ENVIRONMENTAL-PERFORMANCE RESEARCH PRIORITIES:

WOOD PRODUCTS

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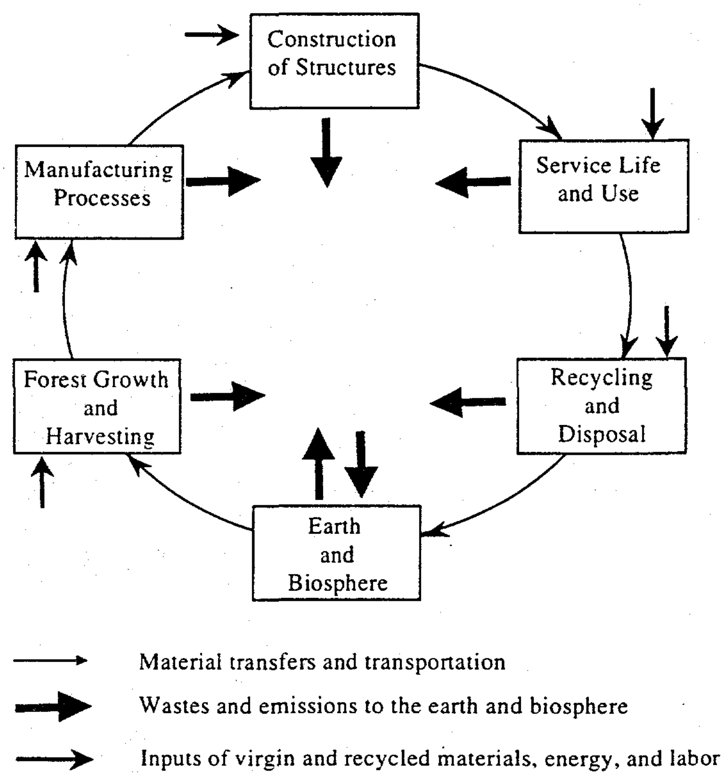
FINAL REPORT

ON THE RESEARCH PLAN TO DEVELOP ENVIRONMENTAL-PERFORMANCE MEASURES FOR RENEWABLE BUILDING MATERIALS WITH ALTERNATIVES FOR IMPROVED PERFORMANCE

Life cycle from regeneration to disposal of wood materials



15 January 1998

Consortium for Research on Renewable Industrial Materials
(CORRIM, Inc.)

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Environmental-Performance Research Priorities: Wood Products

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Submitted by:

Consortium for Research on Renewable Industrial Materials (CORRIM, Inc.)

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JANUARY 15, 1998

ENVIRONMENTAL-PERFORMANCE RESEARCH PRIORITIES: WOOD PRODUCTS

PREFACE (Organization of the Report)

This report describes a research plan to establish environmental, energy, and economic performance measures for renewable building materials, and the identification of attractive management and technology alternatives that can improve environmental performance in a cost-effective manner. The report was developed over a period of 15 months by the Consortium for Research on Renewable Industrial Materials (CORRIM II) with the financial support of its 21 institutional and company members and the Department of Energy. During this period, the CORRIM Board of Directors met several times to organize groups of scientists and reviewers that could prepare the research plan and manage subsequent research efforts. Three technical panels were formed and they convened on three occasions to synthesize the work of panel members in developing the research plan. A Technical Steering Committee was formed to provide overall guidance for the project, and met twice, once to review an intermediate progress report and once to review a completed draft of the research plan. The Steering Committee also arranged for several independent outside reviews of the completed research plan.

The research plan is designed to: (1) collect environmental and economic data on all life-cycle stages from planting and growing the renewable raw material through the manufacturing of product, design and construction of buildings as well as activities associated with occupation, use and final demolition (life-cycle inventories (LCI)); (2) ensure that the data follows consistent definitions and collection procedures; and (3) develop analytical procedures that facilitate integration of results across the full life-cycle for all stages of processing to address environmental performance questions (life-cycle analysis (LCA)). This methodology has been carefully developed after thorough evaluation of worldwide research protocols. Every effort has been made to ensure that the results can be directly compared to research findings of other research groups.

The report is organized as follows: Major points are briefly summarized in an executive summary preceding the table of contents. Sections I-IV of the main report provide the background, mission, organization of effort, and objectives. Section V describes the environmental-performance measures that will be targeted as well as the environmental-performance related questions that can be answered with the completed research results. Section VI develops the design for a sequence of modularized research projects which characterize different stages of processing and regional practices. Section VII provides an abbreviated description for each project module. Section VIII describes the research methodology to insure consistency across the research modules. Sections VI, VII, and VIII are supplemented with more extensive detail provided in the first two appendices. Appendix A, Data, Standards, and Procedures: Guidelines for LCI and Economic Analysis, provides a "Users Manual" for the research effort. Appendix B, the Research Modules—Content, describes the 22 identified modules. The report concludes with a discussion of impact assessment procedures and existing modeling capabilities in Section IX; and a description of the management plan to bring the best available science to the tasks in Section X. Additional detail for these sections are provided in Appendix C, Organization of CORRIM's Scientific Expertise, which defines the panels of experts used to develop the research plan and planned projects; Appendix D, an outline of the final reports; and Appendix E, which contains comments from independent reviewers.

ENVIRONMENTAL-PERFORMANCE RESEARCH PRIORITIES: WOOD PRODUCTS

EXECUTIVE SUMMARY

The Consortium for Research on Renewable Industrial Materials (CORRIM) has been organized for the purpose of updating and expanding a 1976 landmark study by the National Academy of Science on the energy implications of producing and using renewable building materials. Because the 1976 study was also known by the CORRIM acronym, this newly-organized research effort is being referred to as CORRIM II.

An expanding list of environmental-performance issues has gained considerable attention over the last two decades, yet there has been no update of the original CORRIM study or extensions to include environmental issues not addressed in the original study. Without a scientifically sound, life-cycle database on performance measures, there can be no basis on which to formulate public policy affecting the renewable materials industries. Moreover, there is little information available to companies on which to base a strategic investment plan that could improve environmental performance.

The scope of the 6 year research plan described in this document is limited to collecting primary data for wood-based products while using secondary data for non-wood products where necessary. After completion of the research on wood products, extensions to include other renewable products will be considered.

The output of the proposed research will be a scientific base of information on the environmental performance of wood-based products. This information base will also identify forest management, product, and process changes that can improve wood use and energy efficiency, increase carbon sequestration, reduce generation of wastes and potentially toxic materials, and sustain healthy forest ecosystems. The study addresses a need identified in Agenda 2020—a research agenda that addresses pre-competitive research issues of importance to the U.S. forest products industry.

Objectives of the proposed study are:

- To create a consistent database of environmental performance measures associated with the production, use, maintenance, re-use, and disposal of alternative wood and non-wood materials used in light construction, i.e., from forest resource regeneration or mineral extraction to end use and disposal, thereby covering the full product life-cycle from "cradle to grave."
- To develop an analytical framework for evaluating life-cycle environmental and economic impacts for alternative building materials in competing or complementary applications so that decision-makers can make consistent and systematic comparisons of options for improving environmental performance.
- To make source data available for many users, including resource managers and product manufacturers, architects and engineers, environmental protection and energy conservation analysts, and global environmental policy and trade specialists.
- To manage an organizational framework to obtain the best scientific information available as well as provide for effective and constructive peer review.

The development of the database and analytical procedures will make it possible to address a range of specific questions and issues related to environmental performance and the cost effectiveness of alternative management and technology strategies. Environmental performance tradeoffs associated with alternative management and technology strategies will be identified. The word tradeoff used here refers to how a change in one performance measure compares to changes in other measures. The analyses will produce measures of the marginal cost associated with environmental changes and other economic impacts, as well as projections of future environmental performance under alternative strategies. Following are examples of the type of analyses proposed and the issues/ questions addressed.

- ***A systematic evaluation and quantification of the environmental performance of wood products and wood-using systems:*** Management and technology alternatives for improving characteristics such as energy efficiency, carbon sequestration, recycling and reuse, and overall durability will be examined. Alternative wood products and wood-using systems will be compared to identify tradeoffs between environmental and economic-performance measures. Corporate strategists and builders will then be able to use these comparisons to determine how they can contribute to reduced carbon emissions (and other environmental measures) and at what cost. Similarly, policy makers will be able to determine for various policy alternatives how much carbon would be sequestered in wood products and buildings over time and the subsequent cost impact on producers and consumers.

- ***An assessment of how changes in forest culture and wood use affect forest health and the nation's energy requirements:*** This assessment will examine the ways in which strategies for longer rotations and higher-quality wood might impact energy use, carbon sequestration, and forest ecosystems and habitats. It will review the potential impact of wood biomass production on the supply of wood products and carbon balances. Policy makers will be able to assess the impact of policy alternatives on reduced energy use, increased energy production with lower carbon emissions, increased carbon sequestration in the forests, higher valued uses of the forest, and sustainable forest ecosystems with the benefits and costs identified for each stakeholder group. Corporate forest managers can determine how they can meet regulatory goals at the lowest cost or contribute to other environmental objectives and at what cost. Builders and environmental groups will be able to determine if the adoption of management certification standards serve their intended goals relative to unintended consequences.

- ***An assessment of the relationship between potential carbon-emission reduction policies, forest culture, and forest product use:*** Since carbon emissions are a product of many different stages of processing, this analysis will provide a broad systems perspective of the impacts of various approaches to reducing emissions across the wood producing and using system. The effect of emissions requirements on the demand for wood products will be analyzed. The opportunities for and likely costs of technologies that reduce carbon emissions will be identified. The influence of a carbon tax on the choice of processing technologies and building materials will be evaluated. Finally, the likely consequences of a carbon-credits trading program will be analyzed. Policy makers will be made aware of the tradeoffs that will result from various proposals to reduce carbon emissions or to alter forest management to achieve other environmental goals and which are most effective to reach certain goals. Corporate interests can determine how they will be impacted and how they can best respond to specific policy proposals.

- ***An examination of ways to conserve wood:*** Consumer demand for wood products is growing, yet changing policies have substantially reduced federal timber harvests and have constrained private harvests to a lesser degree. The potential to mitigate these losses by product reuse, recycling, and increasing durability will be examined. The viability of incineration for energy generation will be compared to reuse and recycling. Innovative designs of products and structures which could improve efficiency in use, energy conservation, and product durability will be investigated. Policy makers will be made aware of the opportunities to improve energy efficiency and reduce carbon emissions as a consequence of increased product durability or reuse. Corporate interests can determine how they can best contribute to efficiency in product use and reuse, at what cost, and whether the direct value to users is commensurate with the cost.

With the results of this research, policy makers will have:

- Reliable measures of carbon emissions, and carbon storage on the forest floor and in wood products for each stage of processing and region where policy impacts may be important, and comparable impacts for policy alternatives that result in substitute products.
- Identification of alternative methods for reducing emissions with quantified impacts across stages of processing and geographic regions including international trade linkages.
- Identification of performance measures and methods to improve environmental performance in areas such as (1) energy and material-use efficiency, (2) biodiversity and habitat protection indices for uplands or riparian zones and other measures of the health and sustainability of forest ecosystems, (3) solid wastes, (4) targeted potentially toxic chemicals.
- Assessments of the impact of policy proposals on the ability of the forest sector to meet expected consumer demand for products.

With the results of this research, corporate decision makers will be able to:

- Determine cost effective approaches to meet changing environmental goals, anticipate future environmental needs, and develop investment strategies that are more responsive to those needs.
- Voluntarily adopt those strategies that improve environmental performance where costs are not a limiting factor and support the development of policy alternatives that could offset cost impacts when necessary.

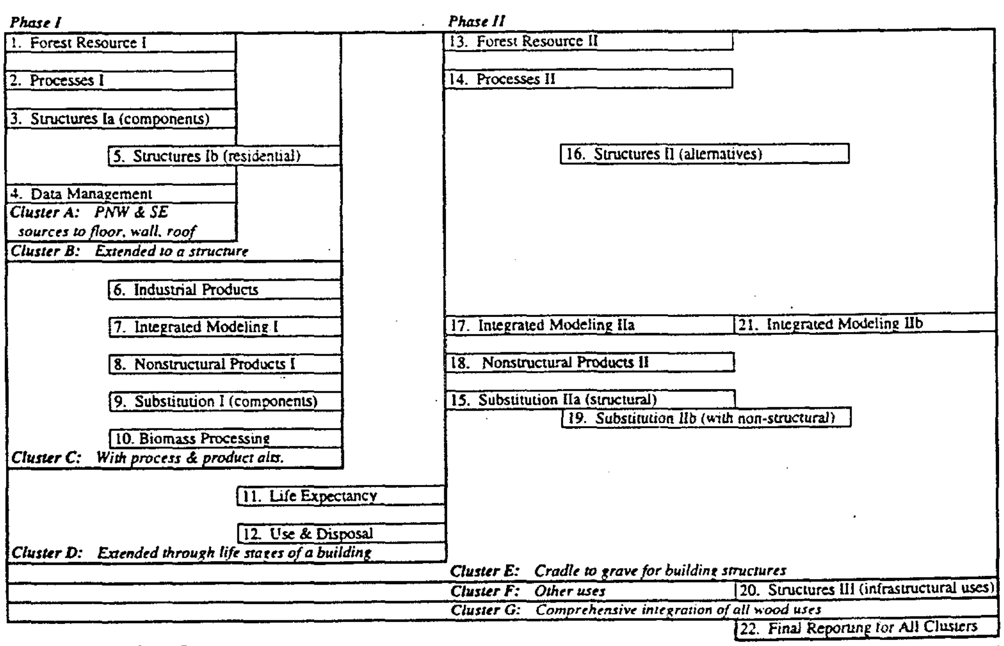
The research will be subdivided into a number of individual project modules governed by a research protocol designed to assure consistency across the work of a number of scientists. The research plan is organized around five processing stages of wood. They are: (1) resource management and harvesting, (2) processing into products and building components or other industrial uses, (3) design and construction of structures, (4) use, maintenance and disposal, and (5) waste recycling which may take place within each of the other stages. The combined research of these stages will address the environmental impacts from cradle (forest regeneration) to grave (disposal).

For each processing stage, a Phase I research module has been designed to pilot-test the development of analysis procedures for a selected set of products which are representative of a particular region. Next, a Phase II research module expands the scope for comprehensive coverage of products and regional usage. Figure 1 illustrates the modular design of research projects. The modular design provides both a sequence and a clustering of research modules that serve specific objectives for subsets of processing stages, product alternatives and/or regions.

The Phase I cluster of research modules covers resources as well as processing of products, building components, and structures. It provides a thorough pilot test for procedures, and allows direct comparisons of energy and material-use efficiency improvements with the 1976 CORRIM study. It necessarily precedes other research activities. The first four modules including Forest Resources, Processing, Structures, and Data Management can be completed in two years at an estimated cost of $1 million. When results from all research modules are combined across all stages of processing and geographic regions, they will provide a comprehensive analysis of environmental-performance tradeoffs for the U.S. and Canada with import and export linkages for a global context. Results from the research modules will be integrated into a computer database and model so that environmental and economic impacts for a wide range of user-selected scenarios can be analyzed. The completion of all modules including infrastructure and internal fixture uses of wood covering US and Canadian regions can be completed in 6 years at an estimated cost of $5 million. The modularized research design will make it possible to obtain financial support from different sources, each with specific interests in some phase of the research.

