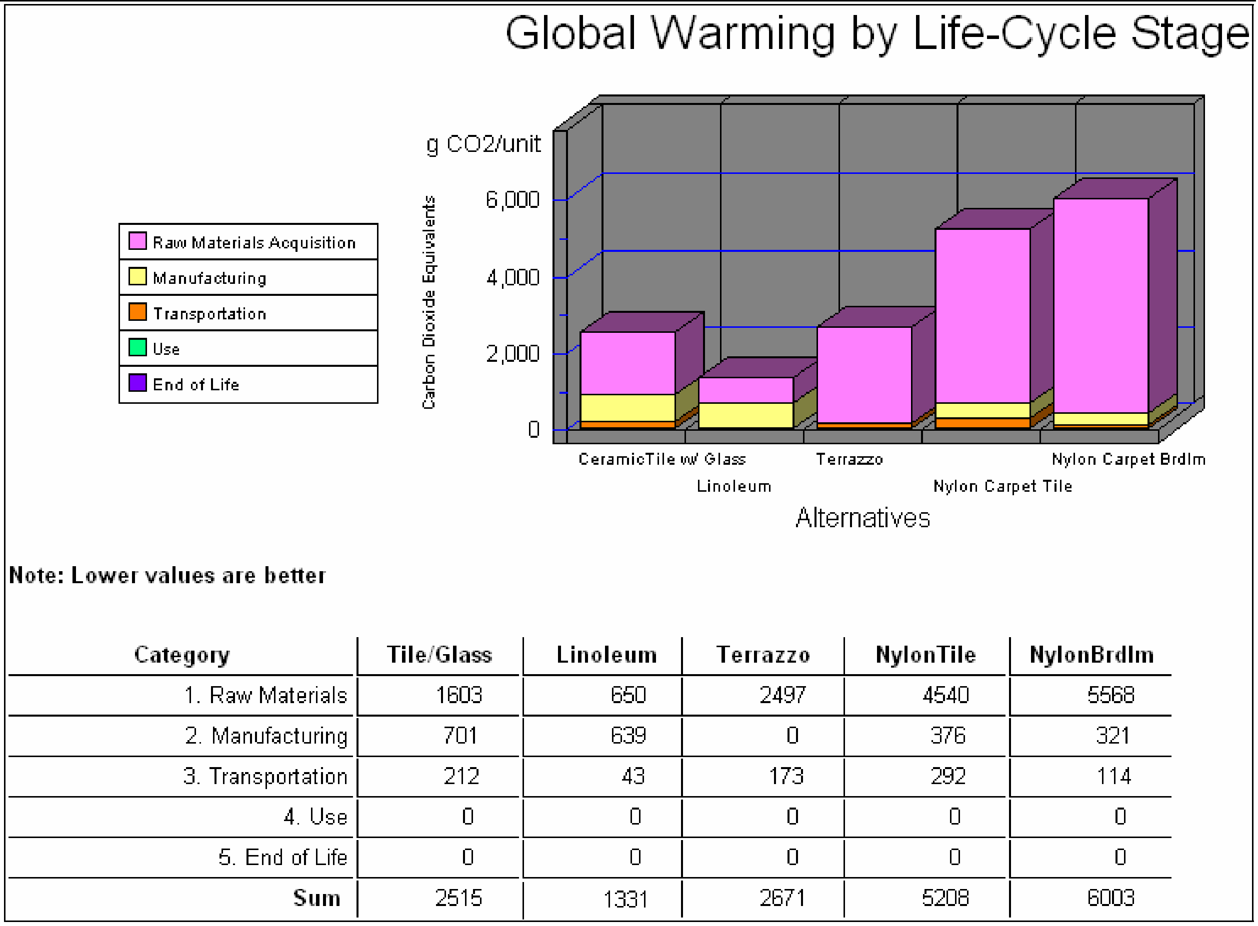
Note: Lower values are better

*Expressed in given impact units per functional unit of product

**Expressed in penalty points per functional unit of product

***Expressed in dimensionless score ranging from 0 to 100 penalty points

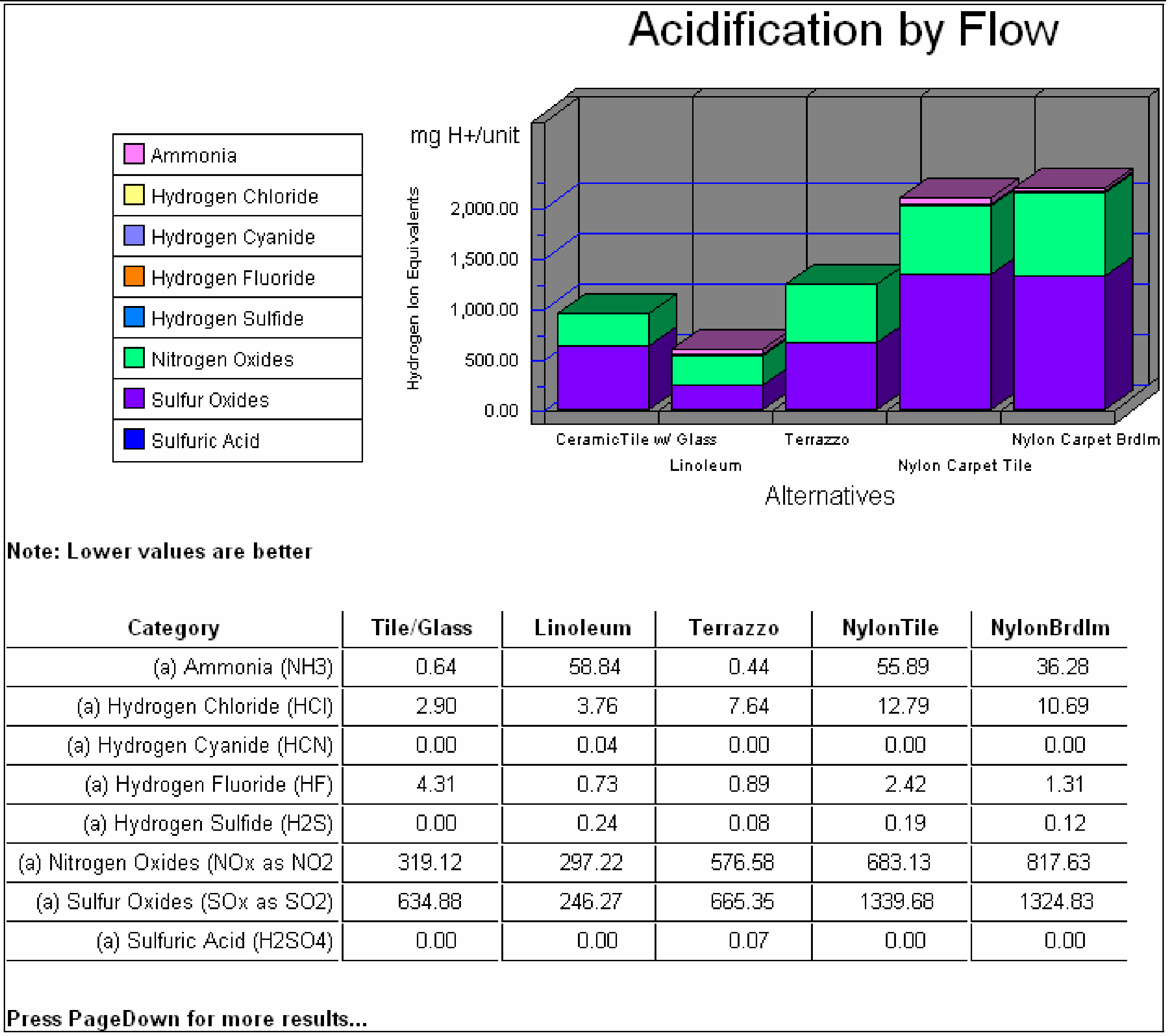
Figure 4.11 Viewing BEES Summary Table



Note: Lower values are better

Category	**Tile/Glass**	**Linoleum**	**Terrazzo**	**NylonTile**	**NylonBrdlm**
1. Raw Materials	1603	650	2497	4540	5568
2. Manufacturing	701	639	0	376	321
3. Transportation	212	43	173	292	114
4. Use	0	0	0	0	0
5. End of Life	0	0	0	0	0
Sum	2515	1331	2671	5208	6003

