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CHAPTER 2

Selecting Environmentally and Economically Balanced Building Materials

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Introduction

Buildings significantly alter the environment. According to Worldwatch Institute[1], building construction consumes 40 percent of the raw stone, gravel, and sand used globally each year, and 25 percent of the virgin wood. Buildings also account for 40 percent of the energy and 16 percent of the water used annually worldwide. In the United States, about as much construction and demolition waste is produced as municipal garbage. Finally, unhealthy indoor air is found in 30 percent of new and renovated buildings worldwide.

Negative environmental impacts flow from these activities. For example, raw materials extraction can lead to resource depletion and biological diversity losses. Building materials manufacture and transport consumes energy, which generates emissions linked to global warming and acid rain. Landfill problems, such as leaching of heavy metals, may arise from waste generation. All these activities can lead to air and water pollution. Unhealthy indoor air may cause increased morbidity and mortality.

Selecting environmentally preferable building materials is one way to improve a building's environmental performance. To be practical, however, environmental performance must be balanced against economic performance. Even the most environmentally conscious building designer or building materials manufacturer will ultimately want to weigh environmental benefits against economic costs. They want to identify building materials that improve environmental performance with little or no increase in cost.

The National Institute of Standards and Technology (NIST) is teamed with the U.S. Environmental Protection Agency's (EPA) National Risk Management Research Laboratory, Air Pollution Prevention Control Division, to develop by 1997 a standardized methodology and publicly available database for balancing the environmental and economic performance of building materials. EPA is developing a database of environmental performance data, and with EPA support, NIST is developing the methodology and implementing it in decision-support software for building designers and materials manufacturers. NIST is adding economic performance data to the database. The decision-support software will access the database of environmental and economic performance data. The combined software and database product will be known as BEES (Building for Environmental and Economic Sustainability).

Measuring Environmental Performance

Environmental performance is measured using an evolving, multidisciplinary tool known as life-cycle assessment (LCA). LCA is a "cradle-to-grave" systems approach for understanding the environmental consequences of technology choices. The concept is based on the belief that all stages in the life of a material generate environmental impacts and must therefore be analyzed, including raw materials extraction and processing, intermediate materials manufacture, material manufacture, 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 general LCA methodology is as follows. LCA begins with goal identification and scoping (defining boundaries). What is the purpose of the LCA? What decision is the LCA meant to support? Where are environmental impact boundaries to be drawn—secondary environmental impacts, tertiary impacts? Do we include all environmental impacts, or only a pre-defined subset of impacts?

After goal identification and scoping, the four-step LCA analytic procedure begins. The inventory analysis step identifies and quantifies the environmental inputs and outputs associated with a material over its entire life cycle. Environmental inputs include water, energy, land, and other resources; outputs include releases to air, land, and water. The impact assessment step characterizes these inputs and outputs in relation to a comprehensive set of environmental impacts. For example, the impact assessment step might relate carbon dioxide (CO_2) emissions to global warming.

The third step, impact valuation, synthesizes the environmental impacts by combining them with stakeholder values. For example, assume there are only two environmental impacts, stratospheric ozone depletion and global warming. The impact valuation step might combine quantitative measures of ozone depletion and global warming into a single measure of overall environmental impact by normalizing the quantitative measures and weighting each impact by its relative importance. (Note that while LCA practitioners generally agree on the nature of impact valuation, not all treat it as a separate LCA step. Some include it as part of impact assessment, while others include it as part of improvement assessment.)

The improvement assessment step identifies and evaluates opportunities for making changes in the product life cycle which improve its cradle-to-grave environmental performance. Depending on the goal of the LCA, the improvement step may be omitted. For example, if the goal of the LCA is to select the most environmentally preferable from among three building materials, the improvement step is unnecessary.

NIST is applying the LCA methodology to building materials. In so doing, NIST is adding explicit guidance to the LCA impact assessment and valuation steps. The guidance consists of the following three principles:

1) **Avoid false precision.**
There is some uncertainty associated with the data used at each LCA step, which influences the precision of the final results. It is important to document the precision with which conclusions can be drawn about the environmental performance of building materials. For example, if at the inventory analysis step, sulfur dioxide emissions are estimated within a range of plus or minus five percent, then an overall environmental impact score cannot be derived with 100 percent certainty. The NIST method-

ology avoids false precision by collecting uncertainty data at each LCA step and propagating (accounting for) uncertainty throughout the LCA. The final environmental impact score will thus be bounded by an uncertainty range.