The research plan provides for a thorough, ongoing review of all findings: first, by expert panels; second by the Technical Steering Committee selected to include broad representation; and third, by a select group of independent outside reviewers.

Figure 1: Research Modules
(with identified clusters of modules for systems analysis)



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I. BACKGROUND

Public interest in the environmental impacts of forest management has reached new heights resulting in the demand for strategies and policies that can improve environmental performance. Unfortunately, the environmental consequences of changes in forest management, product manufacturing and construction are poorly understood, may be severe and, ironically, may be detrimental to global environmental quality. This situation is greatly accentuated by an almost total lack of up-to-date, scientifically sound, product life-cycle data in the United States -- particularly life-cycle data regarding wood and bio-based products. Life-cycle refers to all activities from forest resource regeneration or mineral extraction through manufacturing and on to end-use and disposal, i.e., from "cradle to grave".

For example, consider the concerns about the sustainability of present forest practices. These concerns have led to changes in forest-harvesting activity in the United States. As a result, the U.S. wood-products sector has lost a substantial market share to non-wood substitutes and offshore suppliers with both causing partially unknown yet potentially severe environmental impacts (Koch 1992; Perez-Garcia 1993 and 1995; Eastin, et al. 1996). As public concerns about environmental quality increases, so too will the pressure to make even more changes.

Ultimately, concerns about forests and the wood that flows from them have a direct and significant impact on the U.S. building-materials and home-building industries. Harvest reductions are quickly reflected in wood availability and, in turn, market prices for wood. This triggers use of wood from other regions of the world or substitution of non-wood materials or building systems and increased importation of raw materials and finished products. While the economic impacts have been analyzed and reported, the environmental consequences of these changes in material flow and uses are poorly understood.

Without up-to-date life-cycle data, there is currently no sound basis on which to formulate public policy regarding basic industries including forestry and wood products. Moreover, individual industries, including those that use wood as a raw material, have little information available to them that could provide a basis for strategic planning and investments to improve environmental performance. Lacking is a valid database to evaluate when policy, product, technology, or process changes could really contribute to improved environmental performance.

Any substantial improvement in environmental performance will require a more factual basis than is now available for systematically evaluating the impacts of management as well as product and process alternatives for both renewable and nonrenewable resources. Urgently needed is a means of more effectively assessing environmental performance in producing, distributing, using, maintaining and recycling building materials. Among the performance measures that need to be better addressed are those relating to impacts on forest ecosystems, sustainability of the resource base, processing energy requirements, emissions, carbon sequestration, efficiency of waste reduction, efficiency of raw materials use, recycling and reuse, and the environmental implications of product use, maintenance and disposal.

The last major research effort in the U.S. with a similar focus resulted in a report to the President in 1976. That report was sponsored by the National Academy of Sciences and was prepared by the

Committee on Renewable Resources for Industrial Materials. (National Research Council 1976), hereafter referred to as the 1976 CORRIM study.

The American Forest and Paper Association (AF&PA), the major association of U.S. wood producers, developed "Agenda 2020," a technology and research agenda for America's forest, wood, and paper industry (AF&PA 1994). Agenda 2020 describes the general pre-competitive research needs of the U.S. forest products industry. Within the scope of environmental-performance factors, the Agenda 2020 request for research proposals focuses on (a) supporting an update analysis of the energy and environmental efficacy of renewable building materials and (b) suggesting alternatives for reducing the environmental releases and energy requirements of building materials through their life-cycles. An effort to update environmental performance information in Canada was initiated several years ago and their findings are being made available by the ATHENA™ Sustainable Materials Institute (ERG-UBC 1997). Their efforts will make it easier to develop comparable information for the U.S.

A recent symposium on the role of Life-Cycle Analysis for wood products sponsored by the National Research Council produced the general recognition by participants that "an objective scientifically based analysis is needed that builds on our knowledge of raw material energy impacts outlined in the 1970s and that now turns the focus to environmental impacts . . ." (Ellwood 1997).

With the goal of updating and broadening the environmental-performance findings of the outdated 1976 CORRIM study, a task force of scientists formed a CORRIM II steering committee. As a response to the AF&PA research priorities, CORRIM II was reorganized as a non-profit research corporation, composed currently of 15 member research organizations with start-up funding and technical assistance from six AF&PA member companies.

II. MISSION

The mission of CORRIM II is to develop a scientific base of information on the environmental performance of wood-based products and to identify forest management, product, and process changes that can improve wood use and energy efficiency, increase carbon sequestration, reduce generation of wastes and potentially toxic materials, and sustain healthy forest ecosystems.

III. ORGANIZATION OF EFFORT

Accomplishing the mission of CORRIM II will require:

- A consistent database for evaluating the environmental performance of alternative wood and non-wood materials from the regeneration of forest resources or mineral extraction to end use and disposal, i.e., from "cradle to grave."
- A framework for evaluating life-cycle environmental and economic impacts for alternative building materials in competing or complementary applications.

- Source data for many users, including resource managers and product manufacturers, architects and engineers, environmental protection and energy conservation analysts, and global environmental policy and trade specialists.
- An organizational framework to obtain the best scientific information available as well as provide for effective and constructive peer review.

CORRIM II is organized to congregate panels of experts, including a Data, Standards, and Procedures Panel; a Stages of Processing Panel; and a Strategy Assessment Panel.

The Data, Standards and Procedures Panel is responsible for the methodological protocol to insure that consistency can be maintained across different research modules emphasizing different stages of processing and regions as they will be developed by different groups of scientists. A general research specification and users manual (see Appendix A – Data, Standards, and Procedures: Guidelines for LCI and Economic Analysis) has been developed to assure consistency and to support the subdivision of the research effort into a number of individual project modules.

The Stages of Processing Panel is further subdivided into four technical committees to cover four stages of processing. A fifth stage of processing, waste processing and recycling or disposal, occurs in each of these stages and is therefore integrated into the domain of each of the technical committees. Also endemic to each stage are issues relating to energy use, carbon sequestration, and reduction of wastes and toxic materials. Therefore, each of the four stages will include aspects of these issues that are relevant to that stage. The four stages are:

1. Forest Resource management, forest harvesting, and forest ecosystem evaluation.
2. Processing of resources into products and building components.
3. Design and construction of structural shells and completed buildings.
4. Use, maintenance, remodeling, and disposal of buildings and other products.

Each stage of activity has different impacts on the environment as well as different economic consequences. Each is associated with the use of different forms of raw materials. Each produces different wastes and involves some degree of recycling. Given consistent standards, the measurement of any variable within any stage can be compared with other stages and cumulated from stage to stage to ascertain cumulative effects. The analysis of alternative products or process technologies and of resource management strategies will provide output comparisons of cost, environmental attribute measures, and economic impacts by focusing on a very specific functional end use and the inputs required through the several stages of processing. In turn, these will provide important environmental performance trade-off information when comparing between alternatives.

The project modules are organized into two phases. The Phase I effort covers the initial development of procedures for specific product and functional use examples. Ultimately, these procedures will be extended in Phase II to a full set of product alternatives and regionally-dependent uses. Each research module and cluster of modules also has been designed to produce important deliverables that impact strategic decisions at some stage of processing in some regional context. The Phase I deliverables will have policy and strategic value even without results from other modules. The analysis of results across all research modules provides for a comprehensive treatment of environmental-performance issues that are important at the national and global level. These issues include topics such as energy use, carbon sequestration, forest health, sustainability, waste and toxicity reduction, recycling, and conservation in use.

The Strategy Assessment Panel will focus on the integration of the results from the project modules and the analysis across all stages of processing including linkages for national and global consistency.

It is not envisioned that there will be any extensive research effort to determine the "societal value" of any environmental attribute, such as the monetary value of a ton of carbon sequestered. Nonetheless, by comparison across alternatives, the analyses will reveal marginal costs that contribute to marginal environmental changes and other economic impacts, with projections of future environmental performance. For example, the impact of a change in forest management to longer rotations on carbon sequestration can be projected over time as can the marginal cost of the change. These results can be developed for a specific region or, as more comprehensive regional coverage is developed, scaled to be representative of the U.S. and Canada and linked to international regions. The purpose of any analysis at a broader regional scale is not to imply that regional impacts become unimportant, but rather that results may vary across regions, and also that changes in one region will have impacts on other regions, the nation and the world.

Composite environmental indices based on a system of weights across attributes, which have been developed by others (and are inherently subjective), may be displayed as a part of the analysis for comparison purposes without any endorsement of the weighting system. Additional research on integrated environmental-performance indices may be proposed after more objective source data on individual environmental performance attributes has been developed.

IV. OBJECTIVES

Builders, scientists, economists, policy makers, manufacturers, and others need up-to-date information regarding the long-term environmental and economic consequences of choosing between alternative building materials, processing and construction technologies, and management methods in order to improve environmental performance. To facilitate valid comparisons, this research plan establishes standards for the consistent measurement and analysis of environmental and economic performance for a range of management, processing, material, and construction systems, using renewable and substitute resources, including recycled materials.

The overall research objective is to provide a quantitative analysis of environmental performance for current and prospective material flows for renewable and nonrenewable resources in residential and commercial construction. The analysis will delineate environmental and economic consequences for a range of management and technology alternatives and provide this information in a form that engineers, architects, business strategists, and policy makers can use to make informed decisions that impact environmental performance.

To achieve this objective, questions decision makers have regarding the economic and environmental performance of alternative materials are anticipated. Directing the analysis to answer these questions also determines the appropriateness of various alternatives associated with resource management, manufacturing processes, building materials, and building systems. While it is an important objective of the research plan to directly address these environmental questions, the primary objective is twofold:

- To develop the environmental-performance measurements associated with materials-use systems
- To develop analytical procedures for using these measurements, so that decision makers can make valid environmental-performance comparisons and identify those management and technologies that improve performance.

V. PERFORMANCE TO BE MEASURED: ENVIRONMENTAL AND ECONOMIC

The environmental-performance analysis will focus on the impacts of management and technology on environmental performance measures in six areas:

- Forest ecosystem and sustainability measures
- Efficiency of material use (in manufacturing, construction, and building performance)
- Energy efficiency
- Carbon sequestration
- Reduction in release of targeted (potentially toxic) chemicals
- Waste reduction

The economic-performance analysis will focus on two broad areas:

- Factors affecting the supply and demand of forest resources
- Financial impacts on producers/investors, job holders, and governments

Each performance measure is identified with a stage in the manufacturing process, from timber production to the manufacture of products, structures, and finally their use and disposal. They may also be identified with a production or consuming region, and accumulated across stages of processing to be representative of the performance for a geographic region or when aggregated across regions, the nation.

The specific environmental performance questions to be addressed are listed below and directed toward environmental-performance improvements in the six focus areas described above. Each different management or technology alternative examined will produce a set of environmental and economic performance measures. Direct comparison of these measures across management and technology alternatives produces performance tradeoffs that are important to the determination of how best to answer questions directed at cost effectively improving environmental performance. A more detailed discussion on the assessment of the performance impacts across alternatives in order to answer performance questions is provided in Section IX.

A. Environmental-Performance Measures and Questions:

Management and technology alternatives can be identified that will be responsive to questions about any specific environmental performance measure but there will also be potential unintended impacts on other performance measures.

The base scenario (current practice) and each of the individual alternatives also involves one or more stages of processing. Those management or technology alternatives that look most promising for each stage of processing will be identified and selected to demonstrate the potential impact for that stage of processing and any other that is also impacted.

To the degree that the base scenario is representative of expected (current) practice, the difference between the scenario of a selected alternative and the base scenario provides an estimate of the marginal change in one environmental-performance measure relative to the marginal change in any other.

1. **Forest Ecosystems:** What management and technology alternatives can improve, restore, and/or sustain forest structure diversity and habitat? What are the performance tradeoffs with other environmental and economic measures?

   Some alternatives that can be examined either individually or collectively include:

   - Landscape management treatments that produce high-quality wood, longer rotations, more debris, snags, and understory for enhanced forest diversity and habitat, without increasing fire danger.
   - Mixed management treatments that include commodity management, biodiversity management pathways for upland and riparian zones, set-asides and modified commodity management to enhance diversity with minimal economic loss.
   - High-yield biomass plantations (on abandoned crop land or displacing an agriculture crop).
   - More intensive management of conventional tree farms.
   - The implications of environmentally sensitive high cost harvesting systems like helicopter logging.

2. **Efficiency of Resource Use:** What management and technology alternatives can improve the efficiency of resource use? What are the performance tradeoffs with other environmental and economic measures?

   Some of the alternatives that can be examined either individually or collectively include:

   - State-of-the-art, cost-effective harvesting techniques and equipment designed for minimal environmental impacts and increased product recovery.
   - Revised grading standards that recognize changing resources, improved technologies and market opportunities.
   - Revised design methods and building codes that recognize changing materials, improved energy efficiency, and measures of safety.

- Processing techniques and equipment for enhancing the utilization of small trees resulting from thinning forest stands.
- Innovative manufacturing techniques for composite building materials.
- Innovative products and technologies for utilization of residuals and waste reduction.

3. **Energy Efficiency:** What management and technology alternatives can be employed to reduce energy consumption? What are the performance tradeoffs with other environmental and economic measures?

   Some of the alternatives that can be examined either individually or collectively include:

   - Longer rotations with more intensive forest management that produce both higher quality wood and increased yield per acre.
   - Increasing reliance on wood and biomass-derived composite products using fiber from plantations and agricultural operations.
   - Availability of higher-quality wood products to compare with alternative wood or non-wood products.
   - Increasing the forest land base to produce more wood products and biomass for energy.
   - Processing efficiency improvements such as boiler gasifier technology or power co-generation
   - Increased product and system durability.
   - Increased use of waste for energy production.

4. **Carbon Emission/Sequestration:** What management and technology alternatives can be employed to increase carbon sequestration? What are the performance tradeoffs with other environmental and economic measures?

   Some of the alternatives that can be examined either individually or collectively include:

   - Implications of longer or shorter forest rotation ages.
   - Expanded acreage of genetically superior, fast-growing tree plantations, or agricultural fiber crops.
   - Development and expanded use of highly durable wood products.
   - Development of processing technologies and new or redesigned products that reduce wood waste.
   - Recycling of wood.
   - Increased use of renewable wood energy sources.

5. **Reduction in Release of Targeted (potentially toxic) Chemicals:** What management and technology alternatives can be employed to reduce toxic residues? What are the performance tradeoffs with other environmental and economic measures?