Figure 4.12 Viewing BEES Environmental Impact Category Performance Results by Life-Cycle Stage

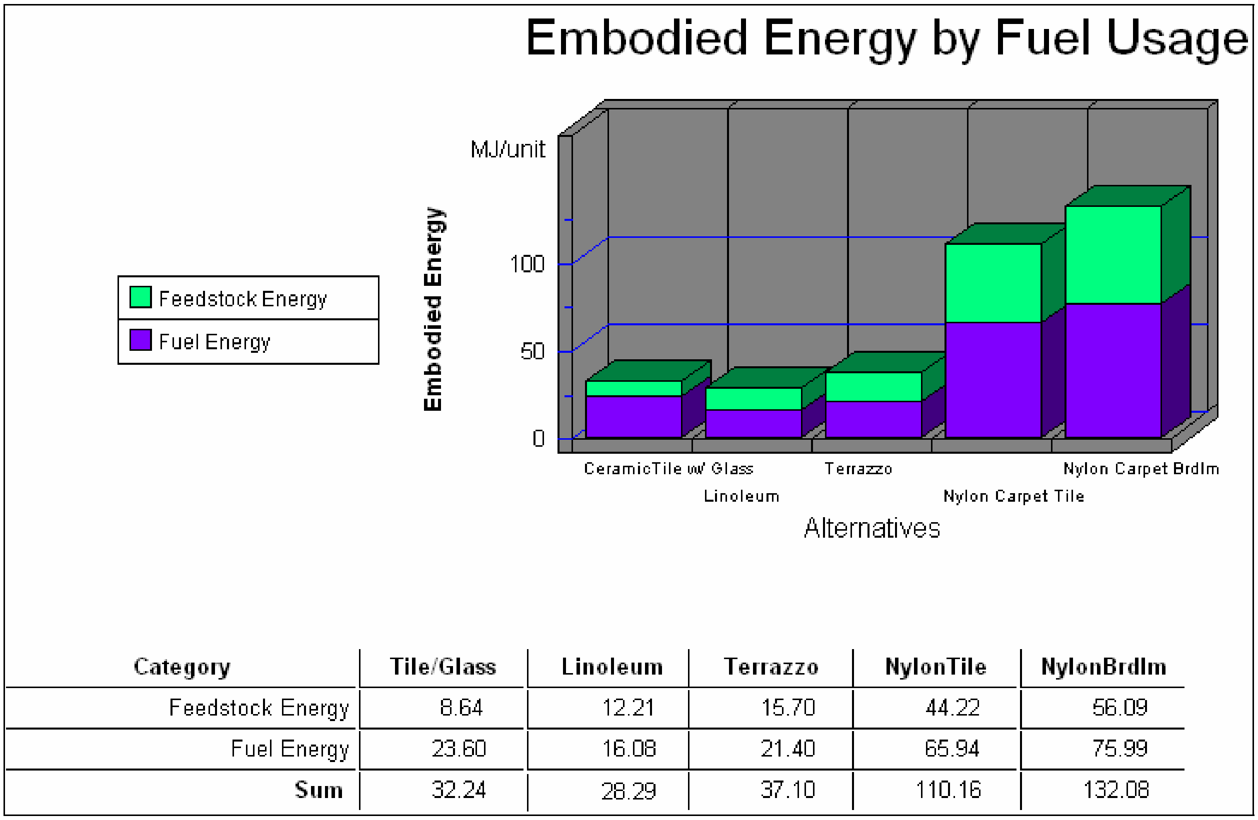


Note: Lower values are better

Category	Tile/Glass	Linoleum	Terrazzo	NylonTile	NylonBrdlm
(a) Ammonia (NH3)	0.64	58.84	0.44	55.89	36.28
(a) Hydrogen Chloride (HCl)	2.90	3.76	7.64	12.79	10.69
(a) Hydrogen Cyanide (HCN)	0.00	0.04	0.00	0.00	0.00
(a) Hydrogen Fluoride (HF)	4.31	0.73	0.89	2.42	1.31
(a) Hydrogen Sulfide (H2S)	0.00	0.24	0.08	0.19	0.12
(a) Nitrogen Oxides (NOx as NO2	319.12	297.22	576.58	683.13	817.63
(a) Sulfur Oxides (SOx as SO2)	634.88	246.27	665.35	1339.68	1324.83
(a) Sulfuric Acid (H2SO4)	0.00	0.00	0.07	0.00	0.00

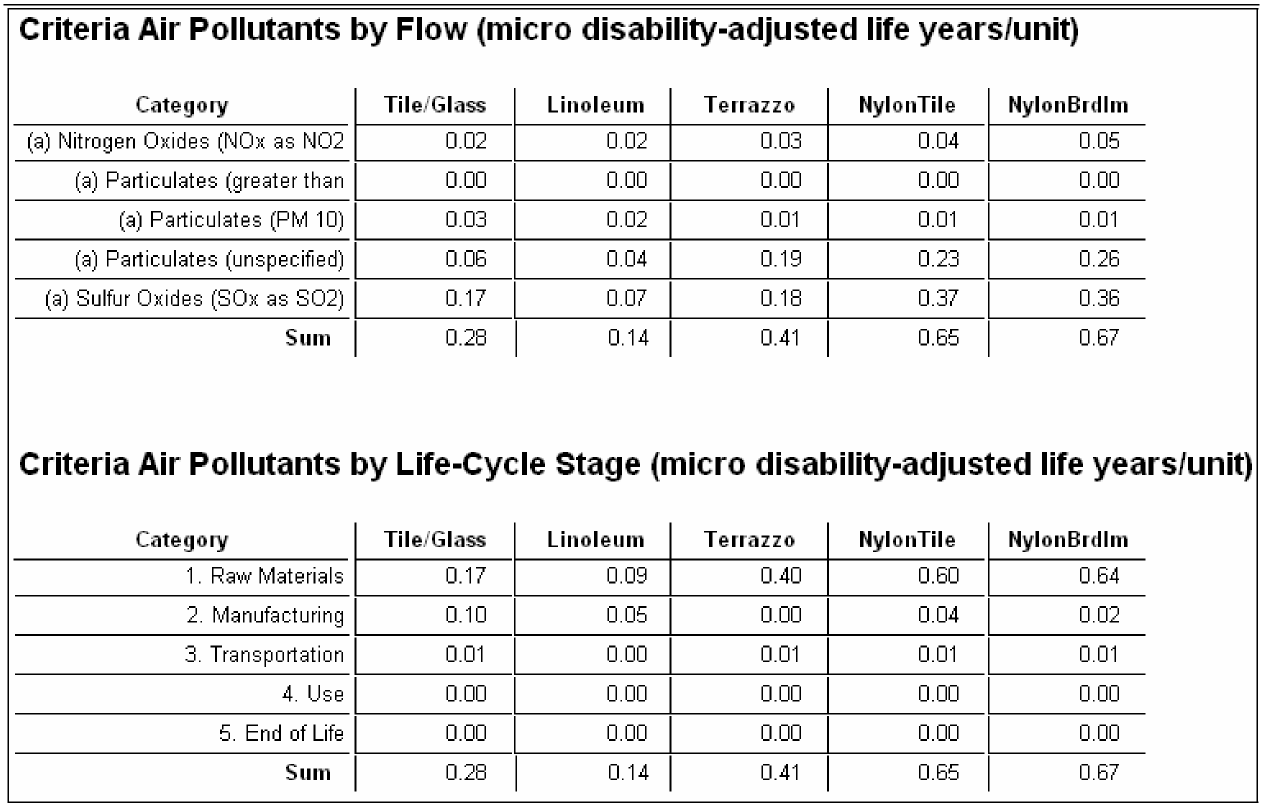
Press PageDown for more results...