2) **Address scale of impact.**
The LCA impact assessment step characterizes the inventory items in relation to environmental impacts. This step will also relate the flows (to or from the environment) occurring during the life cycle of a building material to the total flows occurring at scales such as the U.S. as a whole. For example, the NIST methodology will relate the chlorofluorocarbon (CFC) emissions associated with vinyl siding's life cycle to the total CFC emissions from the U.S., and will use this information in deriving the final environmental performance score for vinyl siding.

3) **Minimize assumptions and uncertainty.**
Each LCA step introduces additional assumptions and uncertainty. The NIST methodology minimizes these by checking data after each LCA step to see if one building material alternative shows dominance or near dominance. Dominance is shown when one alternative performs best on all criteria.

These three principles are implemented in the NIST LCA methodology for measuring the environmental performance of building materials, depicted in *Figure 1.* The goal is to assist material selection decisions by assigning relative environmental scores to a set of building material alternatives. To the extent possible, all environmental impacts will be included. The first step is inventory analysis. Environmental input and output data will be gathered for all building material alternatives on a per functional-unit basis, complete with uncertainty ranges. In the (unlikely) event that one alternative performs best or nearly best with respect to all inventory items, that alternative will be flagged as the dominant or nearly dominant alternative. Note that large uncertainty ranges do not preclude dominance as long as there is no overlap among alternatives.

The next step is impact assessment. First, inventory items are classified by impact category. Then inventory items are characterized within impact categories. For many of the impact categories, published "equivalency factors" are available to normalize the inventory items in terms of strength of contribution[2]. For example, equivalency factors have been developed for each of the major "greenhouse gases." These factors indicate the relative "global warming potential" of each greenhouse gas, taking into account the different strengths of radiative forcing as well as differences in atmospheric lifetimes[3]. The global warming potential equivalency factors will be used to convert all greenhouse gas inventory data (reported as tons of a given greenhouse gas emitted per functional unit of a particular building material—for example, tons emitted per square meter (square yard) of carpet) into "CO_2-equivalents" (reported as tons of CO_2 per functional unit). Following this conversion, all inventory data in the "global warming" impact category can be summed to arrive at a scalar total (tons of CO_2-equivalents) to allow direct numerical comparison among building materials.

Equivalency factors are subject to some uncertainty based on the strength of the underlying science. The NIST methodology will attempt to reflect the literature's assessment of this uncertainty by using intervals (ranges) rather than scalar numbers for the equivalency factors. Arithmetic operations on intervals are well-established[4] and will be used in the NIST methodology as a basic means for propagating uncertainty throughout the LCA.

For some impact categories and inventory items, equivalency factors have not been published, so there is no clear basis for normalizing and summing the inventory data within an impact category. In such instances the NIST methodology will allow the user to check for dominance or near dominance of one material alternative over the others. A flexible heuristic method will be available for assigning a summary score to the dominant and