   Some of the alternatives that can be examined either individually or collectively include:

   - Best management practices and harvesting techniques designed to reduce non-point source pollution.
   - Use of sludge for improving biological productivity of forested areas.
   - Processing techniques requiring less fuel and hazardous chemicals.
   - Materials and building techniques that neutralize or otherwise reduce human contact with toxic materials.
   - Materials and chemical disposal and recycling methods with near-zero toxic emissions.

6. **Waste Reduction:** What management and technology alternatives can be employed to reduce waste or disposal consequences ? What are the performance tradeoffs with other environmental and economic measures?

   Some of the alternatives that can be examined either individually or collectively include:

   - Management and harvesting techniques that optimize the separation of residual woody debris for wildlife and recovery of useable material.
   - Processing techniques that minimize on-site disposal of toxic residues.
   - Generic prefabricated building components resulting in less building-site waste.
   - Economic and institutional incentives for recycling wood materials from dismantled wooden structures.

B. Economic-Performance Measures and Questions:

Specific questions regarding economic performance will also be addressed. The questions will consider the impact on the ability of supply to meet expected demand, and the financial impacts on producers/investors, job seekers, and public finance. These economic measures will make it possible to characterize the cost of potential environmental improvements, who pays, and who benefits. Some of the pertinent questions include:

1. **Product Supply and Demand:** What management and technology alternatives can increase the ability to serve growing demand expectations? What are the performance tradeoffs with other environmental and economic measures?

   Some of the alternatives that can be examined either individually or collectively include:

   - Alternative materials and building systems that expand the effective supply of wood products.
   - Innovative combinations of alternative building materials attractive to environmentally-conscious consumers.

- Materials and building systems that are conducive to cost-effective remodeling and rehabilitation.

2. **Net Present Value on Invested Capital:** What management and technology alternatives can maintain attractive investment opportunities for producers/investors? What are the performance tradeoffs with other environmental and economic measures (e.g., the cost of environmental-performance improvement)?

   Some of the alternatives that can be examined either individually or collectively include:

   - High-yield silvicultural systems including intensive cultured biomass plantations.
   - State-of-the-art, capital-intensive, harvesting and processing methods, such as enhanced boiler/gasifier technology.
   - Innovative waste reduction and recycling processes.
   - Innovative engineered wood products, hybrid products and engineered systems.
   - Financial incentives to meet environmental goals.

3. **Jobs:** What management and technology alternatives contribute to rural jobs and job stability? What are the performance tradeoffs with other environmental and economic measures?

   Some of the alternatives that can be examined either individually or collectively include:

   - Labor-intensive and cost-effective forest management practices.
   - High-tech forestry and processing techniques requiring professionally-trained personnel earning competitive wages and salaries.
   - Modular fabrication and efficient shipping techniques that expand secondary manufacturing opportunities for workers in timber-dependent communities.
   - Increased technology transfer for value-added processing targeted especially at export markets through rural manufacturing center clusters (furniture, cabinets, re-manufacturing, pre-fabricated homes, etc.).

4. **Tax Revenues Less Expenditures:** Are government incentives or regulations effective? What management and technology alternatives contribute to better fiscal performance relative to other benefits achieved? What are the performance tradeoffs with other environmental and economic measures?

   Some of the alternatives that can be examined either individually or collectively include:

   - More intensive management of forest structures to serve both timber markets and biodiversity maintenance.
   - High-yield silvicultural systems.
   - Expanded secondary manufacturing in resource-dependent communities.
   - Innovative waste reduction and recycling processes.

VI. RESEARCH PLAN FOR DEVELOPING PERFORMANCE MEASUREMENTS

The research plan is designed to: (1) collect data on all life-cycle stages from planting and growing the wood raw material through the manufacturing of product, design and construction of buildings as well as activities associated with occupation, use and final disposal; (2) ensure that the data follows consistent definitions and collection procedures; and (3) develop analytical procedures that facilitate integration of results across the life-cycle for all stages of processing and to address environmental performance questions.

This section describes the plan for collecting the environmental performance measures using a modular approach for each stage of processing and geographical region. Section VII briefly describes each specific research module (a more detailed description is provided in Appendix B), and Section VIII describes the protocols and standards that need to be followed.

Overall Plan as Described by Research Modules: To simplify the enormous task of developing life-cycle information across several stages of processing for a large number of alternatives, 22 separate but interconnected research modules have been designed to complete the research plan over a six-year span (see Figure VI.1). The focus area of each research module is shown in the figure, along with its timeline, and an estimated budget. The outputs of each module are sequenced so that they serve the needs of other modules. As pertinent data is developed in each module, it becomes an input to the Integrated Modeling Module for the life-cycle analysis across stages of processing.

The sequencing of the modules was designed to ensure timely, useful outputs early in the research effort. One of the means to accomplish this was to break the research into phases for the critical modules. Most modules are programmed over a two-year period. An important feature of the module sequencing is that the research accomplished at the end of the first two years for the Phase I research offers a complete package of performance measures which can be compared to the 1976 CORRIM results and provides valuable life-cycle data in itself. The probable cost for each of the modules was estimated by comparison of the complexity of the task to similar efforts in Canada and Europe using available information from other sources that can be validated. The CORRIM II research focus is on synthesizing environmental-performance impacts for which some pioneering research has already been developed. Working relationships have been established during the development of the research plan that will provide access to environmental performance software and some secondary data to assist in life-cycle analysis. If a substantial amount of original research is required rather than the synthesis of existing studies and the gathering of primary data for wood processes, the cost estimates may be understated.

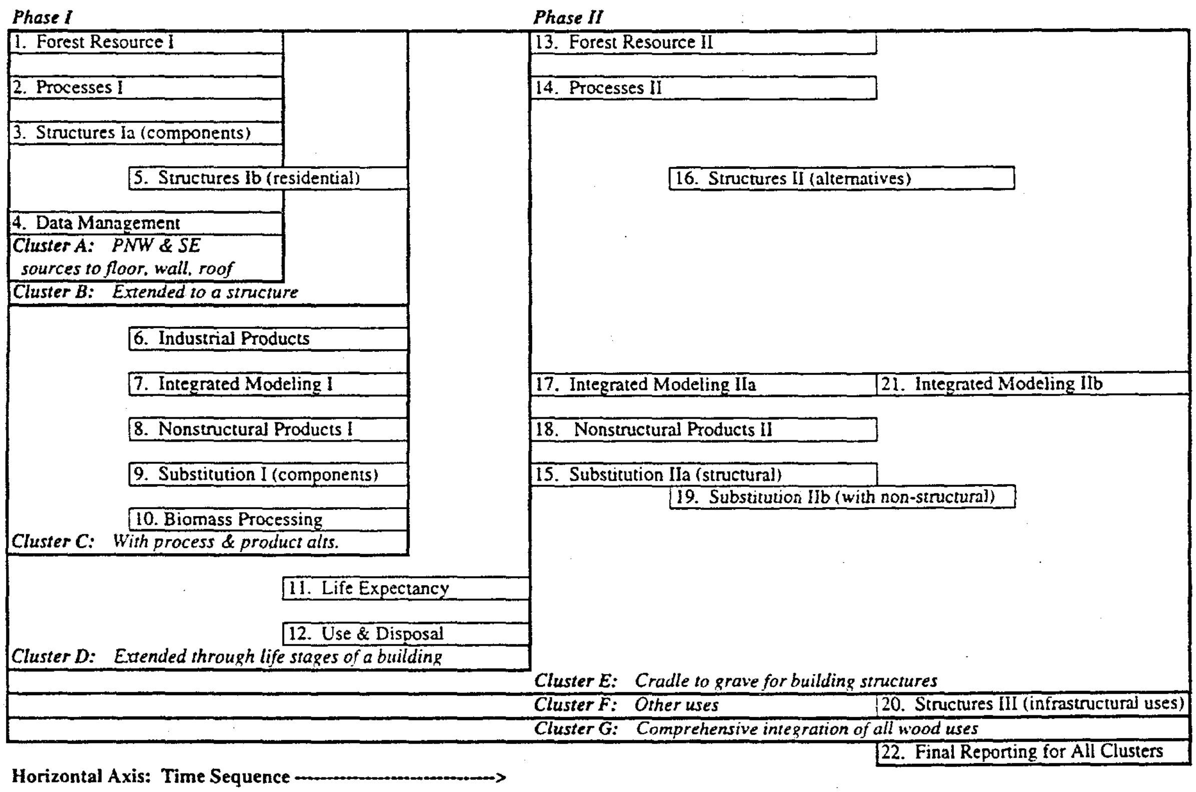
The Phase II modules are designed to extend the scope of the methodology developed in Phase I. Therefore, they directly follow Phase I completion. Specific clusters of modules broaden the analysis. For example, the Processes I module produces useful environmental-performance measures by itself, but with parallel outputs from the Resources I module, the completeness of environmental impact information is substantially improved. Infrastructure uses and non-structural interior products are covered last because they do not involve a complex integration with other structural alternatives but remain important to the understanding of the full impact of using renewable wood resources.

Figure VI.1 CORRIM Research Module Flow Chart ($ in thousands)

FOCUS AREAS	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Forest Resource	1. Forest Resource I Regional - NW/SE $400		13. Forest Resource II Regional - NE/NC/IW/Canada $400			
Manufacturing Processes	2. Processes I Structural Products $400		14. Processes II Nonstructural Products $600			
Structures	3. Structures Ia Component Systems $200		5. Structures Ib Complete Structures $200		16. Structures II Alternatives $200	
Data Management	4. Data Management (Funded as part of each module)					
Industrial Products		6. Industrial Products Treated/Untreaded $150			20. Structures III Infrastructures $150	
Integrated Modelling		7. Integrated Modeling $200		17& 21: Integrated Modeling II a&b $300		
Nonstructural Products		8. Nonstructural Products I Windows/doors/insulation etc. $200			18. Nonstructural Products II Millwork, flooring, etc. $200	
Products Substitution		9. Substitution I Components $200		15. Substitution IIa Comprehensive Structure $200		19. Subsitution IIb Nonstructural $100
Biomass	10. Biomass Processing for Energy $200					
Use, Disposal, Life Expectancy, Durability		11. Life Expectance/Durability $150		12. Use/Maintenace/Disposal/ Final Recycle $300		
Reporting		22. Reporting/Technology Transfer $250				
Total Funding Need	$5,000					

The grouping of modules into clusters designed to support the analysis of selected systems is illustrated in Figure VI.2. For example, Cluster A characterizes performance impacts from resources produced in the two main US producing regions through to their functional use in floor, wall, and roof building components. Cluster B extends the analysis to a completed structural building shell. Each cluster extends the analysis to include additional considerations with Cluster E providing an integrated analysis for building structures, and Cluster G integrating all wood uses including internal fixtures and infrastructure uses such as bridges and docks.

Figure VI.2 Research Modules
(with identified clusters of modules for systems analysis)



The final integration of modeling outputs will require development of linkages between CORRIM II outputs and existing economic models. Linking outputs to economic models provides a means to more completely characterize tradeoffs across regions and products including consistent measures for impacts that are exported to another region or to another substitute product.

While the 1976 CORRIM report encompassed research on material and energy balances in the manufacture and use of wood products that were either prevalent at that time or perceived imminent in the future, this research plan addresses a broader range of environmental factors that are now perceived to be important in addition to materials and energy use. A cradle-to-grave inventory analysis of environmental attributes from forest resources to the eventual recycling or disposal of products made from these resources will be developed for a range of potential technology and management alternatives.

The approach to be taken, much like the 1976 CORRIM report, is to focus on prevalent structural and non-structural materials used in the construction of residential housing and light commercial structures. To provide a comprehensive and comparative evaluation of the use of wood and hybrids or other materials, a number of structural components are identified for study, including floors, walls (exterior and interior), and roofs. Based on the data gathered on these structural components, the study will be expanded further to include an analysis of single-family residential structures, then multi-family, and light commercial or non-residential uses.

With the focus of this study on building materials and related use practices, the scope of the study will address key solid wood materials such as lumber, plywood, and composite panel and lumber products, but will not include a comprehensive study of paper manufacturing. Because of paper's heavy role in the resource flow of material, it will however, be considered as a co-product allocation, or by using secondary data if it becomes available.

Primary data will be used for wood processing into structural materials, while secondary data will be used for alternative materials such as steel, concrete, and plastic. For the processing stage the analysis will also include: (1) an analysis of machine centers within a process (e.g., the performance of machining, drying, blending, and hot pressing as elements of sheathing plywood process) and (2) the use of distribution or range values for the inputs and outputs. Thus, analysis of the selected processes will be done not only by product, e.g., sheathing plywood, but by machine center within a process as well.

Choosing the machine center approach has several benefits. First, it will save time and effort when analyzing other operations that have the same or similar machine center in their operation (e.g., veneer drying is part of both sheathing plywood and laminated veneer lumber processes). Second, information from a machine center will facilitate the analysis of new products and processes based on that machine center. Information gathered using this approach should prove useful in examining process modifications and determining the amount of reduction in environmental, energy, and resource impacts that may be realized through processing and product changes. The models developed should provide more effective analysis tools.

By using range values to proxy for the distribution of inputs and outputs, uncertainty can be characterized and results can be readily tested for sensitivity. Range values can also be identified with changing practices so that the ongoing adoption of best practices can be analyzed and the impacts projected.

The overall flow of the research is illustrated by the following modular design:

Research Modules for Phases I & II: (Phase I provides pilot testing of the data and analysis procedures with a focused coverage, and Phase II provides comprehensive coverage; Phase I also provides data for a progress comparison to the 1976 CORRIM report):

Phase I (focused coverage)	**Phase II** (comprehensive coverage)
Forest resources (PNW & SE)	Forest resources (other regions)
Processes/products (for components)	Processes/products (all)
Substitution (alternative products)	Substitution (range of products and structures)
Structural components (floor, wall, roof)	Structures (Res & non-res bldgs for different regions)
Use, recycle, and disposal (use & retrofits)	Nonstructural components
Biomass processing for energy	Strategy Assessments (alternatives: cost-benefit tradeoffs from cradle-to-grave)
Integrated Modeling (alternatives for cost-benefit and LCA from cradle-to-component)	

The Phase I research effort provides a complete package of life-cycle analysis for building materials along each stage of processing and for selected geographical regions. As a cluster of modules, the first four modules of Phase I (also identified as Cluster A, which includes the Forest Resource I, Processes I, Structures IA, and Data Management modules) provide the complete development of measurements and procedures and are prerequisite to most other research. The total cost of this cluster of modules is estimated at $1.0 million and could be accomplished within two years of project initiation.

Extending this research to include Integrated Modeling I, Substitution I (components), Structures Ib (completed structures), and Nonstructural Products I (doors, windows, cladding, insulation, etc.), extends the analysis procedures and performance measures to completed structures and substitute products. The total cost of this extension (Cluster B and C) is estimated at $950,000 and could be accomplished within three years of project initiation.