Figure 4.13 Viewing BEES Environmental Impact Category Performance Results by Flow



Category	Tile/Glass	Linoleum	Terrazzo	NylonTile	NylonBrdlm
Feedstock Energy	8.64	12.21	15.70	44.22	56.09
Fuel Energy	23.60	16.08	21.40	65.94	75.99
Sum	32.24	28.29	37.10	110.16	132.08

Figure 4.14 Viewing BEES Embodied Energy Results



Criteria Air Pollutants by Flow (micro disability-adjusted life years/unit)

Category	Tile/Glass	Linoleum	Terrazzo	NylonTile	NylonBrdlm
(a) Nitrogen Oxides (NOx as NO2	0.02	0.02	0.03	0.04	0.05
(a) Particulates (greater than	0.00	0.00	0.00	0.00	0.00
(a) Particulates (PM 10)	0.03	0.02	0.01	0.01	0.01
(a) Particulates (unspecified)	0.06	0.04	0.19	0.23	0.26
(a) Sulfur Oxides (SOx as SO2)	0.17	0.07	0.18	0.37	0.36
Sum	0.28	0.14	0.41	0.65	0.67

Criteria Air Pollutants by Life-Cycle Stage (micro disability-adjusted life years/unit)

Category	Tile/Glass	Linoleum	Terrazzo	NylonTile	NylonBrdlm
1. Raw Materials	0.17	0.09	0.40	0.60	0.64
2. Manufacturing	0.10	0.05	0.00	0.04	0.02
3. Transportation	0.01	0.00	0.01	0.01	0.01
4. Use	0.00	0.00	0.00	0.00	0.00
5. End of Life	0.00	0.00	0.00	0.00	0.00
Sum	0.28	0.14	0.41	0.65	0.67

Figure 4.15 A Sampling of BEES "All Tables In One" Display

Table 4.1 BEES Products Keyed to Environmental and Economic Performance Data Codes

MAJOR ELEMENT **Group Element**	***Individual Element*** **BEES Product**	**Environ-mental Data File Name**	**Economic Data Code**
SUBSTRUCTURE **Foundations**	***Slab On Grade***		
	Generic 100 % Portland Cement	A1030A	A1030,A0
	Generic 15 % Fly Ash Cement	A1030B	A1030,B0
	Generic 20 % Fly Ash Cement	A1030C	A1030,C0
	Generic 20 % Slag Cement	A1030D	A1030,D0
	Generic 35 % Slag Cement	A1030E	A1030,E0
	Generic 50 % Slag Cement	A1030F	A1030,F0
	Generic 5 % Limestone Cement	A1030G	A1030,G0
	Generic 10 % Limestone Cement	A1030H	A1030,H0
	Generic 20 % Limestone Cement	A1030I	A1030,I0
	Lafarge Silica Fume Cement	A1030J	A1030,J0
	Anonymous IP Cement Product	A1030K	A1030,K0
	Lafarge NewCem Slag Cement (20 %)	A1030L	A1030,L0
	Lafarge NewCem Slag Cement (35 %)	A1030M	A1030,M0
	Lafarge NewCem Slag Cement (50 %)	A1030N	A1030,N0
	Generic 35 % Fly Ash Cement	A1030O	A1030,O0
	Lafarge Portland Type I Cement	A1030P	A1030,P0
SUBSTRUCTURE **Basement Construction**	***Basement Walls***		
	Generic 100 % Portland Cement	A2020A	A2020,A0
	Generic 15 % Fly Ash Cement	A2020B	A2020,B0
	Generic 20 % Fly Ash Cement	A2020C	A2020,C0
	Generic 20 % Slag Cement	A2020D	A2020,D0
	Generic 35 % Slag Cement	A2020E	A2020,E0
	Generic 50 % Slag Cement	A2020F	A2020,F0
	Generic 5 % Limestone Cement	A2020G	A2020,G0
	Generic 10 % Limestone Cement	A2020H	A2020,H0
	Generic 20 % Limestone Cement	A2020I	A2020,I0
	Lafarge Silica Fume Cement	A2020J	A2020,J0
	Anonymous IP Cement Product	A2020K	A2020,K0
	Lafarge NewCem Slag Cement (20 %)	A2020L	A2020,L0
	Lafarge NewCem Slag Cement (35 %)	A2020M	A2020,M0
	Lafarge NewCem Slag Cement (50 %)	A2020N	A2020,N0
	Lafarge BlockSet	A2020O	A2020,O0
	Lafarge Portland Type I Cement	A2020P	A2020,P0
SHELL **Superstructure**	***Beams***		
	Generic 100 % Portland Cement 4KSI	B1011A	B1011,A0
	Generic 15 % Fly Ash Cement 4KSI	B1011B	B1011,B0
	Generic 20 % Fly Ash Cement 4KSI	B1011C	B1011,C0
	Generic 20 % Slag Cement 4KSI	B1011D	B1011,D0
	Generic 35 % Slag Cement 4KSI	B1011E	B1011,E0
	Generic 50 % Slag Cement 4KSI	B1011F	B1011,F0
	Generic 5 % Limestone Cement 4KSI	B1011G	B1011,G0
	Generic 10 % Limestone Cement 4KSI	B1011H	B1011,H0
	Generic 20 % Limestone Cement 4KSI	B1011I	B1011,I0
	Generic 100 % Portland Cement 5KSI	B1011J	B1011,J0
	Generic 15 % Fly Ash Cement 5KSI	B1011K	B1011,K0
	Generic 20 % Fly Ash Cement 5KSI	B1011L	B1011,L0