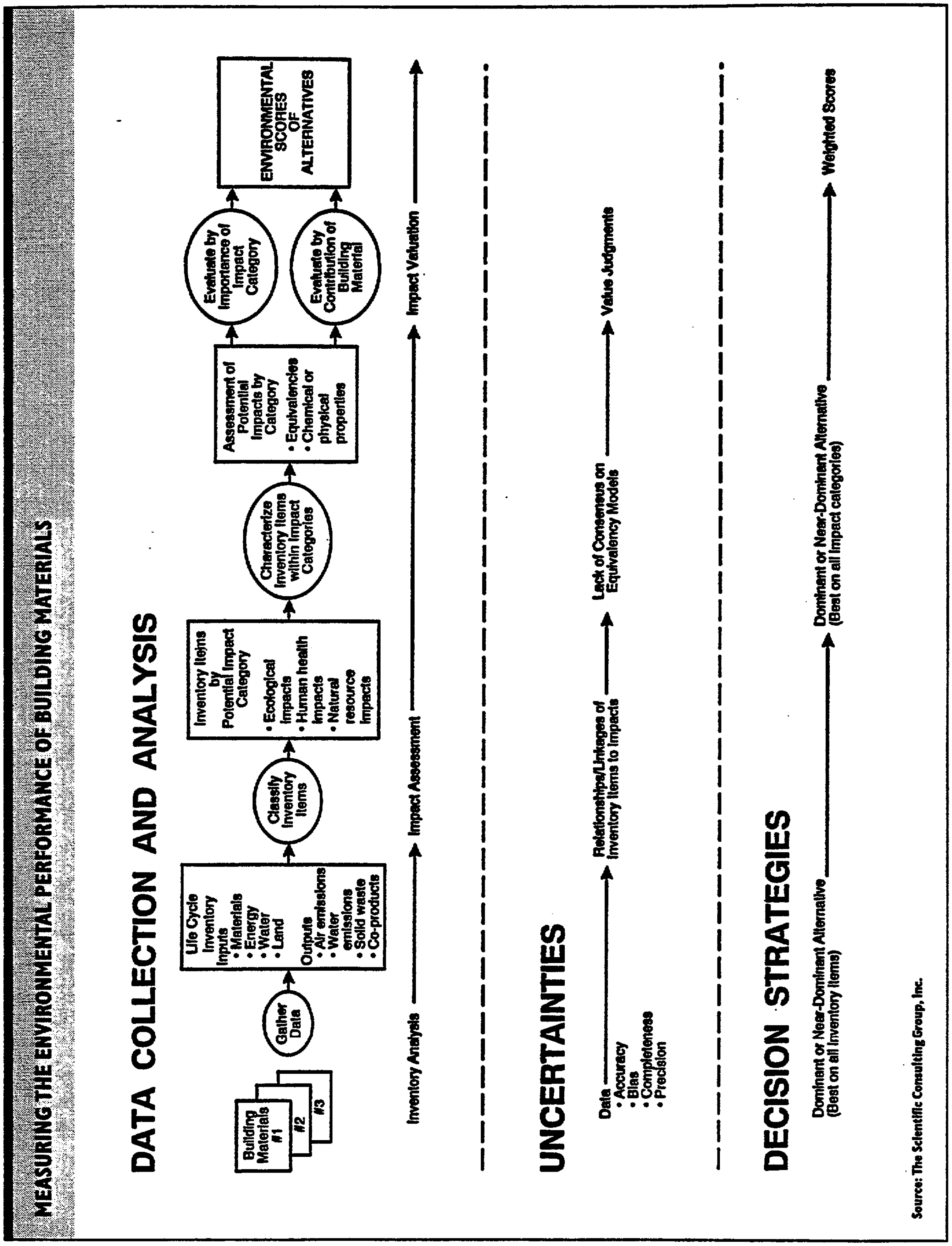
MEASURING THE ENVIRONMENTAL PERFORMANCE OF BUILDING MATERIALS
DATA COLLECTION AND ANALYSIS
Building Materials #1
#2
#3
Gather Data
Life Cycle Inventory
Inputs
• Materials
• Energy
• Water
• Land
Outputs
• Air emissions
• Water emissions
• Solid waste
• Co-products
Classify Inventory Items
Inventory Items by Potential Impact Category
• Ecological impacts
• Human health impacts
• Natural resource impacts
Characterize Inventory Items within Impact Categories
Assessment of Potential Impacts by Category
• Equivalencies
• Chemical or physical properties
Evaluate by Importance of Impact Category
Evaluate by Contribution of Building Material
ENVIRONMENTAL SCORES OF ALTERNATIVES
Inventory Analysis
Impact Assessment
Impact Valuation
UNCERTAINTIES
Data
• Accuracy
• Bias
• Completeness
• Precision
Relationships/Linkages of Inventory Items to Impacts
Lack of Consensus on Equivalency Models
Value Judgments
DECISION STRATEGIES
Dominant or Near-Dominant Alternative (Best on all Inventory items)
Dominant or Near-Dominant Alternative (Best on all Impact categories)
Weighted Scores
Source: The Scientific Consulting Group, Inc.

Figure 1

non-dominant alternatives within all such impact categories, but the software will also flag these impact category results to indicate that the relative scores are not based on peer-reviewed, scientific methods for normalizing the inventory data in terms of strength of impact within the impact categories.