To study the environmental, energy, and resource impacts of construction, use, and recycling/ disposal of residential housing, the primary building components consisting of floors, walls, and roofs were selected for the initial Phase I research modules. A number of structural configurations will be selected for the Phase II modules based on regional practices and building codes to compare the impact of wood with other substitution materials on a use-specific basis.

The initial study will be directed to those materials commonly used in the construction of floors, walls, and roofs for residential and light commercial structures. The wood products selected for the Processes I module include a basic set of structural materials:

- Softwood lumber
- Softwood plywood
- Oriented strandboard (OSB)
- Laminated veneer lumber (LVL)
- Parallel strand lumber (PSL)
- Glulam or composite beams
- Trusses

A more complete list of products is included with the full description of each module in Appendix B.

To integrate the environmental analysis with the resource, the forest resource regions that are most likely to provide raw materials to the Processes I module were identified. The initial research on resources is identified as the Forest Resource I module and is limited to the two largest supply regions. A more comprehensive regional coverage of resource alternatives is included as the Forest Resource II module in order to evaluate the impacts for the remaining materials and their various sources.

The geographical regions to be studied in each of the resource modules are:

Research Module	Resource region studied
Forest Resource I	NW (U.S.) softwood; SE softwood and hardwood
Forest Resource II	NE/NC (U.S. & Canada) hardwood & softwood; Inland West (U.S. & Canada) softwood; NW (U.S. & Canada) softwood and hardwood

The Forest Resource module provides a critical response to environmental issues at a time when current policies are constraining management and harvesting practices. These constraints are occurring even though recent studies suggest that management alternatives exist that could improve both carbon storage and habitat, two of the current environmental pressures. Just as the mix of past management practices determined a current mix of environmental attributes such as merchantable inventory, carbon stored, forest structures, and habitat, analysis of management alternatives will allow projections of changes in environmental attributes, costs and economic impacts. By developing the Phase I Forest Resource module in parallel with the Phase I Processing module, the characteristics of the impacts from a range of alternatives will have been developed from the cradle (forest regeneration) to building system components (floors, walls, roofs).

Results from a cluster of modules (shown in figure VI.2) can provide a more complete view of environmental performance than is possible from a single module. The overall focus will be on examining changes to the environment, both positive and negative. While many life cycle analyses have focused only on negative impacts, e.g., emissions and solid waste, the technology and management changes to be analyzed may also increase carbon storage, reduce energy consumption, and offer other positive amenity values. The results of any one stage of processing could be negative but could be more than offset by positive attributes gained through management or technology alternatives from other stages of processing.

VII. INDIVIDUAL RESEARCH MODULE DESCRIPTIONS

The planned sequence of modules ensures that peer review of the procedures developed in the initial Phase I modules can be completed before extending the analyses to a comprehensive set of regions, products, and construction assemblies in a Phase II sequence. To lay out the objectives that are accomplished by each module and cluster of modules we present first a very brief description of each module (or group of modules). A more thorough research specification for each module including the Objective, Justification, Inputs, Outputs, Procedures, and a Brief Summary in the format of Agenda 2020 RFPs (requests for proposal) is provided in Appendix B. The modules are numbered by their approximate sequence for contributing to the analysis as shown also in Figure VI.1 and VI.2.

1. **Forest Resource I:** Considers all impacts from the growing and removal of biomass from the forest. This module will investigate the impact of various forest management and harvest alternatives (as case studies of current and proposed practices) on the production of timber, sustainability, energy use, emissions, carbon storage, habitat, biological diversity, and cost. The scope of the study will be from the planting of seedlings through the harvesting and transportation of timber. The first phase of the module will look at those regions producing the largest volumes of timber in the United States—the Northwest softwood and the Southeast softwood and hardwood regions. This first phase will be used to test and refine the CORRIM II protocol for measuring life-cycle impacts. A second phase of the research (module 13: Forest Resource II) will look at the remaining major timber producing regions.

2. **Processes I:** Examines the manufacture of structural building materials based on resources from Northwest softwood and Southeast softwood and hardwood regions. The assessment of these materials will be used as inputs to the Structures IA module which assesses structural units of floors, walls, and roofs composed of various building materials. This study considers those impacts associated with the manufacture of softwood lumber, softwood plywood, oriented strand board (OSB), laminated veneer lumber (LVL), parallel strand lumber (PSL), glulam beams, I-beams, and trusses. Primary data will be used for wood products processing for the structural materials, while secondary data will be used for comparisons to alternative materials such as steel, concrete, and plastic. The scope of the study will be all the inputs and outputs from the raw material's transport to the facility to a manufactured product ready for shipment. Several new analysis methods will be employed to enhance the value of the CORRIM II data. They are (1) analysis of machine centers within a process and (2) the use of distribution or range values for the inputs and outputs. This module provides benchmark data for these products (which will enable comparison across alternative processes), provides a comparison for energy and resource impacts for these products relative to the 1976 CORRIM study, and provides a measure of resource use efficiency.

3. **Structures IA:** Considers all impacts on constructing a residential or low-rise commercial structure. This first of two phases will examine the impacts of constructing floor, wall and roof assemblies from individual components of joists, trusses, studs, sheathing, and their combination (Structures IA). The second phase will examine the construction of structures that are comprised of floors, walls, roofs, windows, doors, roofing, and cladding (Structures Ib). The structures considered will be both site and factory built. The analysis will use those materials studied in Processes I module to construct the floors, walls, and roofs. Primary data will be used for the wood products whereas secondary data will be used for the non-wood alternatives. This module provides benchmark data for these assemblies which will enable comparison of alternative construction practices and materials. It also provides a comparison of energy and resource impacts with the findings in the 1976 CORRIM study as a measure of progress, and provides a measure of resource use efficiency.

4. **Data Management:** The database management module requires collaboration with all other research module teams to assure consistency and compatibility in the design of data collection procedures. Appropriate units of measure will be developed for data collection along with conversion factors for converting information gathered from various forestry and forest products sectors to a common basis. Access to appropriate data sets must be available to researchers without compromising proprietary data collection and amalgamation procedures. It is expected that existing data management software from other projects will be used and there will be no major focus on software development.

5. **Structures Ib:** Extends the characterization of a structure from floor, walls, and roof as developed in Structures IA to include nonstructural elements such as doors, windows, roofing and cladding to form a structural shell. The completed structures will use data developed for assemblies from Structures IA. The building will be designed to meet code for two cases -- warm and cold climate -- and will not include electrical and plumbing systems which are independent of wood use. Alternative structural components comprised of different material combinations, including, wood, steel, concrete, and plastic will be characterized by case studies.

6. **Industrial Products:** Evaluates the manufacturing processes of untreated and preservative or fire retardant treated wood used for industrial purposes. Untreated wood is used for items such as pallets, packing, and other industrial uses where resistance to biodeterioration is not a consideration. Treated wood consists of, but is not limited to, products such as sill plates, utility poles, piling, railroad ties, cooling towers and other products that are used in industrial applications. Processes I and II, and Forest Resource I modules will identify input values for the wood employed for these processes, and the Structures I and III modules will use the output of this module for their inputs. The treated products are primarily treated with creosote, pentachlorophenol, or one of the inorganic arsenicals—materials that have come under increasing scrutiny from the Environmental Protection Agency and whose use is tightly controlled to minimize potential risks during treatment and use. Industrial inputs related to the production of preservative components will be particularly important, but the possible inputs from waste mitigation strategies and other aspects of treatment mandated by Federal regulations will be addressed. Primary data will be used for assessing the impacts of production of treated and untreated industrial products, while secondary data will be used for alternative materials such as steel, concrete, and plastic. The data will be analyzed on a process basis for treated wood products rather than on an individual commodity basis. This approach should minimize duplication of data and assist in the identification of process changes that can reduce environmental, energy, and resource impacts.

7. **Integrated Modeling I:** Integrated modeling modules develop the linkages and synthesis among the various resource, product, structure, and use/disposal modules thereby providing the integration and analytic capability of consumption of materials and energy, associated environmental credits and debits, and benefit/cost analysis across the full life-cycle. Integrated Modeling I will focus on the linking and synthesis of the Forest Resource I, Processes I, Structures IA, and Biomass Processing for Energy modules to provide early deliverables comparing the products and component systems developed in these modules and developing results that can be compared to the original 1976 CORRIM study. Integrated

Modeling II will expand the analytic capabilities to include the other modules as they are completed. Since the research modules will be based on different resource and building construction regions, the integrative modeling will include the capability to examine inter-regional flows and tradeoffs.

8. **Nonstructural Products I:** Examines nonstructural products made from wood or wood-based composites used to enclose major openings and to finish exterior surfaces of residential structures. Materials studied include windows, doors, insulation, cladding, and roofing. All material types will be considered, including wood-based, metal, concrete and plastics. The assessment of these materials will be used as input values for the Structures I and Substitutes II modules. The study will use the outputs developed in the Processes I and II and Biomass Processing for Energy modules as raw material inputs to the manufacturing operation in this module.

9. **Substitution I:** Analyzes the use of hybrid or novel structural systems for single residential structures. The study, first examines the impacts of alternative floor, wall and roof assemblies, before consideration of case studies on completed residential structures that are comprised of floors, walls, roofs, doors, windows, roofing, and cladding in Phase II. A hybrid system is one in which multiple material or material-based systems are combined into a single structural system. The specific application of any given material is based on its positive and negative attributes, as well as those of the other materials in the system. Materials considered in addition to all wood materials studied in Structures I module include steel, aluminum, concrete, masonry, and plastics. The results of Structures I module will be used as a baseline for comparison. The study will look at evaluation of substitute materials and components for traditional wood-based products. An important aspect of this is the inclusion of life-safety and performance criteria in the life-cycle evaluation procedure. The results will be reported for each component and assembly type category discussed above. Regional categories may be introduced if such factors are deemed significant. A range of configurations will be examined by case studies.

10. **Biomass Processing for Energy:** Analyzes the impact of using biomass in its various forms either starting with the tree or as residue to generate energy for manufacturing of wood products or electricity. Some environmental-benefit/cost analyses will be made between biomass energy and alternative fossil fuel energy. The study will examine the input types of biomass (as well as their potential contaminants) and ancillary fuels to the outputs of energy in various forms including solid, liquid, or gaseous fuel, chemicals, emissions, and costs. Primary data will be used for biomass analysis, while secondary data will be used for fossil fuels analysis. Comparisons will be made among alternative processing technologies and methods of biomass energy procurement including conventional forest management operations, dedicated short rotation intensive silviculture for power plants, salvage operations, and waste stream alleviation. Extensions to the dedicated biomass for power studies developed for the Department of Energy (Mann and Spath 1997) will include consideration of extended rotations with joint energy and wood product outputs that may improve carbon sequestration. Best case scenarios for current biomass energy use, incremental gains, and potential for future technology applications will be provided. The scope of the analysis will be from the transport of the biomass to a facility to its exit as energy or feedstock.

11. **Life Expectancy and Durability:** Examines the life expectancy and durability of residential structures made from wood-based and non-wood-based resources. The focus of the study is to define life expectancy and durability and then categorize parameters, with output measures, that impact the life expectancy and durability of a structure. Durability influences structure life and therefore is a critical component in life-cycle analysis of the structure. The end result of this effort will be quantitative information on durability (longevity) that can be used as input variables by other modules. The life of product/structure will be studied at four levels of life service: the aesthetic life of a product, the service life of a product, the functional life of the structure (e.g., replacement due to a zoning change), and the structural life of a complete structure. The scope of the study will be from the inputs such as product type, product quality (grade), regional environmental influences, construction design/type/quality, maintenance schedules, aesthetic considerations of materials/structure, and structure use (how we inhabit/use the structure during its life) to the outputs in terms of component life, and structure life expectancy.

12. **Use, Maintenance, and Disposal:** Studies the use, maintenance, and disposal of materials incorporated into residential or light commercial structures. Final life costs are the last contributing factor in an overall life-cycle assessment of a structure, but must also include the intermediate costs associated with repair and remodel of the structure during its life. The focus of the study is to assess recycle options for the structure at intermediate repair and remodeling events, and the final life disposal costs for the structure including non-structural materials (cladding, roofing, siding, flooring, windows, doors). Environmental impacts between alternative structures designed to code for an identified functional use would not be different in terms of energy for the period covering operational use. However, the energy associated with operational use is sufficiently large relative to potential improvements that it will be included as a part of a base case. Energy used during operations will be different across different design codes which may provide important alternatives. The end result of the study module will be quantitative information on recycle and final disposal costs of the structure that can be used as input variables by other modules. Outputs from other modules will be necessary to complete the data analysis for this module, including Life Expectancy and Durability, and Structures I.

13. **Forest Resource II:** Extends Forest Resource I to cover all major timber producing regions in the U.S. and Canada.

14. **Processes II:** Analyzes the manufacture of non-structural building materials, taking into account regional differences in resources and processes. The assessment of these materials will be used as inputs to the Nonstructural modules that use these materials. This study considers those impacts associated with the manufacture of hardwood lumber, hardwood plywood, underlayment and industrial particleboard, medium density fiberboard (MDF), hardboard, insulation board, wood/plastic composites, and wood/cement composites. Primary data will be used for wood products processing for the nonstructural materials, while secondary data will be used for comparisons to alternative materials such as steel, concrete, and plastic. The scope of the study will cover all of the inputs and outputs from the raw material's transport to the facility through to a manufactured product ready for shipment.

15. **Substitution IIa:** Considers the impacts of the substitution for primary materials analyzed in the Processing I and II modules in both site and factory built residential or light commercial dwellings. This module looks at a number of substitutions as follows: wood-based materials for wood (e.g., an I-beam made with LVL and SSB substituting for a solid lumber beam); hybrid composites comprised of wood and other materials such as concrete, metal, and plastics for wood; and novel materials whether wood-based or non-wood-based for wood. The results of Processes I and II modules will be used as baselines for comparison. The module will be conducted in two phases with the first focused on the structural elements of a building and the second (Substitution IIb) on the nonstructural elements. The study will primarily focus on evaluation of substitute materials for traditional wood-based products. Regional categories may be introduced if such factors are deemed significant.

16. **Structures II:** Considers all impacts on constructing multi-family and light commercial structures. The analysis will use those materials studied in Processes I and Nonstructural Products I to determine the impacts of constructing these completed structures. The buildings will be built to code for two cases—warm and cold climates—and will not include electrical and plumbing hardware. Assemblies comprised of different material combinations including wood, steel, concrete, and plastic will be characterized by case studies. Primary data will be used for the wood products whereas secondary data will be used for the non-wood alternatives. This module provides benchmark data for a range of structures which will enable comparison of alternative construction practices and materials and provides a measure of resource use efficiency.

17. **Integrated Modeling IIa:** Expands the analytic capabilities to include the outputs from other modules as they are completed. Since the research modules will be based on different resource and building construction regions, the integrative modeling will include the capability to examine inter-regional flows and tradeoffs. As each cluster of modules is completed, integrated modeling provides the capability to cumulate impacts across stages of processing and regions.