	Generic 20 % Slag Cement 5KSI	B1011M	B1011,M0
	Generic 35 % Slag Cement 5KSI	B1011N	B1011,N0
	Generic 50 % Slag Cement 5KSI	B1011O	B1011,O0
	Generic 5 % Limestone Cement 5KSI	B1011P	B1011,P0
	Generic 10 % Limestone Cement 5KSI	B1011Q	B1011,Q0
	Generic 20 % Limestone Cement 5KSI	B1011R	B1011,R0
	Lafarge Silica Fume Cement 4KSI	B1011S	B1011,S0
	Anonymous 4KSI Product	B1011T	B1011,T0
	Lafarge NewCem Slag Cement 4KSI (20 %)	B1011U	B1011,U0
	Lafarge NewCem Slag Cement 4KSI (35 %)	B1011V	B1011,V0
	Lafarge NewCem Slag Cement 4KSI (50 %)	B1011W	B1011,W0
	Lafarge Silica Fume Cement 5KSI	B1011X	B1011,X0
	Anonymous 5KSI Product	B1011Y	B1011,Y0
	Lafarge NewCem Slag Cement 5KSI (20 %)	B1011Z	B1011,Z0
	Lafarge NewCem Slag Cement 5KSI (35 %)	B1011AA	B1011,AA
	Lafarge NewCem Slag Cement 5KSI (50 %)	B1011BB	B1011,BB
	Lafarge Portland Type I Cement 4KSI	B1011CC	B1011,CC
	Lafarge Portland Type I Cement 5KSI	B1011DD	B1011,DD
SHELL **Superstructure**	***Columns***		
	Generic 100 % Portland Cement 4KSI	B1012A	B1012,A0
	Generic 15 % Fly Ash Cement 4KSI	B1012B	B1012,B0
	Generic 20 % Fly Ash Cement 4KSI	B1012C	B1012,C0
	Generic 20 % Slag Cement	B1012D	B1012,D0
	Generic 35 % Slag Cement 4KSI	B1012E	B1012,E0
	Generic 50 % Slag Cement 4KSI	B1012F	B1012,F0
	Generic 5 % Limestone Cement 4KSI	B1012G	B1012,G0
	Generic 10 % Limestone Cement 4KSI	B1012H	B1012,H0
	Generic 20 % Limestone Cement 4KSI	B1012I	B1012,I0
	Generic 100 % Portland Cement 5KSI	B1012J	B1012,J0
	Generic 15 % Fly Ash Cement 5KSI	B1012K	B1012,K0
	Generic 20 % Fly Ash Cement 5KSI	B1012L	B1012,L0
	Generic 20 % Slag Cement 5KSI	B1012M	B1012,M0
	Generic 35 % Slag Cement 5KSI	B1012N	B1012,N0
	Generic 50 % Slag Cement 5KSI	B1012O	B1012,O0
	Generic 5 % Limestone Cement 5KSI	B1012P	B1012,P0
	Generic 10 % Limestone Cement 5KSI	B1012Q	B1012,Q0
	Generic 20 % Limestone Cement 5KSI	B1012R	B1012,R0
	Lafarge Silica Fume Cement 4KSI	B1012S	B1012,S0
	Anonymous 4KSI Product	B1012T	B1012,T0
	Lafarge NewCem Slag Cement 4KSI (20 %)	B1012U	B1012,U0
	Lafarge NewCem Slag Cement 4KSI (35 %)	B1012V	B1012,V0
	Lafarge NewCem Slag Cement 4KSI (50 %)	B1012W	B1012,W0
	Lafarge Silica Fume Cement 5KSI	B1012X	B1012,X0
	Anonymous 5KSI Product	B1012Y	B1012,Y0
	Lafarge NewCem Slag Cement 5KSI (20 %)	B1012Z	B1012,Z0
	Lafarge NewCem Slag Cement 5KSI (35 %)	B1012AA	B1012,AA
	Lafarge NewCem Slag Cement 5KSI (50 %)	B1012BB	B1012,BB
	Lafarge Portland Type I Cement 4KSI	B1012CC	B1012,CC
	Lafarge Portland Type I Cement 5KSI	B1012DD	B1012,DD
SHELL **Superstructure**	***Roof Sheathing***		
	Generic Oriented Strand Board Sheathing	B1020A	B1020,A0
	Generic Plywood Sheathing	B1020B	B1020,B0
SHELL **Exterior Enclosure**	***Exterior Wall Systems***		
	CENTRIA Formawall Insulated Composite Panel	B2010A	B2010,A0
SHELL	***Exterior Wall Finishes***		
	Generic Brick & Mortar	B2011A	B2011,A0

Exterior Enclosure	Generic Stucco	B2011B	B2011,B0
	Generic Aluminum Siding	B2011C	B2011,C0
	Generic Cedar Siding	B2011D	B2011,D0
	Generic Vinyl Siding	B2011E	B2011,E0
	Trespa Meteon Panels	B2011F	B2011,F0
	Anonymous Brick & Mortar Product 1	B2011G	B2011,G0
	Headwaters Scratch & Brown Stucco Type S	B2011H	B2011,H0
	Headwaters FRS	B2011I	B2011,I0
	Anonymous Brick & Mortar Product 2	B2011J	B2011,J0
	Headwaters Masonry Cement Type S	B2011K	B2011,K0
	Dryvit EIFS Cladding Outsulation	B2011L	B2011,L0
	Dryvit EIFS Cladding Outsulation Plus	B2011M	B2011,M0
SHELL	***Wall Insulation***		
Exterior Enclosure	Generic Blown Cellulose R-13	B2012A	B2012,A0
	Generic Fiberglass Batt R-19	B2012B	B2012,B0
	Generic Fiberglass Batt R-15	B2012C	B2012,C0
	Generic Blown Mineral Wool R-13	B2012D	B2012,D0
	Generic Fiberglass Batt R-13	B2012E	B2012,E0
	Anonymous R-13 Product	B2012F	B2012,F0
	Anonymous R-15 Product	B2012G	B2012,G0
	Anonymous R-19 Product	B2012H	B2012,H0
SHELL	***Framing***		
Exterior Enclosure	Generic Steel Framing	B2013A	B2013,A0
	Generic Wood Framing--Treated	B2013B	B2013,B0
	Generic Wood Framing--Untreated	B2013C	B2013,C0
SHELL	***Wall Sheathing***		
Exterior Enclosure	Generic Oriented Strand Board Sheathing	B1020A	B2015,A0
	Generic Plywood Sheathing	B1020B	B2015,B0
SHELL	***Exterior Sealers and Coatings***		
Exterior Enclosure	BioPreserve SoyGuard Wood Sealer	B2040A	B2040,A0
	Anonymous Masonry Waterproofing Product	B2040B	B2040,B0
SHELL	***Roof Coverings***		
Roofing	Generic Asphalt Shingles--Black	B3011A	B3011,A0
	Generic Asphalt Shingles--Coral	B3011A	B3011,A0
	Generic Asphalt Shingles--Dk Brown	B3011A	B3011,A0
	Generic Asphalt Shingles--Dk Gray	B3011A	B3011,A0
	Generic Asphalt Shingles--Green	B3011A	B3011,A0
	Generic Asphalt Shingles--Lt Brown	B3011A	B3011,A0
	Generic Asphalt Shingles--Lt Gray	B3011A	B3011,A0
	Generic Asphalt Shingles--Tan	B3011A	B3011,A0
	Generic Asphalt Shingles--White	B3011A	B3011,A0
	Generic Asphalt Shingles	B3011A	B3011,A0
	Generic Clay Tile	B3011B	B3011,B0
	Generic Clay Tile--Red	B3011B	B3011,B0
	Generic Fiber Cement--Lt Gray/Lt Brown	B3011C	B3011,C0
	Generic Fiber Cement Shingles	B3011C	B3011,C0
	Generic Fiber Cement--Dk Color	B3011C	B3011,C0
	Generic Fiber Cement--Med Color	B3011C	B3011,C0
SHELL	***Ceiling Insulation***		
Roofing	Generic Blown Cellulose R-38	B3012A	B3012,A0
	Generic Fiberglass Batt R-38	B3012B	B3012,B0
	Generic Blown Mineral Wool R-38	B3012C	B3012,C0
	Generic Blown Fiberglass R-38	B3012D	B3012,D0
	Anonymous R-38 Product	B3012E	B3012,E0
SHELL	***Roof Coatings***		