The third step in the LCA is impact valuation. At this step, impact assessment results will be normalized and synthesized into an overall environmental score for each material alternative. Multiattribute decision analysis (MADA) techniques are useful here[5]. MADA techniques apply to problems where the decision-maker is choosing or ranking a finite number of alternatives (building materials) which differ by two or more relevant attributes (environmental impacts). The attributes in a MADA problem will generally not all be measurable in the same units, and some may be either impractical, impossible, or too costly to measure at all (as is the case with some environmental impacts). Most MADA methods require the decision-maker to assign different levels of importance to the different attributes of the problem.

MADA techniques will be used to arrive at overall, relative environmental scores for building material alternatives. The NIST/EPA team plans to conduct workshops in 1996 to collect sets of MADA importance weights for environmental impacts from several stakeholder perspectives (e.g., policymaker, environmentalist, and building industry perspectives), with input from environmental scientists and others. The decision maker may then select that set of importance weights most appropriate for the decision at hand, and may also test the sensitivity of the environmental scores to the different stakeholder perspectives.

The LCA is complete after the impact valuation step. Impact valuation yields environmental scores, which are the goal of this LCA application, so the improvement assessment step is unnecessary.

Measuring Economic Performance

Measuring the economic performance of building materials is more straightforward than measuring environmental performance. Standardized methodologies and quantitative, published data are readily available.

The American Society for Testing and Materials (ASTM) Subcommittee E06.81 on Building Economics has published a compilation of standards for evaluating the economic performance of investments in buildings[6]. The single standard most appropriate for evaluating the economic performance of building materials for subsequent comparison with environmental performance is ASTM E 917-93, *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*[7]. The life-cycle-cost (LCC) method sums over a given study period the costs of an investment. The sum is expressed in either present value or annual value terms. Alternative building materials for a given functional requirement, say flooring, can thus be compared on the basis of their LCCs to determine which is the least-cost means of providing flooring over that study period.

The LCC method includes the costs over a given study period of initial investment (less resale or salvage value), replacements, operations, maintenance and repair, and disposal. It is essential to use the same study period for each alternative whose LCCs are to be compared, even if they have different useful lives. The appropriate study period varies according to the stakeholder perspective. For example, a homeowner would select a study period based on the length of time he or she expects to live in the house, whereas a long-term owner/occupant of an office building might select a study period based on the life of the building.

It is important to distinguish between the life cycles underlying the LCA method (used to measure environmental performance), and the LCC method (used to measure economic performance). LCA uses an environmental life-cycle concept, whereas LCC uses a building life-cycle concept. These are different. The environmental life cycle of a building material begins with raw materials extraction and ends with recycling, reuse, or disposal of the material. The building life cycle of a building material begins with its installation in the building and lasts for the duration of the LCC study period, which is determined in part by the useful life of the material and in part by the time horizon of the investor. While there is overlap between these two life cycles once the material is installed in the building, it is important not to confuse the two. The reason why LCC uses a building life cycle rather than an environmental life cycle is because out-of-pocket costs to the investor are borne over this time frame. It is these costs to the investor upon which financial decisions are made.

The LCC for a building material is computed by discounting all costs occurring over the study period to the present and then summing. The discount rate converts future costs to their equivalent present values and accounts for the time value of money. Discount rate values to be used in federal projects are legislated by the Office of Management and Budget; these values apply to analyses of private-sector projects as well.