18. **Nonstructural Products II:** Looks at nonstructural products made from wood or wood-based composites used in some fashion in residential structures. Materials to be studied include moulding, cabinets, countertops, stairways, etc. All material types and their combinations will be considered, including wood-based, metal, concrete, and plastics. The study will use the outputs developed in the Processes I and II and Biomass Processing for Energy modules as inputs to the manufacturing operation in this module.

19. **Substitution IIb:** This module extends the analysis capabilities for substitute products to include nonstructural elements such as non-wood windows, and cladding. The study will primarily focus on evaluation of substitute materials for traditional wood-based products. Regional categories may be introduced if such factors are deemed significant.

20. **Structures III:** Examines the applications of wood for other industrial uses including timber bridges and bridge components, marine facilities (i.e., docks, piers, etc.), pile foundations, utility poles, etc. These applications are similar to those in building systems; however, they typically involve larger timbers, more treated materials, and the direct

application of material components into a complete structure (versus the use of sub-assemblies in building systems). Additionally, in other industrial applications, there is less use of "non-structural" components. The structural materials considered are treated and untreated wood-based materials, both solid and composites. Some examples of such materials are lumber, glued laminated lumber, wood trusses, laminated veneer lumber, parallel strand lumber, and wood/synthetic composites. Based on available data, several typical (representative) designs will be analyzed in detail. Regional categories may be introduced if such factors are deemed significant.

21. **Integrated Model IIb:** Expands the integrated modeling capability to include all modules and the development of comprehensive environmental and economic tradeoffs across all uses of wood. It also considers links to international supply and substitute products for the development of those environmental-performance attributes for which a globally consistent estimate is particularly important such as energy use and carbon sequestration.

22. **Reporting for Integration of all Modules:** A project of this scope with many modular outputs requires an ongoing effort to repackage the cumulating results for ease of use by others. The technology transfer activities focus attention on developing reports and making presentations on the integrated results from the various analysis phases. A further repackaging of the material for various education groups is also needed. The activity will be aligned with the outputs of individual modules and clusters of modules and hence is composed of a number of ongoing milestones of developing environmental-performance analysis capabilities.

VIII. RESEARCH STANDARDS AND PROTOCOL

To assure that CORRIM II researchers working on different modules apply consistent definitions, data collection procedures, data formats, and analytic methods, the research plan provides a data, standards, and procedures "code of practice" user manual for life-cycle inventory and economic analysis (Appendix A to this report). This manual was developed in order to support consistency internally as well as with ongoing international research. It also provides guidance on the special requirements essential for understanding the environmental issues associated with renewable materials as contrasted with non-renewable materials.

The manual includes (1) procedural protocols for developing life-cycle inventories associated with forestry, wood products, and use/disposal of wood products; (2) important definitions and illustrative examples; and (3) references to standard, internationally-accepted LCI and LCA methods. For situations where alternative methods can be implemented, the manual characterizes each of the approaches without identifying which should be preferred. While researchers may decide on a specific alternative as the primary approach, other approaches may be used in sensitivity analysis. Each chapter of the manual contains definitions of terms, data collection procedures, and methods for LCI calculations. Chapters were developed in outline form with cross-referencing to other chapters and literature with the expectation that the content of the manual will be refined as part of the implementation plan. In this sense, the manual provides a working guide to methodology that will be continuously refined as part of ongoing research.

While LCI measurements provide a useful perspective on environmental impacts and have become an accepted standard in some international settings, they do not provide criteria useful in suggesting which of several technology or management alternatives is more attractive. A complete analysis must integrate the environmental differences among alternatives provided by the LCI with some form of traditional benefit/cost analysis. To this end, the manual describes procedures for the collection of economic data (costs, labor requirements, etc.) for processes within life-cycle stages.

Furthermore, CORRIM II must contend with the long-term dimension of forest growth and the duration of use of many products and structures. This time dimension feature must be treated to explicitly account for the fact that many environmental impacts associated with the life cycle occur at very different times and should not be simply aggregated. The time dimension also has implications for understanding the rate at which environmental changes associated with technology or management alternatives occur as well as implications for the relative costs of these alternatives. The manual provides a chapter on "Linking Life-Cycle Inventory and Benefit/Cost Analysis in Forest Products" where a conceptual accounting approach is introduced that allows an analyst to combine the tools of life-cycle inventory, epoch forecasting, and benefit/cost analysis to accommodate this time dimension issue and evaluate various scenarios using marginal costs and economic impacts associated with projected changes. This conceptual approach has not been necessary when analyzing products with short life-cycles but is essential for evaluating the environmental performance of biomass raw materials with long production periods and for long-lived products and structures. This approach will be fully evaluated and refined in the early projects that link resource management through assembled products.

Summary of Primary Protocols and Standards Developed in the Users Manual (Appendix A: Data, Standards, and Procedures: Guidelines for LCI and Economic Analysis)

The life cycle of wood products and wood-based systems begins with seed for growing trees and continues through consumer use of finished products or completed structures until discarded materials from deconstruction are recycled, reused, incinerated for energy, or returned to the earth.

The basic methodologies underlying CORRIM II research are the internationally accepted principles for conducting life-cycle inventories and life-cycle analyses, as set forth in ISO 14041 and 14040. CORRIM II will expand upon these basic life-cycle inventory principles by integrating them with data collected for standard economic benefit/cost analysis and an accounting method to treat the very long time frames that accompany the growth of forests and the use of wood products.

CORRIM II will develop an inventory of consumption of raw materials, energy, and water along with impacts on environmental performance over the entire life-cycle of products and structures made from wood, including gathering economic data on each of the life-cycle stages and processes.

In examining environmental performance, CORRIM II will study both potentially positive as well as negative effects on the environment. This is in contrast to many life-cycle studies which have only focused on the latter, commonly referred to as "environmental burdens." CORRIM II will examine the "environmental changes," both positive and negative, in order to provide a more balanced account of environmental credits and debits against each product, process or system. This balanced approach is a prerequisite for unbiased analyses and comparisons.

CORRIM II does not endorse any particular method to translate these objective inventory data into valuation-assessments of impacts. Many such methods are in use, any of which could be applied depending on the objectives of a specific study. CORRIM II research will provide the scientific information that may be used in these assessments and to support sensitivity analyses of conclusions to the various methods that may be applied.

CORRIM II will develop procedures for capturing geographic and temporal aspects of the life-cycle of wood systems to ensure that any perceived improvements in environmental performance are real and not simply the result of shifting environmental changes to other locations or other time periods. This will include developing linkages between regions of the U.S. as well as linkages to global considerations.

CORRIM II will use standard methods of benefit/cost analysis to display economic differences among alternative systems as well as their differences in consumption of resources and energy and other environmental-performance changes. This will provide a more comprehensive basis on which the tradeoffs among alternatives can be studied.

CORRIM II will utilize three levels of review. These include:

- Internal reviews by all CORRIM II technical panels of all research
- A review by the CORRIM II Steering Committee
- An independent peer review as deemed necessary by the CORRIM II Steering Committee

Specific CORRIM II Procedures Include:

- Maintaining thermodynamic balance on energy, which requires tracking the energy content of materials (e.g., wood, plastics, adhesives).
- Pre-combustion energy associated with energy resources will be included; this will be developed explicitly for fossil fuels and implicitly for wood and wood products.
- Transportation for each specific unit operation in the life-cycle will be examined. A unit operation is considered completed when the output is delivered to the next unit operation in the life-cycle sequence. In addition to identifying transportation for each unit operation, a mechanism will also be developed to track and aggregate transportation as a separate activity.
- Ancillary material within the boundary will be included if it constitutes 2% or more of the mass of inputs or if the aggregate group of ancillary materials constitutes more than 10% of the mass of inputs. Even if ancillary materials fail to be included by this mass-of-contribution criterion, they should be included if they are highly toxic, classed as hazardous waste, or have extraordinary effects on energy consumption, extraction, or disposal.
- Co-product allocation will be based on mass of contribution except when a strong case can be made that an alternative is preferable. Sensitivity analysis of alternative allocation methods is highly desirable. Where the value difference between co-products is large such as for near waste by-products, allocations may be based on relative monetary values.

- Age cohorts of forests and their structure classification will be quantified and their behavior forecast over time to provide a perspective on changes in ecosystem behavior. Because long time periods are involved in producing forests and using many wood products and structures, accounting linkages to conventional life-cycle inventory data will be developed (Appendix A, Chapter 8 outlines such an approach).
- Geographic differences in forest resources, industrial processes, and building design requirements will be captured by dividing the U.S. and Canada into regions for which data will be collected and analyzed. There will be additional regions to reflect import and export of major raw materials and products.
- An outline of data categories that will be collected is contained in Table VIII.1.
- Results and calculations will be expressed in SI units, the International System (Systeme International d'Unites) that is the modern metric system of measures that received global recognition at the 11th International Conference on Weights and Measures in 1960. Capabilities for expressing information in other units and standard industrial conventions will be developed.

TABLE VIII.1A: Data Categories

A. Inputs

Category	Example
Primary Materials	-trees and logs (species & grade) -lumber, plywood, and other products (species and grade) -subassemblies (floor, wall, roof, etc.) -metallic minerals (iron ore, etc.) -non-metallic minerals (sand, gravel, gypsum, etc.) -fossil fuels used in plastics, fertilizers, adhesives
Ancillary Materials	-metal fasteners -adhesives -finishes -fertilizers -forest chemicals -other
Energy	-electricity (hydro, thermal, nuclear, other) -natural gas (incl. LPG) -coal -refined petroleum -wood (hog fuel, spent pulping liquor, wood wastes) -other
Environmental	-carbon dioxide uptake in photosynthesis -water (surface, ground, other) -soil nutrients -other
Economic	-employment -costs (labor, energy, materials) -other

TABLE VIII.1B: Data Categories

B. Outputs

Category	Example
Products finished intermediate	-logs -lumber -veneer -panels (plywood, OSB, etc.) -engineered products (glulams, composite beams, LVL, etc.) -millwork (windows, doors, etc.) -assemblies (floors, walls, roofs, etc.)
Co-Products	-pulp chips -other
Energy	-electricity -other
Environmental	
air	-carbon dioxide, carbon monoxide, methane (from both biomass and non-biomass sources) -sulfur oxides -nitrogen oxides -volatile organic compounds -particulates and fumes
water	-biochemical oxygen demand -suspended solids -dissolved solids -pH -polynuclear aromatic hydrocarbons -other
land	-land use -solid waste (extraction, primary processing, secondary processing, construction, post-consumer) -forest structure, habitat classification -other
Economic	-prices -costs (solid waste disposal) -other

IX. ASSESSMENT OF ENVIRONMENTAL AND ECONOMIC IMPACTS FOR MANAGEMENT AND TECHNOLOGY ALTERNATIVES

Environmental and Economic-Performance Tradeoffs: The research effort within each module will produce measures of economic and environmental performance for alternative management and technologies. These impacts will be cataloged over time for representative geographic regions. With some degree of spatial and temporal aggregation they will also be displayed in performance tradeoff matrices showing environmental and economic consequences for alternative management and technologies at each stage of processing and for a system-wide combination of alternatives.

For example, the impact-analysis tradeoff matrix (Table IX.1) provides a *hypothetical* outline of the various kinds of analyses involved in comparing these environmental and economic performances.

Entries in the table show the hypothetical change in performance from a baseline specification for management and technology to various alternatives at each stage of processing and for various combinations across all stages of processing. One table will be constructed with the actual performance measurements and another using a comparative summary scale of low impacts to high impacts as a method of focusing on the most significant changes. The vertical axis of the table provides examples of management and technology alternatives, e.g.,

- Alternative scenarios for the resource stage
  - (1) a "long rotation"
  - (2) biomass plantations from marginal agricultural land
- Alternative scenarios for the product/processing stage
  - (3) product set *A*
  - (4) product set *B*
- Alternative scenarios for the structures stage
  - (5) structure *A*
  - (6) structure *B*
- Alternative scenarios for the use and disposal stage
  - (7) A: more durable system
  - (8) B: different waste collection
- System wide combinations of these alternatives across all stages such as (1), (4), (5), & (7) vs. (2), (4), (6), & (8).

The scope reflects a range of management and technology alternatives for improving the environmental and economic performance of alternative materials. The cell entries on the horizontal axis (e.g., "0" for no change, from "+" to "+++" for a low to high improvement, and "-" to "---" for a small to large loss in performance) indicate how the performance of a particular combination of management and technology compares with the current or baseline situation. Cross cell comparisons can also be made with other alternatives.

Table IX.1: Impact-Analysis Tradeoff Matrix (specific to geographic and temporal definitions)

Module And Scenario	Attributes of Environmental Performance						Attributes of Economic Performance			
	Forest Ecosystem	Efficiency of Use	Energy Eff.	Carbon Seq.	Toxicity Reduction	Waste Reduction	Product Supply	NPV to Investor	Jobs-rural	Public Finance
Resource										
1. Long rotation	+++	0	+++	+++	++	0	+	---	++	++
2. Biomass plantations	--	0	+	++	0	0	+	0	+	+
Product/ Processes			(+ or -	entries	are	examples	only)			
3. Product Set *A*	etc.	etc.								
4. Product Set *B*										
Structures										
5. Structure *A*										
6. Structure *B*										
Use & Disposal										
7. A										
8. B										
Best Combinations										
1+4+5+7										
2+4+6+8										

In this hypothetical example for Resources, the scenario 1 "Long rotation" management would significantly increase forest diversity, reduce fuel consumption and increase the carbon stored in products and in the forest, but with a substantial loss in the landowners' net present value (NPV). Scenario 2 indicates that increased acres in biomass plantations may reduce forest diversity somewhat while contributing some energy savings, and even more carbon sequestration given a larger forest land base. Ultimately the research will develop performance measures and normalizations to facilitate comparisons for these example scenarios and many more. Some scenarios will reflect the impact of strategy changes in management and technology applications independent of cost or policy issues and therefore can be tailored to have a significant impact on the environmental performance of a particular stage of processing. Others will be designed to reflect the likely responses to proposed policy changes and, as a consequence, may need to characterize responses across all stages of processing.

Tasks for developing performance assessments as tradeoffs: The tasks required to develop the entries in the tradeoff matrix are:

For Each Stage of Processing Research Module:

1. Define appropriate units of measure. Objective measures of economic performance are usually self-evident – "value per unit volume" of product supplied, return on investment, and number of jobs. Some measures of environmental performance are likewise self-evident, e.g., tons of carbon and joules of electrical energy. However, measures of forest diversity and toxicity reduction may be less universal and to some degree specific to a given region. Definitions will need to account for this.

2. Establish the linkages between changes in management or technology and environmental and economic-performance measures.
3. Describe a baseline scenario that conforms to current performance expectations (for each stage of processing and region).
4. Conduct sensitivity analyses to determine the most important alternatives for each performance area. Select those alternatives that produce the best performance for each environmental-performance area, i.e., those with the least negative impact.
5. Select alternatives that will be effective for multiple objectives to the degree possible (in order to reduce the number of alternatives that need to be considered).
6. Display the economic and environmental-performance impacts by stage of processing and as tradeoffs for each alternative (specific to a geographic region and time-dimension definition).
7. Evaluate important tradeoffs in terms of marginal benefits and costs via the tradeoff matrices and relative rankings.