	Prime Coatings Utilithane	B3013A	B3013,A0
INTERIORS **Interior Construction**	***Partitions***		
	Generic Gypsum Board	C1011A	C1011,A0
	Trespa Virtuon Panels	C3030A	C1011,B0
	Trespa Athlon Panels	C3030B	C1011,C0
	P&M Plastics Altree Panels	C1011D	C1011,D0
	Anonymous Biobased Panel Product 2	C1011E	C1011,E0
INTERIORS **Interior Construction**	***Lockers***		
	Trespa Virtuon Panels	C3030A	C1030,A0
	Trespa Athlon Panels	C3030B	C1030,B0
INTERIORS **Fittings**	***Fabricated Toilet Partitions***		
	Trespa Virtuon Panels	C3030A	C1031,A0
	Trespa Athlon Panels	C3030B	C1031,B0
INTERIORS **Interior Finishes**	***Wall Finishes to Interior Walls***		
	Generic Virgin Latex Paint	C3012A	C3012,A0
	Generic Consolidated Latex Paint	C3012B	C3012,B0
	Generic Reprocessed Latex Paint	C3012C	C3012,C0
INTERIORS **Interior Finishes**	***Floor Coverings***		
	Generic Ceramic Tile w/ Recycled Glass	C3020A	C3020,A0
	Generic Linoleum Flooring	C3020B	C3020,B0
	Generic Vinyl Composition Tile	C3020C	C3020,C0
	Generic Composite Marble Tile	C3020D	C3020,D0
	Generic Terrazzo	C3020E	C3020,E0
	Generic Nylon Carpet Tile	C3020F	C3020,F0
	Generic Wool Carpet Tile	C3020G	C3020,G0
	Generic Nylon Carpet Tile/Low-VOC Adhesive	C3020I	C3020,I0
	Generic Wool Carpet Tile/Low-VOC Adhesive	C3020J	C3020,J0
	Generic Nylon Carpet Broadloom	C3020L	C3020,L0
	Generic Wool Carpet Broadloom	C3020M	C3020,M0
	Generic Nylon Carpet Broadloom/Low-VOC	C3020O	C3020,O0
	Generic Wool Carpet Broadloom/Low-VOC	C3020P	C3020,P0
	C&A ER3 Modular Tile, Climate Neutral	C3020Q	C3020,Q0
	Forbo Linoleum	C3020R	C3020,R0
	Anonymous Carpet Tile Product	C3020S	C3020,S0
	C&A ER3 Cushion Roll Goods, Climate Neutral	C3020T	C3020,T0
	UTT Soy Backed Nylon Broadloom	C3020U	C3020,U0
	C&A Ethos Modular Tile, Climate Neutral	C3020V	C3020,V0
	C&A Ethos Cushion Roll Goods, Climate Neutral	C3020W	C3020,W0
	C&A ER3 Modular Tile	C3020X	C3020,X0
	C&A ER3 Cushion Roll Goods	C3020Y	C3020,Y0
	C&A Ethos Modular Tile	C3020Z	C3020,Z0
	C&A Ethos Cushion Roll Goods	C3020AA	C3020,AA
	IFC Transformation Carpet Tile, Climate Neutral	C3020CC	C3020,CC
	J&J Industries Certificate Broadloom Carpet	C3020DD	C3020,DD
	Mohawk Regents Row Broadloom Carpet	C3020FF	C3020,FF
	Mohawk Meritage Broadloom Carpet	C3020GG	C3020,GG
	Natural Cork Parquet Tile	C3020HH	C3020,HH
	Natural Cork Floating Floor Plank	C3020II	C3020,II
	Forbo Linoleum/ No-VOC Adhesive	C3020NN	C3020,NN
	UTT Soy Backed Nylon Broadloom/Low-VOC	C3020PP	C3020,PP
	IFC Sabi Carpet Tile, Climate Neutral	C3020QQ	C3020,QQ
	BPS Capri Broadloom Carpet	C3020RR	C3020,RR
	BPS Capri Broadloom, Climate Neutral	C3020SS	C3020,SS
	BPS Scan Broadloom Carpet	C3020TT	C3020,TT
	BPS Scan Broadloom Carpet, Climate Neutral	C3020UU	C3020,UU

	BPS UPC Carpet Tile	C3020VV	C3020,VV
	BPS UPC Carpet Tile, Climate Neutral	C3020WW	C3020,WW
	IFC Entropy Carpet Tile, Climate Neutral	C3020XX	C3020,XX
INTERIORS **Interior Finishes**	***Ceiling Finishes***		
	Trespa Virtuon Panels	C3030A	C3030,A0
	Trespa Athlon Panels	C3030B	C3030,B0
EQUIPMENT & FURNISHINGS **Furnishings**	***Fixed Casework***		
	Trespa Virtuon Panels	C3030A	E2010,A0
	Trespa Athlon Panels	C3030B	E2010,B0
EQUIPMENT & FURNISHINGS **Furnishings**	***Chairs***		
	Herman Miller Aeron Office Chair	E2020A	E2020,A0
	Herman Miller Ambi Office Chair	E2020B	E2020,B0
	Generic Office Chair	E2020B	E2020,B0
EQUIPMENT & FURNISHINGS **Furnishings**	***Table Tops, Counter Tops, Shelving***		
	Trespa Toplab Plus Panels	E2021A	E2021,A0
	Trespa Athlon Panels	C3030B	E2021,B0
BUILDING SITEWORK **Site Improvements**	***Roadway Dust Control***		
	Anonymous Roadway Dust Control Product	G2015A	G2015,A0
	Environmental Dust Control Dustlock	G2015B	G2015,B0
BUILDING SITEWORK **Site Improvements**	***Parking Lot Paving***		
	Generic 100 % Portland Cement	G2022A	G2022,A0
	Generic 15 % Fly Ash Cement	G2022B	G2022,B0
	Generic 20 % Fly Ash Cement	G2022C	G2022,C0
	Asphalt with GSB88 Seal-Bind Maintenance	G2022D	G2022,D0
	Generic Asphalt with Traditional Maintenance	G2022E	G2022,E0
	Anonymous IP Cement Concrete Product	G2022F	G2022,F0
	Lafarge Alpena Type I Cement	G2022G	G2022,G0
BUILDING SITEWORK **Site Improvements**	***Fertilizers***		
	Perdue MicroStart 60 Fertilizer	G2060A	G2060,A0
	Four All Seasons Fertilizer	G2060B	G2060,B0
BUILDING SITEWORK **Site Electrical Utilities**	***Transformer Oil***		
	Generic Mineral Transformer Oil	G4010B	G4010,B0
	Generic Silicone Transformer Oil	G4010C	G4010,C0
	Cooper Envirotemp FR3	G4010D	G4010,D0
	ABB BIOTEMP	G4010E	G4010,E0
	Generic Biobased Transformer Oil	G4010F	G4010,F0
BUILDING MAINTENANCE **Cleaning Products**	***Carpet Cleaners***		
	Anonymous Carpet Cleaning Product	H1011A	H1011,A0
	Racine HOST Dry Carpet Cleaning System	H1011B	H1011,B0
BUILDING MAINTENANCE **Cleaning Products**	***Floor Stripper***		
	Nano Green Floor Stripper	H1012A	H1012,A0
BUILDING MAINTENANCE **Cleaning Products**	***Glass Cleaners***		
	Anonymous Glass Cleaning Product	H1013A	H1013,A0
	Spartan Green Solutions Glass Cleaner	H1013B	H1013,B0
BUILDING MAINTENANCE **Cleaning Products**	***Bath and Tile Cleaner***		
	Spartan Green Solutions Restroom Cleaner	H1014A	H1014,A0
BUILDING MAINTENANCE **Cleaning Products**	***Grease & Graffiti Remover***		
	Anonymous Graffiti Remover Product 1	H1015A	H1015,A0
	Anonymous Graffiti Remover Product 2	H1015B	H1015,B0
	VertecBio Gold Graffiti Remover	H1015C	H1015,C0
BUILDING REPAIR & REMODELING **Remodeling Products**	***Adhesive and Mastic Removers***		
	Franmar BEAN-e-doo Mastic Remover	J1010A	J1010,A0
	Nano Green Mastic Remover	J1010B	J1010,B0

5. Future Directions

Development of the BEES tool does not end with the release of version 4.0. Plans to expand and refine BEES include releasing updates every 24 months with model and software enhancements as well as expanded product coverage. Listed below are a number of directions for future research that have been proposed in response to obvious needs, feedback from BEES users, and peer review comments:[250]