BALANCING ENVIRONMENTAL AND ECONOMIC PERFORMANCE

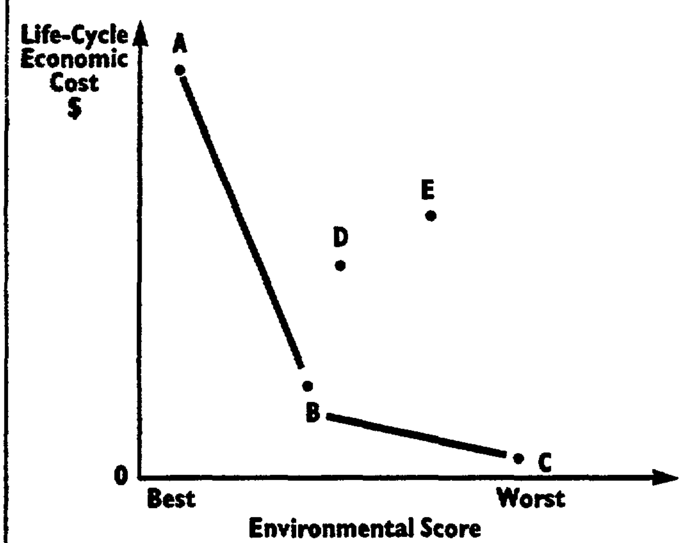

Figure 2

Balancing Environmental and Economic Performance

Figure 2 displays how environmental and economic performance are balanced. Suppose a building designer is choosing from among five alternative flooring materials and that each point in *Figure 2* represents one material's environmental/economic performance balance. The designer will first rule out Alternatives D and E because they are dominated by at least one other alternative; that is, they perform worse than another alternative (Alternative B) with respect to both the environment and economics. Of the remaining alternatives, Alternative A costs the most, but offers the best environmental performance. Alternative C offers the best economic performance and the worst environmental performance. Alternative B improves environmental performance (relative to C) at little increase in cost. The designer can now make an informed decision. He or she will select from among Alternatives A, B, and C that which best reflects the relative importance he or she gives to environmental versus economic performance.

Decision-Support Software Features

Decision-support software is being developed by NIST to implement the methodology described above for balancing the environmental and economic performance of building materials. The software will use as input the database of environmental and economic performance data. Together the software and database are known as BEES. BEES will be available over the Internet, which will offer instantaneous access to the tool as well as instant dissemination of data refinements. Data refinements are expected over time as the state of the art of environmental assessment advances, new building materials arrive on the scene, and the costs of building materials change.

BEES will accommodate different levels of user expertise. It will include built-in, "default" data so that users unfamiliar with LCA may readily make and defend building material selections. Note, however, that BEES will not include default values for the relative importance of environmental and economic performance. Rather, BEES will display, as in *Figure 2,* the environmental/economic tradeoffs offered by the decision alternatives. It will remain up to the user to select the alternative that best reflects his or her viewpoint.

The more experienced user will be able to customize the default data. For example, a materials manufacturer will be able to enter proprietary data on its products. Other data, such as relative importance weights for environmental impacts and the discount rate for LCC computation, will also be editable. These users will thus be able to do "what if" analyses to examine how changing the data affects the environmental/economic performance balance.

Finally, BEES will follow the data transparency principle of the LCA methodology by documenting data used and assumptions made at every LCA stage.

Summary

The building community is making decisions today that have environmental and economic consequences. Its decisions are plagued by incomplete and uncertain data as well as the lack of a standardized methodology for evaluating the data. The NIST/EPA team seeks to support these decisions by gathering environmental and economic performance data and by structuring and computerizing the decision-making process. The resulting BEES tool will be publicly available over the Internet.

NOTES

1 D. M. Roodman and N. Lenssen, "A Building Revolution: How Ecology and Health Concerns are Transforming Construction," *Worldwatch Paper* 124 (Washington, D.C.: Worldwatch Institute, March 1995).

2 K. A. Weitz and J. L. Warren, *Life-Cycle Impact Assessment: A Conceptual Framework, Key Issues, and Summary of Existing Methods* (Research Triangle Park, N.C.: U.S. EPA, Office of Air Quality Planning and Standards, June 1995).

3 Intergovernmental Panel on Climate Change, *Climate Change: The 1990 and 1992 IPCC Assessments* (Geneva, Switzerland: World Meteorological Organization and United Nations Environment Program, 1992).

4 R. E. Moore, *Methods and Applications of Interval Analysis* (Philadelphia: SIAM Press, 1979).

5 G. A. Norris and H. E. Marshall, *Multiattribute Decision Analysis: Recommended Method for Evaluating Buildings and Building Systems*, NISTIR 5663 (Gaithersburg, Md.: National Institute of Standards and Technology, July 1995).

6 American Society for Testing and Materials, *ASTM Standards on Building Economics*, 3d ed. (Philadelphia, 1994).

7 American Society for Testing and Materials, *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*, ASTM Designation E 917-93 (Philadelphia, March 1993).

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