For Each Cluster of Processing Stages and Regions:

8. Provide these same impacts accumulated across stages of processing and specific regions.
9. Evaluate important tradeoffs in terms of marginal benefits and costs integrated across selected stages of processing and regions.

The linkages between changes in management or technology and environmental and economic-performance measures implies the development and use of models to characterize the linkages in order to maintain consistency. Several LCA software tools and assessment models are available or in the process of development and can simplify the task of representing information on renewable wood resources.

Software Tools: Meake, Daves, and Vigon (1996) identified 37 software tools and performed evaluations on 14. The others were not available for review because they were under development, proprietary, or in a foreign language. They selected five for an in-depth evaluation which tended to focus on hardware requirements, input requirements, data management capabilities, types of analyses, and output formats. Relatively little evaluation focused on critical analysis of specific methods and assumptions embedded within the software packages. Curran, et al., (1996) provides practical applications involving life-cycle assessments, including a discussion of software systems and databases. Additional software has become available recently and more can be expected making a comprehensive review of specific software capabilities an important element of the Phase I research modules rather than a part of the general research plan protocol.

Most of the computational models appear to extract point-estimate values (usually referred to as "industry averages") from their data bases and perform all subsequent inventory calculations in a purely deterministic fashion. The results are point-estimates which are commonly compared among alternative systems where differences are highlighted. This approach of relying on point-estimates and deterministic calculations may produce misleading conclusions since variation that is inherent within and between similar processes, products and functions is largely ignored. Many "differences" that may appear to be important may, in fact, be unproved from a statistical perspective if the variation were also acknowledged in the calculations.

This problem can occur even if the data are well-described from a statistical point of view (distribution form, mean, mode, standard deviation, range, etc.) in the database. Most models rely on simple engineering calculations where they extract point estimates for each variable from the database, and ignore variation from that point onward. Some of the software tools do define data quality fields to provide guidance where uncertainty may be large and sensitivity analysis more important. Most do not treat uncertainty as part of the calculation process but instead appear to rely on the analysts choice for functions that are examined by sensitivity analysis and their judgment on the range for changes to be considered.

The CORRIM research must include a thorough review of this issue and develop database and modeling methods where variability can be explicitly treated and implications on results and comparisons understood. The need for analyzing the impact of uncertainty in data sources can be reduced by first using sensitivity analysis to identify the areas were the impacts are large enough to warrant a more thorough treatment.

As another consideration, several non-US modeling efforts have focused on building products, and have accumulated substantial data comparing wood products and other materials, such as the ATHENA™ Institute in Canada (FORINTEK and Trusty 1997). It is anticipated that their data bases can be customized with primary data gathered by CORRIM II from US operations, such that comparisons can then be made directly with their analysis of other competing products and building systems.

Global Trade and Product Substitution Linkages: Changes in management, or technology (including the consequences of policy changes, e.g., taxes, tariffs, or trade barriers impacting environmental goals) may affect product prices, trade flows, harvest levels, etc. The inference that product consumption responds by simply changing an equivalent amount is not valid. For example, a reduction in harvest level in one region will be accompanied by trade flow adjustments and increases in international harvests that must be considered for a consistent environmental performance analysis at the global level. Consistent global performance impacts can be provided by linking the CORRIM results for U.S. and Canada to international forest sector models. Changes in product flows at the U.S. and Canada boundary become input parameters to determine an international response including product trade flow adjustments. These changes in international flows are linked to environmental performance impacts in other countries to avoid the problem of understated impacts as a consequence of exporting the problem. For example, the CINTRAFOR Global Trade Model has been used for carbon mitigation and climate change scenario analyses under contract with EPA and the USFS (Perez-Garcia 1994).

Many of these linkages can be established by using existing models, i.e., the key economic model components such as harvest levels and product flows can be linked to international trade models for trade flow adjustments and product substitution. As a consequence there is a U.S. performance impact and a global or international region impact, the combination providing a consistent analysis at the global level.

Similar to trade flow adjustments there may be substitution by non-wood products which requires a spread sheet linkage to the impact of the substitute product. The substitution can be in response to wood product volume changes or price changes that induce substitution. Substitution models are currently not as well developed as global forest sector trade models but studies are underway that should provide the methodology to determine how much of any supply change will be compensated by non-wood substitution, by general conservation, or by international supply changes. Impact displays for the U.S. and Canada will be extended to include international impacts (import/export accounts) and substitution impacts (import/export to other than wood accounts).

These international trade and product substitution linkages become a part of the Integrated Linkage Modeling Modules with the parameters being derived from Global Trade Models and product substitution analyses.

X. MANAGEMENT OF RESEARCH

An important component of both developing and implementing the research plan is the identification and organization of expertise to work on and review each research module. Developing this organizational structure was identified as Task 1 in the DOE Cooperative Agreement. To facilitate and manage such a complex research endeavor, CORRIM II member research institutions each provided a representative to a voting Board of Directors. Supporting companies provided additional non-voting representatives to facilitate information flow and review by experienced practitioners. The Board elected officers to carry out operational needs.

To guide technical efforts, the Board formed a Technical Steering Committee made up of the Board plus selected independent experts representing government agencies and research laboratories, environmental interests, professional architects, and other materials experts. The Steering Committee became the principal technical adviser and reviewer of the research plan and research findings. The Board selected panel chairs to manage groups of technical experts and assisted the chairs in identifying the expertise needed to serve on those panels. While the Steering Committee and panels provide the primary forum for ongoing review, the Steering Committee also identified a group of independent outside reviewers to assess the objectivity and adequacy of completed research activities. Figure X.1 characterizes the CORRIM II organization including its technical panels, committees, and review groups. Appendix C provides a list of CORRIM members, Steering Committee members, panel chairs, and panel and technical committee members and candidates, while noting those who provided active review in the development of this research plan.

Task 1.1: Panel/Sub-Panel Formation - The Board identified three primary panels and a number of supporting Technical Advisory Committees (TACs) to assist the panels. The three primary panels are (1) Data, Standards, and Procedures, (2) Stages of Processing, and (3) Strategy Assessment. The Stages of Processing Panel was subdivided into four TACs: (1) Resources, (2) Processing, (3) Structures, and (4) Use and Disposal. Each of these committees covers the disposal/recycling impacts appropriate for that stage. The Data, Standards, and Procedures Panel includes expertise covering (1) measurements, (2) economic analysis, (3) environmental impacts, (4) global linkages, and (5) other material issues such that its members can operate as ad hoc subcommittees in these areas when needed.

Task 1.2: Service Agreements - CORRIM II developed service agreements with its member institutions for support needs. The institutions designate principal investigators for their support on the panels. For support from other individuals, direct support contracts are arranged.

Task 2: Data, Standards, and Procedures Panel - The Board selected a chair and assisted in identifying members of the panel. The Panel reviewed available information from many sources and developed a user manual titled: "Data, Standards, and Procedures: Guidelines for LCI and Economic Analysis" which is included as Appendix A.

Task 3: Stages of Processing Research Module Design - The Stages of Processing Panel chair was selected by the Board while also providing assistance in selecting chairs for the four TACs and their members. The Panel and its committees identified a sequence of research modules that essentially subdivides the research effort by stage of processing, region, and Phase I vs. Phase II levels of comprehensiveness. A description of each module is included as Appendix B.

Task 4: Integration of Processing Research Modules and Data Management - The Steering committee provides the final review on the integration of the research modules. The Panel and TAC chairs make up the executive group to implement the integration across research modules. The Strategy Assessment Panel has identified the key questions on the environment that can be addressed and the framework for tradeoff analysis; it also oversees the integration modeling activities that are largely focused on the analysis of alternatives for strategy assessment. The integrated modeling activities are further modularized by identifying clusters of modules that serve a set of intermediate stage of processing or regional objectives and performance tradeoffs, leading up to a comprehensive set of environmental and economic-performance tradeoffs. A description of the focus for each cluster of modules and the integrated modeling tasks are contained in Appendix B.

Task 5: Reporting/Project Management Plan - CORRIM II utilized its Board of member research institutions to set policy, allocate budget, and organize the technical panels and committees. An Executive Director for the Board facilitates meetings, service contracts, budget tracking and other operational needs (the President acted as the Executive Director for the development of the research Plan). Conference calls were used in lieu of in-person meetings for budget and policy decision approval. Research tasks were allocated to each panel. A PERT diagram for the overall research plan (simplified version shown in Figure X.2) shows the linkage of modules early in the sequence to serve those later in the sequence. Modules have both intermediate first year output requirements and final output requirements to serve the needs of other modules. An outline for the final reports anticipated from the research project is included as Appendix D. Quarterly project reports were provided during the development of the research plan and an interim mid-term report on the full scope of the research plan development was provided in February 1997.

Figure X.1: CORRIM Organization Chart

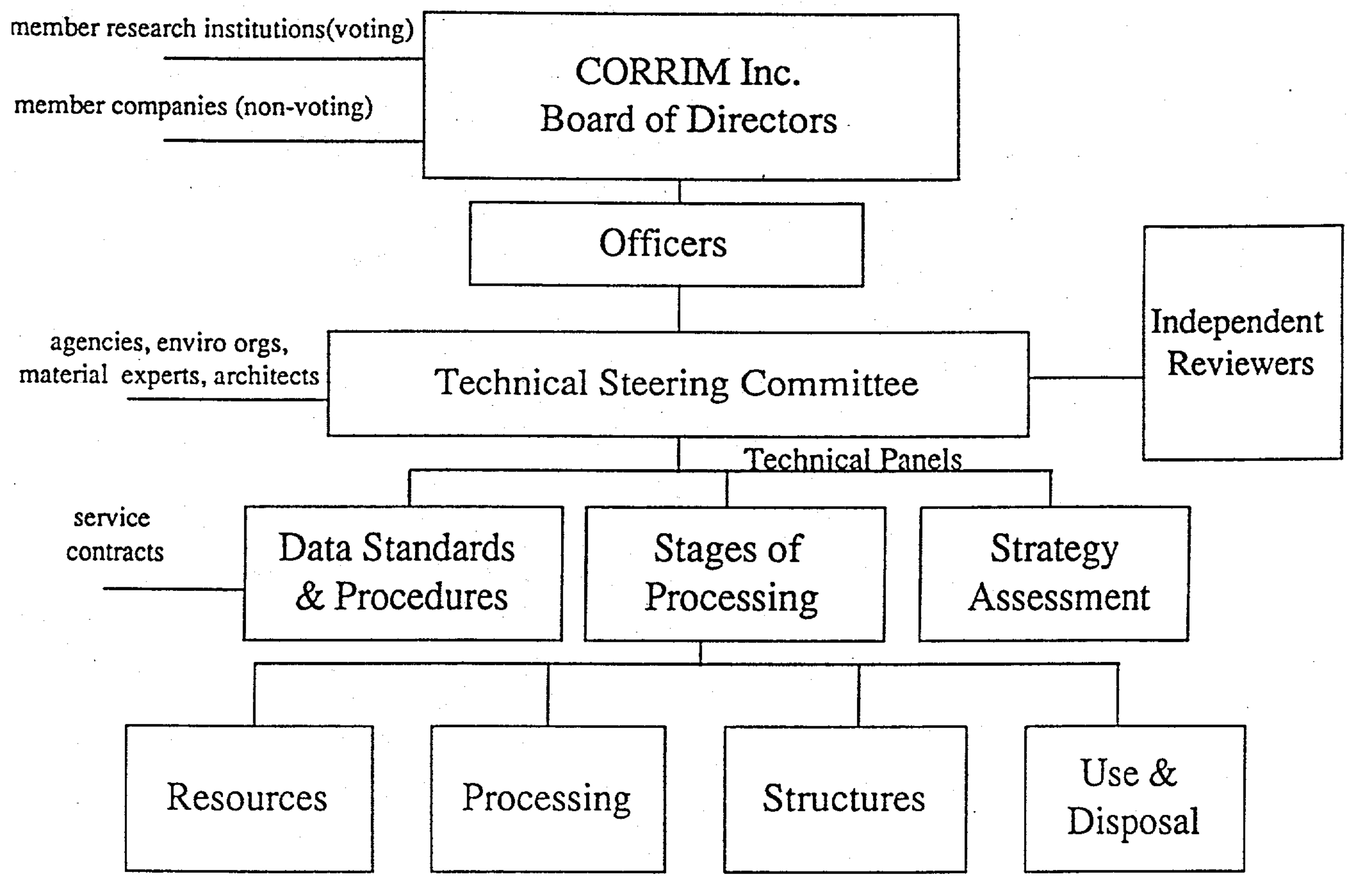
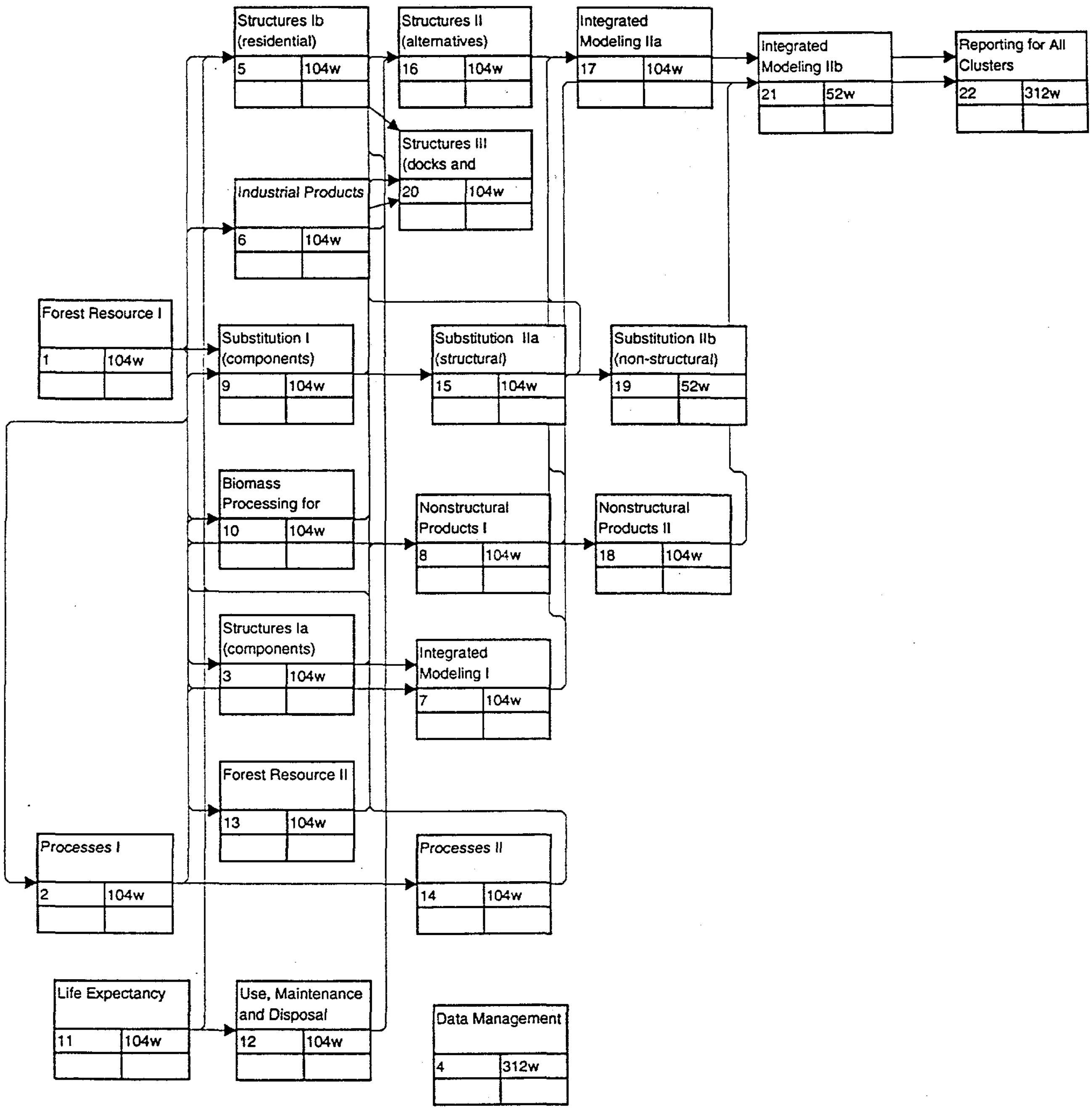


Figure X.2: Module PERT Chart



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APPENDIX A

Environmental Performance of Wood Systems

Data, Standards, and Procedures: Guidelines for LCI and Economic Analysis

Consortium for Research on Renewable Industrial Materials (CORRIM, Inc.)