Proposed Model Enhancements

- Combine building products to permit comparative analyses of entire building components, assemblies, and ultimately entire buildings
- Conduct and apply research leading to the refinement of impact assessment methods for indoor air quality, habitat alteration, and water intake
- Characterize uncertainty in the underlying environmental and cost data, and reflect this uncertainty in BEES performance scores
- Update the BEES LCA methodology in line with future advances in the evolving LCA field

Proposed Data Enhancements

- Continue to solicit cooperation from industry to include more manufacturer-specific building products in future versions of BEES (this effort is known as the *BEES Please* program)
- Refine all data to permit U.S. region-specific BEES analyses. This enhancement would yield BEES results tailored to regional fuel mixes and labor and material markets, and would permit more accurate assessment of local environmental impacts such as locally scarce resources (e.g., water)
- Permit flexibility in study period length and in product specifications such as useful lives
- At least every 10 years, revisit products included in previous BEES releases for updates to their environmental and cost data
- Evaluate biobased products using BEES to assist the Federal procurement community in carrying out the biobased purchasing mandate, known as BioPreferred, of the *2002 Farm Security and Rural Investment Act* (Public Law 107-171)

Proposed Software Enhancements

- Make streamlined BEES results available on a web-based platform
- Add feature soliciting product quantities from the BEES user to automate the process of comparing BEES scores across building elements
- Add feature permitting import and export of life cycle inventories
- Add feature permitting integrated sensitivity analysis so that the effect on BEES results of changes in parameter settings may be viewed on a single graph

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[250] P. Hofstetter et al., *User Preferences for Life-Cycle Decision Support Tools: Evaluation of a Survey of BEES Users*, NISTIR 6874, National Institute of Standards and Technology, Washington, DC, July 2002; and M.A. Curran et al., *BEES 2.0, Building for Environmental and Economic Sustainability: Peer Review Report*, NISTIR 6865, National Institute of Standards and Technology, Washington, DC, 2002.

Appendix A. BEES Computational Algorithms

A.1 Environmental Performance

BEES environmental performance scores are derived as follows.

$$\mathrm{EnvScore}_j = \sum_{k=1}^{p} \mathrm{IAScore}_{jk},\ \text{where}$$

$\mathrm{EnvScore}_j$ = environmental performance score for building product alternative j;
p = number of environmental impact categories;
$\mathrm{IAScore}_{jk}$ = characterized, normalized and weighted score for alternative j with respect to environmental impact k:

$$\mathrm{IAScore}_{jk} = \frac{\mathrm{IA}_{jk} * \mathrm{IVwt}_k}{\mathrm{Norm}_k} * 100,\ \text{where}$$

IVwt_k = impact category importance weight for impact k;
Norm_k = normalization value for impact k (see section 2.1.3.3);
IA_{jk} = characterized score for alternative j with respect to impact k:

$$\mathrm{IA}_{jk} = \sum_{i=1}^{n} \mathrm{I}_{ij} * \mathrm{IAfactor}_i,\ \text{where}$$

n = number of inventory flows in impact category k;
I_{ij} = inventory flow quantity for alternative j with respect to inventory flow i, from BEES environmental performance data file (See section 4.4.);
$\mathrm{IAfactor}_i$ = impact assessment characterization factor for inventory flow i

The BEES life-cycle stage scores, $\mathit{LCScore}_{sj}$, which are displayed on the environmental performance by life-cycle stage graph, are derived as follows:

$$\mathrm{LCScore}_{sj} = \sum_{i=1}^{n} \mathrm{IAScore}_{jk} * \mathrm{IPercent}_{ij} * \mathrm{LCPercent}_{sij},\ \text{where}$$

$\mathrm{LCScore}_{sj}$ = life cycle stage score for alternative j with respect to stage s;

$$\mathrm{IPercent}_{ij} = \frac{\mathrm{I}_{ij} * \mathrm{IAfactor}_i}{\sum_{i=1}^{n} \mathrm{I}_{ij} * \mathrm{IAfactor}_i};$$

$$\mathrm{LCPercent}_{sij} = \frac{\mathrm{I}_{sij}}{\sum_{s=1}^{r} \mathrm{I}_{sij}},\ \text{where}$$

I_{sij} = inventory flow quantity for alternative j with respect to flow i for life cycle stage s;
r = number of life cycle stages

A.2 Economic Performance

BEES measures economic performance by computing the product life-cycle cost as follows:

$$LCC_j = \sum_{t=0}^{N} \frac{C_t}{(1+d)^t}, \text{ where}$$

LCC_j = total life-cycle cost in present value dollars for alternative j;
C_t = sum of all relevant costs, less any positive cash flows, occurring in year t;
N = number of years in the study period;
d = discount rate used to adjust cash flows to present value

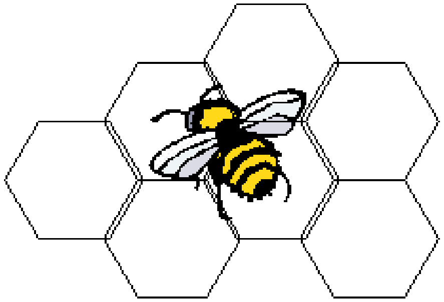
A.3 Overall Performance

The overall performance scores are derived as follows:

$$Score_j = \left[(EnvWt * \frac{EnvScore_j}{\sum_{j=1}^{n} EnvScore_j}) + (EconWt * \frac{LCC_j}{\sum_{j=1}^{n} LCC_j}) \right] * 100, \text{ where}$$

$Score_j$ = overall performance score for alternative j;
EnvWt, EconWt = environmental and economic performance weights, respectively
(EnvWt + EconWt = 1);
n = number of alternatives;
$EnvScore_j$ = (see section A.1);
LCC_j = (see section A.2)

Appendix B. Interpreting BEES Environmental Performance Scores: A Primer



Product ABC has a BEES Environmental Performance Score of 0.0230 and Product XYZ a score of 0.0640. What does that mean?

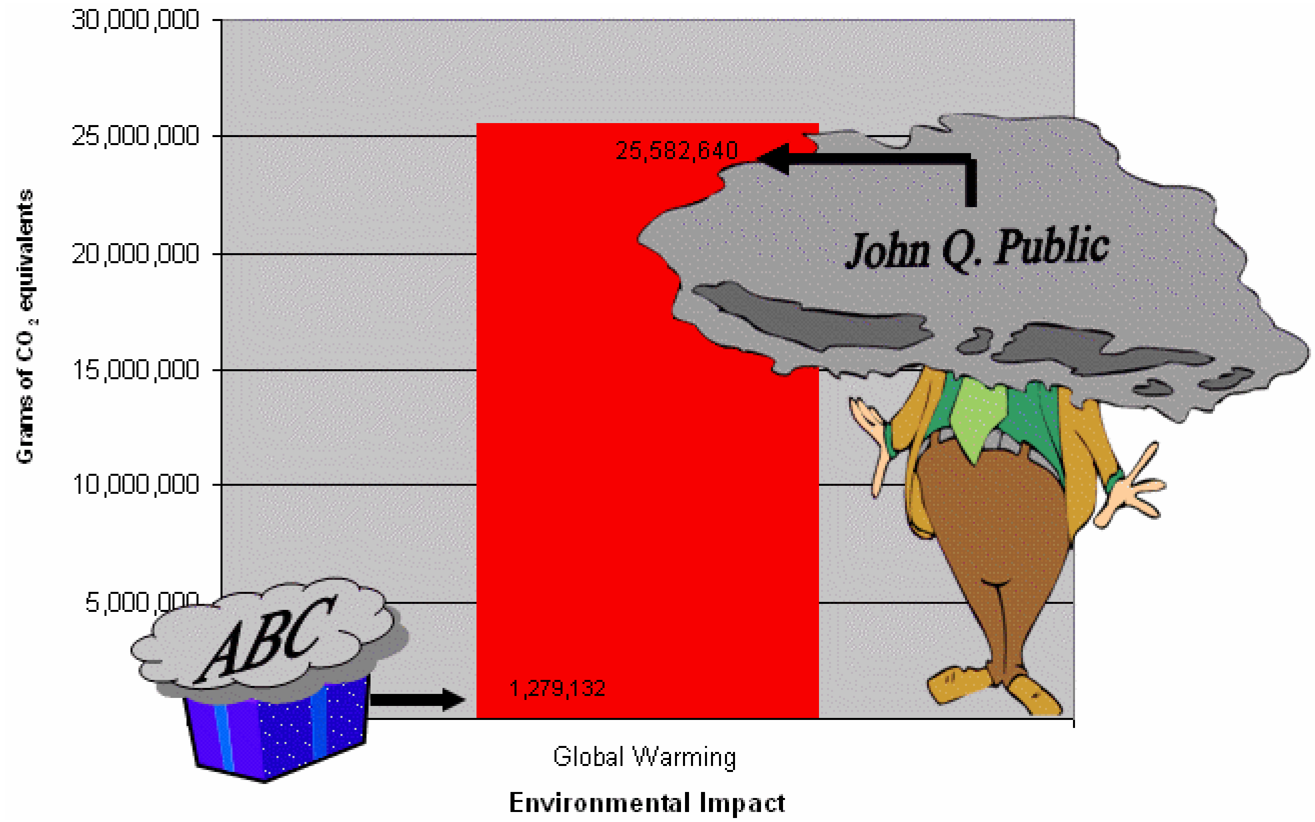
Let’s start from the beginning, considering just one product and one environmental impact at a time. Let’s take a look, say, at the Global Warming performance of Product ABC, and ask:

Q. How much does Product ABC contribute to Global Warming over its life cycle?

A. BEES tells me that Product ABC contributes 1,279,132 grams of carbon dioxide and other greenhouse gases over its life cycle.

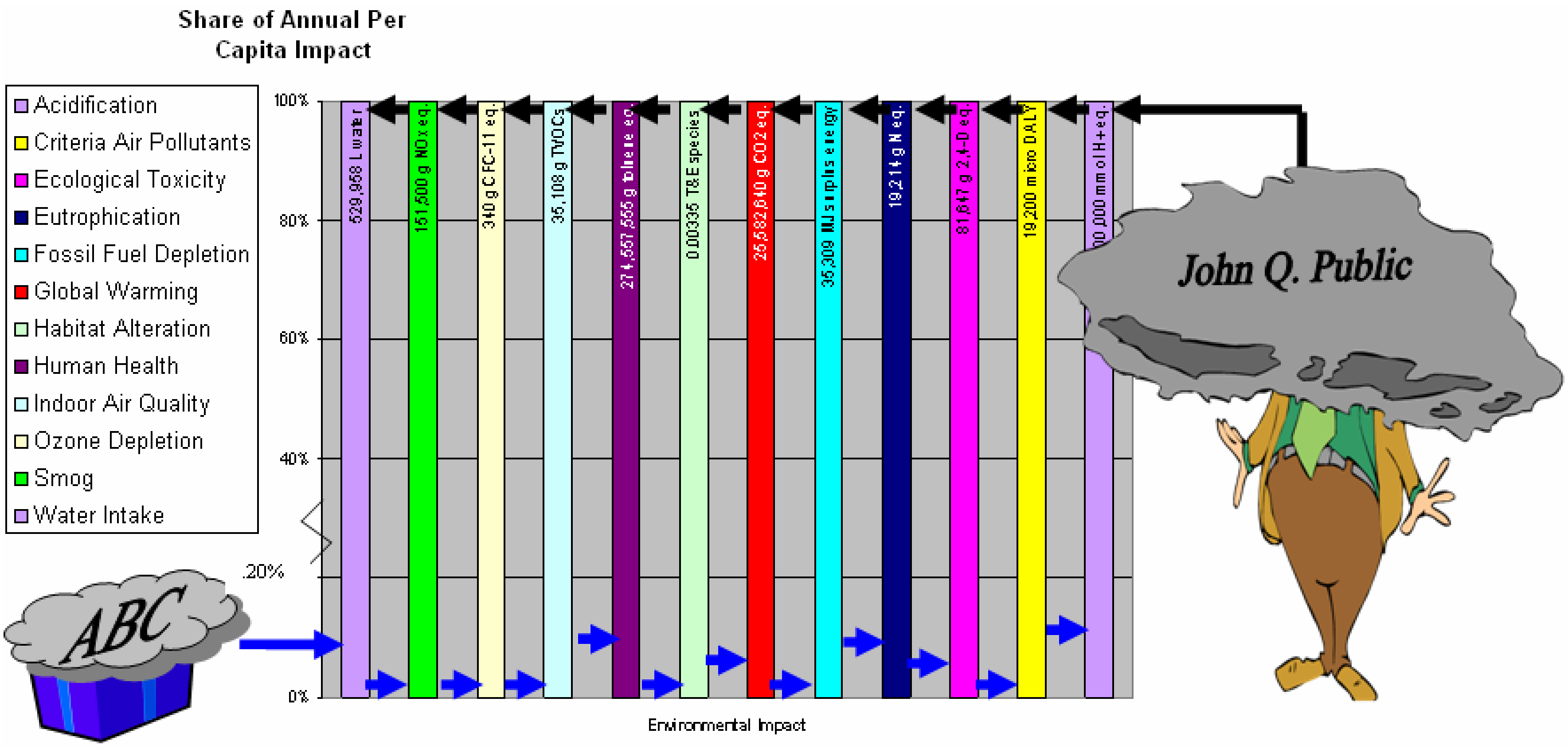
Q. So what? All products contribute greenhouse gases over their life cycle. Is 1,279,132 grams a lot or a little? How can I make sense of this number?