CORRIM II Panel on Data, Standards and Procedures

David Briggs, Panel Chair, University of Washington

John Zerbe, Panel Vice-Chair, Consultant, U.S. Forest Products Laboratory
Jim Bowyer, University of Minnesota
Leonard Johnson, University of Idaho
Pat Layton, AF&PA
Bruce Lippke, University of Washington
Jamie Meil, JKM Associates, FORINTEK, Canada
Reid Miner, NCASI
John Perez-Garcia, University of Washington
Jim Wilson, Oregon State University

Use of this Guideline Document

This guideline was written with two primary objectives:

- to provide a common framework for use by the members of the Consortium for Research on Renewable Industrial Materials (CORRIM, Inc.) and others in their research.
- to provide a description of CORRIM II's methods to technical reviewers and interested users.

This guideline was written for studies undertaken with the main purpose of identifying and assessing environmental performance of wood or substitute materials used in construction or other applications. It provides procedural guidance in using established life-cycle and economic methods consistently for both analysis and presentation of results and is presented in a format that allows it to be used both as a checklist in conducting a study or presenting results, or performing a critical review and verifying that guidelines have been followed.

This guideline summarizes and references applicable procedures and methods regarding life cycle inventory. It does not delve into detailed mathematics nor specify which of possible alternative methods should be applied, nor prescribe the final list of data categories that must be measured. The decisions on which alternative method is preferred and which data categories should be measured will be made during the initiation of CORRIM II research. This document provides background and suggestions and is intended to aid researchers in reaching decisions during the initiation phase of actual research. In fact, CORRIM II researchers may deliberately choose to use all alternative methods as part of exploring the sensitivity of results to assumptions and methods.

Chapter 1 presents a brief overview of CORRIM II. Chapter 2 introduces the life-cycle concept and develops an overview of the structure and procedures of life-cycle assessment. Chapters 3-5 present details of planning a life-cycle study and conducting an inventory and Chapter 6 discusses aspects of modeling. Chapter 7 has a special focus on energy and Chapter 8 presents an approach for integrating life-cycle inventory with economics in the special situation of long time periods over which a life cycle for forestry and wood products often plays out.

Definitions of many terms used in this document are provided in the Glossary. (Terms bolded within the text can be found in the Glossary.)

Summary of Protocol Recommendations

The mission of CORRIM II research is to develop a scientific base of information on the environmental performance of wood-based products and to identify forest management, product, and process changes that can improve wood use and energy efficiency, increase carbon sequestration, reduce generation of wastes and potentially toxic materials, and sustain healthy forest ecosystems.

The life cycle of wood products and wood based systems begins with seed for growing trees and continues through consumer use of finished products or completed structures until discarded materials from deconstruction are recycled, reused, incinerated for energy, or returned to the earth.

The basic methodologies underlying CORRIM II research are the internationally accepted principles for conducting life-cycle analyses and life-cycle inventories, as are set forth in ISO 14040 (see Appendix I) and ISO 14041. CORRIM II will expand upon these basic life-cycle inventory principles by integrating them with data collected for standard economic benefit/cost analysis and an accounting method to treat the very long time frames that often accompany the growth of forests and the use of wood products.

CORRIM II will develop inventories of consumption of raw materials, energy, and water, and of effluents, emissions, and wastes, and their impacts on environmental performance over the full life-cycle of products and structures made from wood. Economic data on each of the **life-cycle stages** and processes will be gathered.

In examining environmental performance, CORRIM II will study both potentially positive as well as negative effects on the environment. This is in contrast to many life-cycle studies that have only focused on the latter, commonly referred to as "environmental burdens." CORRIM II will examine the "environmental changes," both positive and negative, to provide a more balanced account of environmental credits and debits against each product, **process** or system. This more balanced approach is a prerequisite for unbiased analyses and comparisons.

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CORRIM II will utilize three levels of review:

- Internal reviews of research by all CORRIM II panels
- Review by the CORRIM II Steering Committee
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Specific CORRIM II procedures include:

- Maintaining thermodynamic balances on energy which requires tracking the energy content of materials (e.g., wood, plastic, adhesive).
- An accounting of **pre-combustion energy** associated with energy resources; this will be developed explicitly for fossil fuels and implicitly for wood and wood products.
- Examination of transportation for each specific unit operation in the life cycle will be examined. A unit operation is considered completed when the output is delivered to the next unit operation in the life-cycle sequence. In addition to identifying transportation for each unit operation, a mechanism will also be developed to track and aggregate transportation as a separate activity.
- Inclusion of an ancillary material within the boundary if it constitutes 2% or more of the mass of inputs or if the aggregate group of ancillary materials constitutes more than 10% of the mass of inputs. Even if ancillary materials fail to be included by this mass-of-contribution criterion, they should be included if they are highly toxic, classed as hazardous waste, or have extraordinary effects on energy consumption, extraction, or disposal.
- **Co-product allocation** will be based on mass-of-contributions except when a strong case can be made that an alternative is preferable. Sensitivity analysis of alternative allocation methods is highly desirable. Where the value difference between co-products is large, such as for near waste by-products, allocations may be based on relative monetary values.
- Age cohorts of forests and their structural classifications will be quantified and their behavior forecast over time to provide a perspective on changes in ecosystem behavior. Similarly, age cohorts of buildings and their characteristics will be quantified and forecast over time. Because long time periods are involved in producing forests and using many wood products and structures, accounting linkages to conventional life-cycle inventory data will be developed. Chapter 8 outlines an approach.
- Capturing of geographic differences in forest resources, industrial processes, and building design requirements by dividing the U.S. and Canada into regions for which inventory data will be collected and analyzed. Additional regions will be identified to reflect import and export of major raw materials and products. An outline of data categories that will be collected is contained in Table 5.1.

- Reporting of all results and calculations in SI units, the international system (Systeme International d'Unites) of modern metric measures which was globally recognized at the Eleventh International Conference on Weights and Measures in 1960. Capabilities for expressing information in other units and standard industrial conventions will be developed.

Table of Contents

Chapter 1. Purpose and Organization of CORRIM II

In 1976, a landmark study (National Research Council 1976) of the energy and material use efficiency of wood and biomass products was completed by the Committee on Renewable Resources for Industrial Materials (CORRIM). This study has been widely quoted as the basis for many comparisons of the energy efficiency of products and assemblies based on wood and substitute materials. Unfortunately, the CORRIM study did not have a focus on environmental issues such as releases of pollutants by processes, **solid waste** produced by industry and consumers, **global warming**, etc. Furthermore, much of the information in the CORRIM II study has become obsolete as products and processes have changed and many new products have emerged. To remedy this, a group of academic institutions formed the non-profit Consortium on Renewable Resources for Industrial Materials (CORRIM, Inc.) The overall goal of this group is to develop an updated and expanded study which will be referred to throughout this document as CORRIM II.

1.1 CORRIM II Mission Statement

To develop a scientific base of information on the environmental performance of wood-based products and to identify forest management, product, and process changes to improve wood use and energy efficiency, increase carbon sequestration, reduce generation of wastes and potentially toxic materials, and sustain healthy forest ecosystems.

Accomplishing this will require

- A consistent database for evaluating the environmental performance of alternative wood and non-wood materials from the regeneration or forest resources or mineral extraction to end use and disposal, i.e., from "cradle to grave."
- A framework for evaluating life-cycle environmental and economic impacts for alternative building materials in competing or complementary applications.
- Source data for many users, including resource managers and product manufacturers, architects and engineers, environmental protection and energy conservation analysts, and global environmental policy and trade specialists.
- An organizational framework to obtain the best scientific information available as well as provide for effective and constructive peer review

1.2 CORRIM II Research Organization

In order to plan and conduct research, the Board of Directors of CORRIM, Inc., composed of consortium members, has formed three panels of scientists:

- Data, Standards and Procedures Panel
- Stages of Processing Panel
- Strategy Assessment Panel

The Board of Directors also formed a Steering Committee to provide technical guidance and a broad review, with perspectives from academia, industry, and other interested parties.

1.3 CORRIM II Objectives

The long-term objectives of CORRIM II are:

- To provide quantitative environmental-performance analyses of materials and associated energy flows and balances for a wide range of industrial material and construction **systems** using renewable and potential substitute resources, including recycled materials and incorporating life-cycle (cradle-to-grave) considerations.
- To supplement the above physical performance analyses with economic benefit/cost analyses to help guide assessments of trade-offs.
- To examine the inter-changeability of renewable resources and potential substitutes as the basis for materials use. Examine trends in substitution of materials and the properties and environmental performance of those substitutions. Examine implications of emerging, advanced composite materials as potential substitutes for more traditional materials.
- To assess technological alternatives and trends leading to improvements in the yield of **raw materials**, efficiency of processing, and **recycling**. Examine current and emerging technologies that will likely influence environmental performance in the future.
- To evaluate environmental characteristics and long-term sustainability issues associated with the use of resources, including assessments from both domestic and global perspectives.
- To identify legislation and regulations that influence the development and use of domestic renewable and non-renewable resources and evaluate the implications of public policies on the environment and economy with respect to raw materials from both domestic and global perspectives.

1.4 Scope of CORRIM II Research Plan

1.4.1 Technical System

CORRIM II will gather data on processes associated with production of the timber resource from seed to harvest; conversion of logs into products which are combined with **ancillary materials** into engineered subassemblies and finished structures; the consumption, occupancy and maintenance of finished structures; and the eventual dismantling of structures with recycling, incineration or other disposal of the components. Later research will focus on other wood products sectors (furniture, pallets and containers, etc.) and on other agricultural materials.

Supplementary data will be required on processes for materials such as adhesives, metal fasteners, and finishes that are either used in creating wood products (i.e. plywood, glulam beams, etc.) or are used in conjunction with wood products in forming assemblies and structures. Initially, CORRIM II will rely on external sources of information on these ancillary materials.

1.4.2 Geographic and Temporal Considerations

The most current data available will be collected for these materials, processes and products in the United States and Canada. Data for production elsewhere may be used if imports are a significant percentage of the commodity consumed in both countries. The United States and Canada will be further subdivided into resource supply regions and housing construction regions to reflect differences in forest resources and building code requirements.

Given the long time period involved in growing forests and the long useful life of many wood products and buildings, CORRIM II must integrate techniques from life-cycle inventory, forecasting, and economic analysis into a consistent and logical study framework.

1.4.3 Economics

In addition to developing a technical framework for assessing the current status of the forest-wood product system and forecasting how it may change through time, an understanding the interaction of the dynamics of this technical system with economic factors must be developed. The technical system operates in the context of local, national, and international economic forces hence CORRIM II must develop procedures that provide dynamic linkages between the technical and economic systems in order that changes, constraints, and strategies be properly understood and developed.