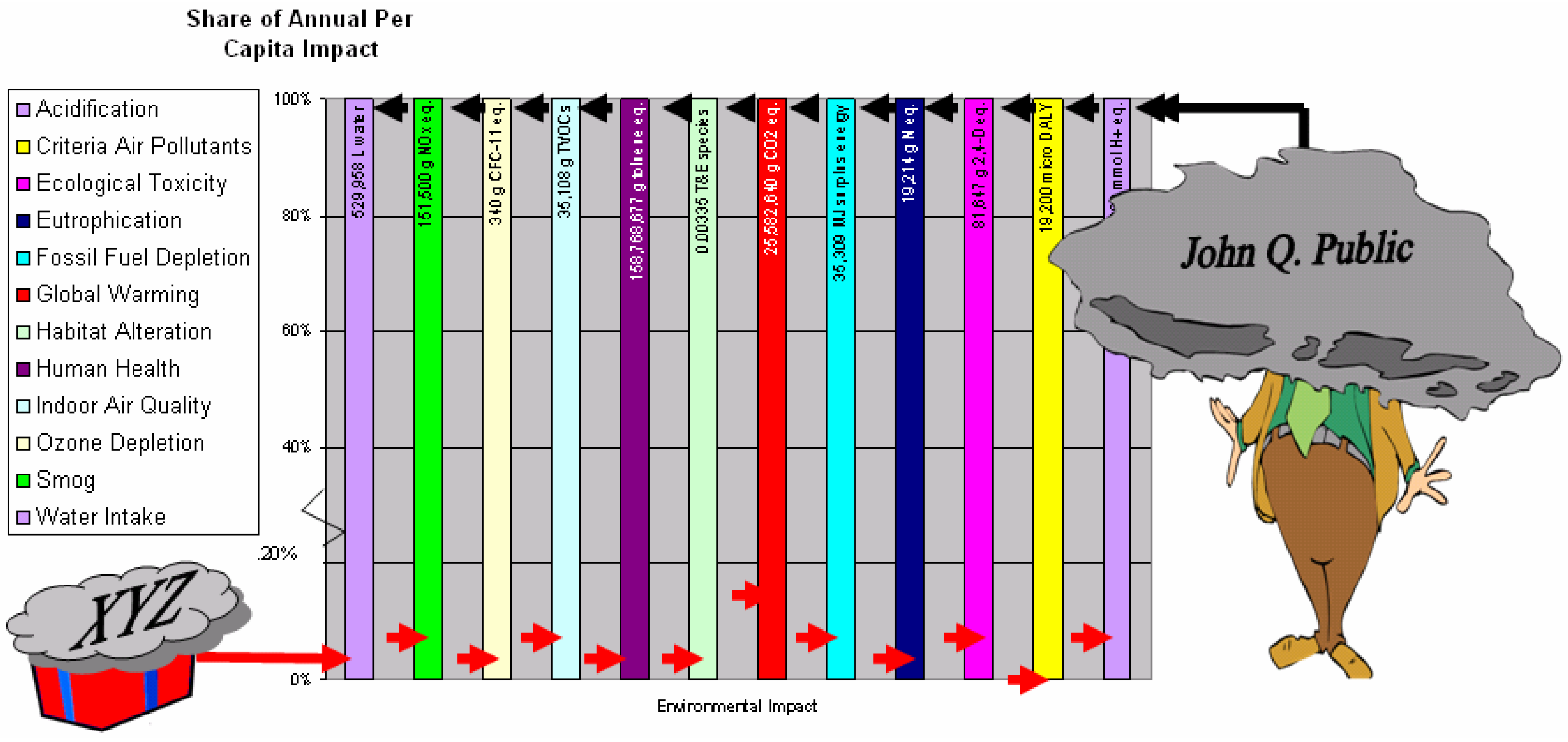
A. By relating the number to the total amount of greenhouse gases released every year, per person, in the United States. Let’s make this person—John Q. Public—our yardstick, and mark the spot showing Product ABC’s greenhouse gases relative to his.



Q. Okay. Let's say you do that for Product ABC for all 12 environmental impacts. But then what? How can you combine all 12 yardsticks when they're measuring different things? Wouldn't you be mixing apples and oranges?

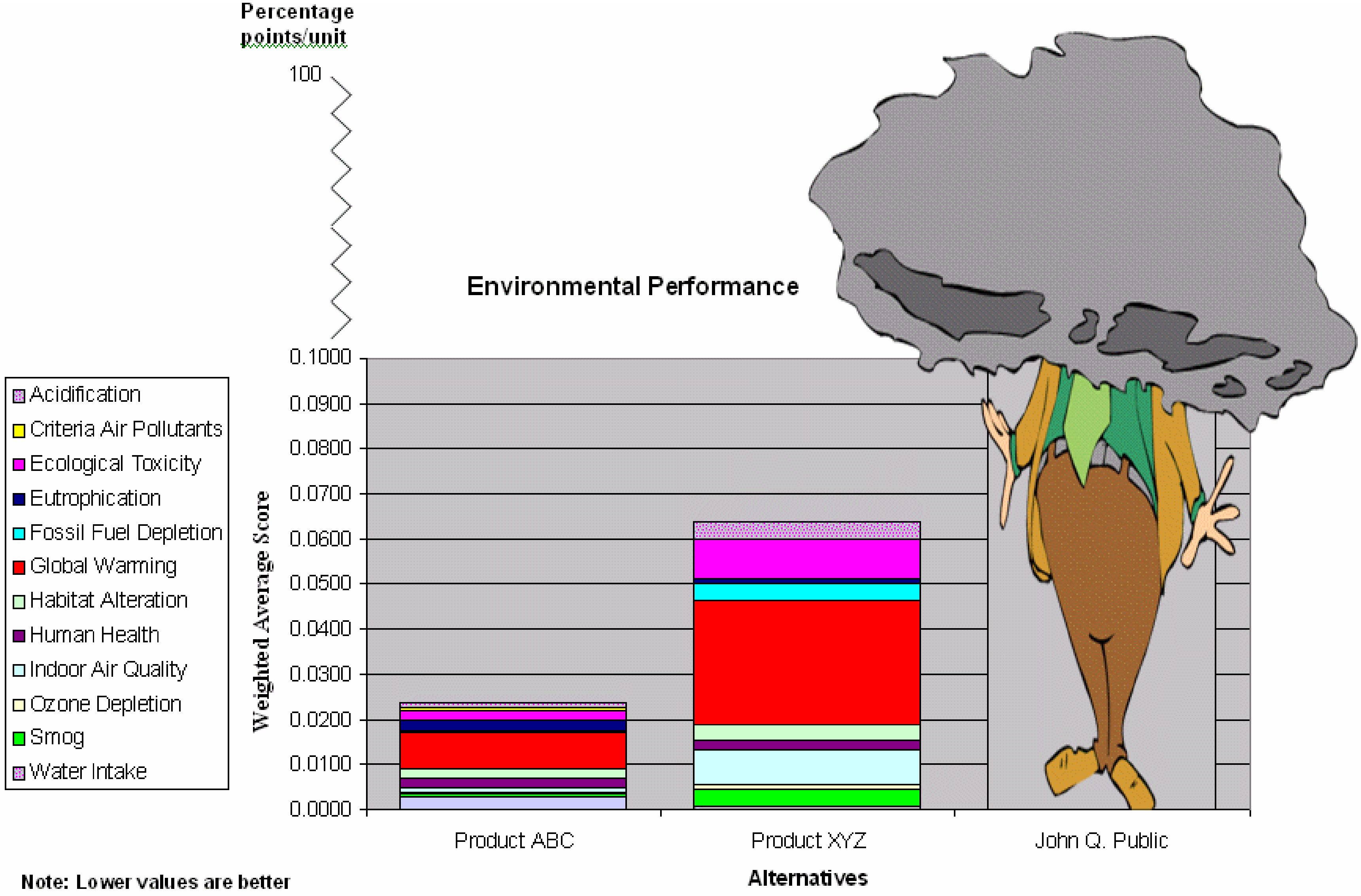
A. Yes, you would be, unless you made a single, common yardstick for all impacts—one based on Product ABC's *percentage share* of John Q. Public's impacts. That way, you could plot all impacts on the same graph. It's like a nutrition label, but instead of reporting a product's percentages of recommended daily allowances, we're reporting its percentages of John Q. Public's environmental impacts. Let's do this for Product ABC and Product XYZ.





Q. I'm still confused. It looks like Product ABC scores better on Global Warming, but worse on Human Health, than Product XYZ. How do I know which product is environmentally preferred, all things considered? Can't you just give me a simple average score?

A. I could, but that would mean all environmental impacts are of the same importance. Most experts say that's not the case, so I'll give you a weighted average score instead, using weights from U.S. EPA experts. Then you can compare Product ABC side-by-side with Product XYZ when you're shopping for "green" products. But always remember, it's better to have a *lower* BEES Environmental Performance Score. Think of the BEES Score as a penalty score—the higher it is, the worse it is.



Note: Lower values are better

Q. Okay. But after all this, when I tell my colleagues that Product ABC, with a BEES Environmental Performance Score of 0.0230, is greener than Product XYZ, with a score of 0.0640, what am I really saying?

A. You’re saying that, over its life cycle, one unit of Product ABC does less damage to the environment than does one unit of Product XYZ. If your colleague’s eyes start to glaze over, quickly finish by saying that products with lower BEES scores are greener. Otherwise, explain that Product ABC is greener because it contributes, on average, 0.0230 % of annual per capita U.S. environmental impacts, while Product XYZ contributes a larger share, 0.0640 %.

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