Chapter 2. Introduction to Life-Cycle-Assessment

2.1 Life-Cycle Concept

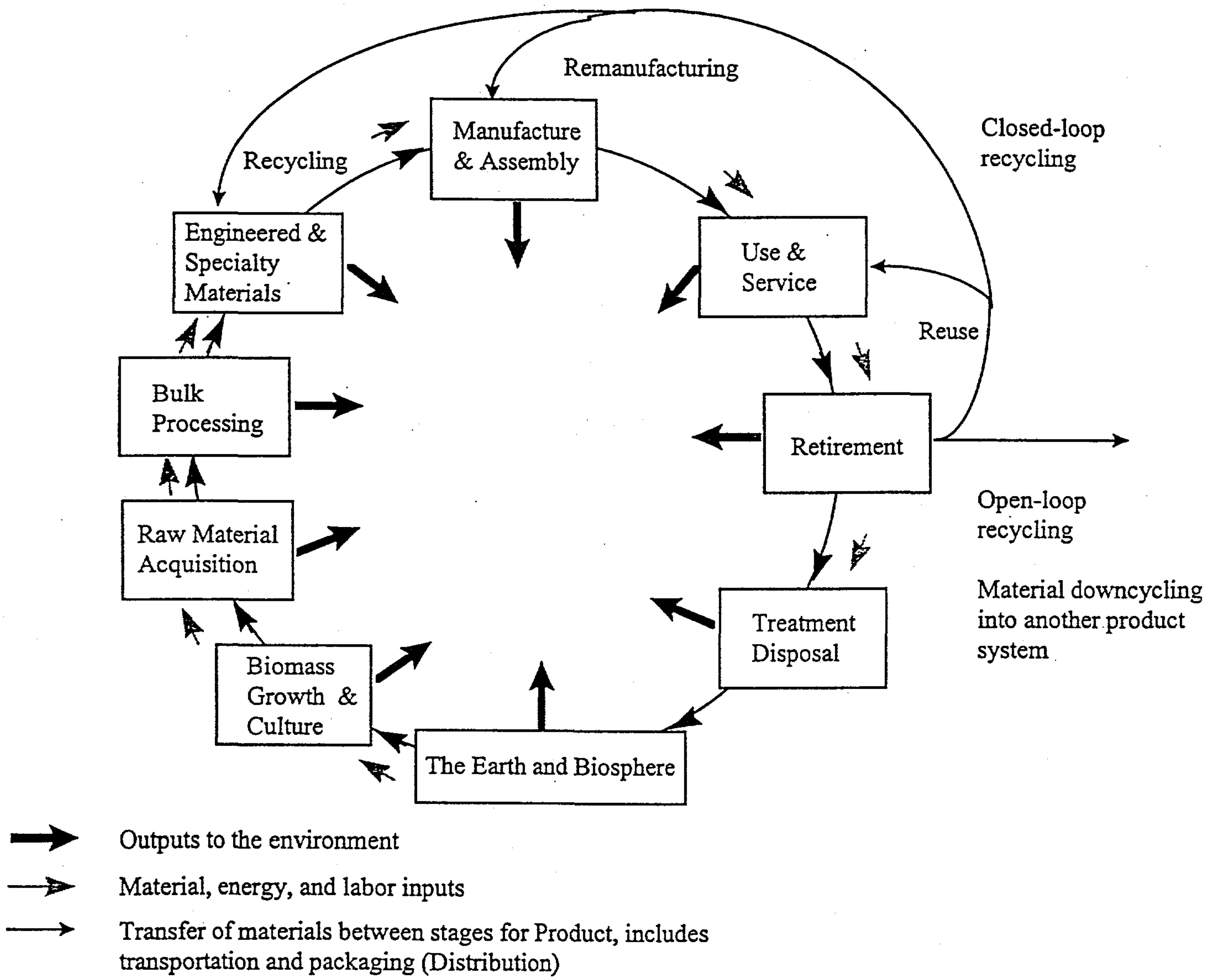
Improving energy and materials efficiency in the manufacture and use of products is an on-going activity of industry. Starting in the late 1960's, work also began on reducing **solid waste**, emissions to air, and discharges to water. This was driven by public concern with environmental degradation and has produced many forms of regulatory controls on **pollutants**. The oil crisis of the 1970's created further impetus in the use of methods for analyzing the energy efficiency of processes, products, and consumption activities. In many cases, energy use and pollution have been reduced, particularly readily visible, local "point source" pollution which has been handled through "end-of-pipe" solutions and regulations. However, despite these improvements, environmental problems continue and are growing in magnitude and complexity. Much of this is due to the fact that pollution sources are often diffuse and distributed over wide areas. Environmental protection is therefore an increasingly important strategic issue for industry and business in locating facilities and in managing the performance of their processes and products.

As product related environmental issues become more focused by public concern and market pressures, industry and society are beginning to move away from regulatory legislation to fix problems. In its place a broad holistic approach is emerging that leads to understanding of sources and causes of environmental problems and developing proactive strategies to prevent them. As a result, analysis of pollution problems is changing with regard to the major pathways of pollutants with increasing effort directed toward tracing the full spectrum of pollution generation from acquisition of raw materials, conversion to product, to consumer use, and to possible reuse and eventual disposal. This broadened life-cycle perspective seems necessary to understand the process by which pollution is created and to more effectively direct efforts toward reducing pollutants and combating environmental damage. Furthermore, since production of energy and consumption and disposal of products are major sources of pollutants, it is natural to extend the life-cycle concept to integrate energy use, raw material use, and consumption/disposal and pollution into a single theme (Figure 2-1).

The integrated approach has the advantage that one can, with a little extra accounting, follow pathways as raw materials, energy, products, and associated pollutants cross borders through international trade and occur at different points in time. This broadened perspective helps ensure that efforts aimed at resource conservation, energy efficiency, and pollution reduction are real and do not simply shift problems across borders or generations.

The life-cycle concept is becoming the basis for understanding, managing, and reducing environmental, health, and resource consumption aspects of processes, products, and product use. This concept has created a need for methods that provide information on environmental impacts of processes, products, and product use from the initial removal of resources from the earth to eventual disposal of products to the earth i.e. "cradle to grave." Life-cycle Assessment(LCA) has evolved as an important internationally recognized technique that is useful for these analyses.

Figure 2.1. Integrated Life-Cycle Concept



Source: Adapted from Keoleian and Menerey, 1993

2.2 Overview of Life-Cycle Assessment (LCA)

Definition of LCA: (ISO DIS 14040, 1996)

> *LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by*
>
> - *compiling an inventory of relevant inputs and outputs of a system*
> - *evaluating the potential environmental impacts associated with those inputs and outputs*
> - *interpreting the results of the inventory and impact phases in relation to the objectives of the study*

The history of LCA can be found in the general LCA literature with origins in the beverage industry in the late 1960's. Although intensive international efforts have been made to harmonize LCA methodology, details are still evolving and consensus is lacking in some aspects. LCA does, however, provide a general framework within which a set of alternative specific methods and approaches have been developed the choice among which depends on the purpose of a particular study.

LCA is primarily a technique for identifying and estimating the **environmental changes** and **impacts** caused by a product, **process** or activity. An LCA begins by defining the product, process, or activity to be studied; establishing the context in which the assessment is being made; identifying the life-cycle stages to be covered; quantifying materials, energy, and water use; and quantifying the environmental changes associated with each stage. LCA then evaluates specific and aggregate impacts of the environmental changes and aids in identifying opportunities for environmental improvements.

The LCA definition does not specify the type of aggregation to be used to summarize results, nor the level of geographic detail to be included, nor the time period for which the analysis is to be performed. These are defined by the purpose, scope and boundaries of the specific study. Similarly, the definition does not exclude economic and social considerations which may require integration with other techniques. Many past LCA studies have excluded these aspects and focused only on technical data. The actual conduct of an LCA study involves many decisions and assumptions which are partly dependent on the specific study objectives and partly dependent on generally accepted LCA principles and procedures that are discussed in subsequent sections of this guideline.

2.3 Applications of LCA

LCA is primarily conducted to provide information helpful in identifying opportunities and priorities for improving environmental performance. Examples of applications include:

- Examining the materials, processes, and systems associated with a specific product to
  - ⇒ identify its current resource use, energy use, and **environmental profile**.
  - ⇒ identify stages within the life-cycle where reduction of resources, energy, or emissions can be achieved and thereby focus further technical and economic analysis.
  - ⇒ evaluate how changes in resources or technology may affect resource use, energy use, and the environmental profile.
  - ⇒ identify aspects of the life-cycle that may be critical for long-term strategic planning.

- Comparing functionally equivalent alternative products or end-uses to
  - ⇒ identify where there are, and are not, significant differences
  - ⇒ benchmark against other manufacturer's products, industry averages, or best practices
  - ⇒ evaluate potential benefits of alternative materials and technologies

- Aiding in the design and development of new products, processes, or systems that reduce materials, energy, and emissions over the full life-cycle.

- Supplying information to decision makers, legislators, and agencies concerned with material use, resource conservation, pollution reduction, **waste management**, and monitoring requirements associated with processes and products.

- Informing and educating professionals and the general public regarding resource and energy use and emissions associated with the full life-cycle of products.

- Identifying gaps in information and knowledge and helping to establish research priorities.

- Helping to establish, evaluate, and substantiate statements regarding environmental labeling of products

This list of applications gradually changes from those that may primarily serve interests of the private sector to those of greater interest in the public sector. It illustrates the importance of clearly defining the objective(s) of a study and identifying the audience(s) to whom the results will be directed and how those results will be used.

2.4 LCA Structure and Terminology

2.4.1 General

A typical LCA is an iterative process consisting of four interrelated phases: goal definition and scoping (including establishment of boundaries), **inventory analysis**, **impact assessment**, and **improvement assessment** (Figure 2-2). LCA is a conceptual and technical framework or model for developing assessments of environmental performance. The model assists with establishing materials use, energy use, water use, and environmental changes associated with each stage of an industrial system. The model can also assist in collecting economic data on various life-cycle stages.

2.4.2 Goal Definition and Scoping

Goal definition and scoping, also called the initiation phase, is the process of problem definition, establishing objectives, defining study boundaries, and identifying data that will be needed and the quality required of that data. Goal definition and scoping are covered in more detail in Chapter 3.

Establishing boundary conditions for the study is critical since boundary definition interacts with establishing the purpose and scope of the study. During initiation, the product, process, or activity is defined for the context in which the study is being made. This connects the purpose of the assessment and the system(s) to be studied with the resources and time available for the analysis and outlines what will and will not be included.

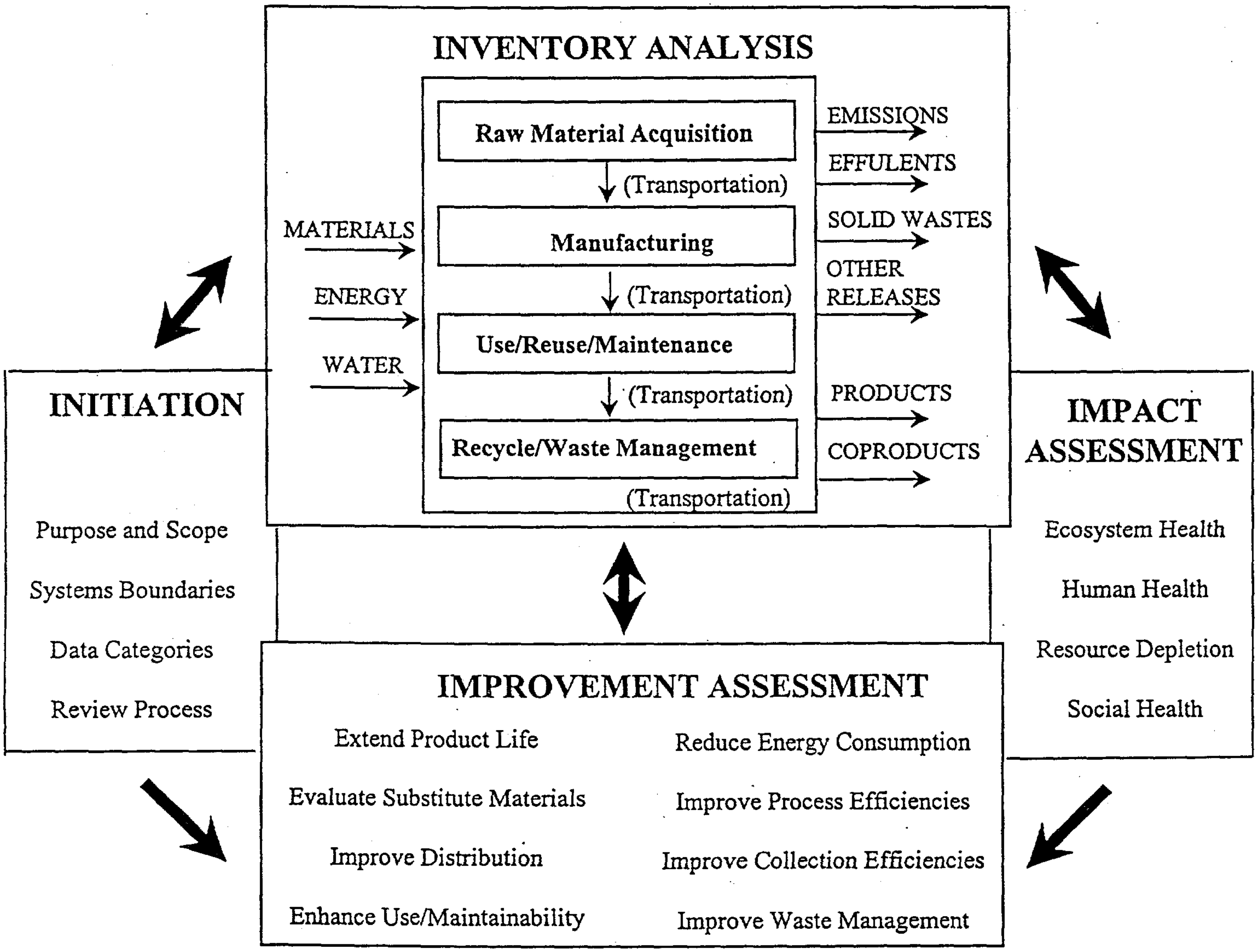
2.4.3 Inventory Analysis

Inventory analysis is an objective, data-based process for quantifying raw material, energy, and water consumption; air emissions; water discharges; solid waste; and other environmental changes that occur over the life-cycle of a product, process or product use activity. This phase is often called a Life-Cycle Inventory (LCI) and is covered in more detail in Chapter 4. The inventory can be amended to include a process for collecting economic data (costs of materials, labor, etc.) for the various life-cycle stages.

2.4.4 Impact Assessment

Impact assessment, or impact analysis, is a technical, quantitative, and qualitative process to characterize and assess the effects of the environmental changes identified in the inventory. Once the inventory has quantified the inputs to and outputs from a system, impact assessment may be conducted to assess the consequences of resource consumption and the environmental changes associated with each life-cycle stage. Impact assessment converts inventory information into an idealized itemization of environmental-performance indicators (amounts of CO_2 sequestered, **waste** sent to landfill, etc.). These indicators can be further analyzed to predict the consequences on human health, **ecosystem** health, etc. resulting in a detailed and documented review of the impacts associated with the system being studied. Methods for analysis of some types of impacts exist, but further research is needed before these individual impacts can be integrated into an overall valuation of environmental performance. The itemized list of indicators and/or the analysis results can, however, be used to assess the changes in terms of their relative importance with respect to the goals and objectives established in the initiation phase.

Figure 2.2. A Generic Life-Cycle Model



Source: Canadian Standards Association, 1994

LCA impact analysis procedures are still under development and many different approaches have been developed without universal consensus. Procedures will be developed further by CORRIM II researchers and tailored to specific research objectives.

2.4.5 Improvement Assessment

Improvement assessment, or improvement analysis, is a systematic evaluation of the needs and opportunities to reduce the environmental burden associated with energy, water and materials consumption, air and water emissions, and solid waste over the entire **life cycle** of the system investigated. This includes quantitative and qualitative aspects of potential improvements such as changes in product design to extend life or enhance recyclability; to evaluate potential material substitutions; improve production, process and collection efficiencies; enhance consumer use and maintenance procedures; and improve recycling and solid waste management techniques.

Improvement assessment procedures are not covered further in this guideline but will again be tailored to specific research objectives.

2.5 Procedure

The typical LCA procedure is illustrated by Figure 2-2 in which an initial definition of the study objectives, boundaries, and data needs for the system to be studied leads to a preliminary inventory, which, as it progresses, may lead to revision of the study objectives, boundaries, or data needs depending on data availability and initial analyses of sensitivity and uncertainty. A Data Availability Survey, covered in Chapter 5.3, is a very useful tool for identifying data needs and associated quality requirements and deciding if these are compatible with study objectives. After one or more iterations finalizes definition of the inventory requirements, data is collected and summarized for the system. The study may then move on to impact analysis and improvement analysis either of which may require further refinement of the system definition. The key point to emphasize is the iterative nature of the procedure.

2.6 Quality Assurance Process

An important issue in LCA is data quality. Procedures for data quality assurance are rapidly evolving along with recommendations as to how to ensure that data quality is sufficient for the different types of decisions and uses of LCA results that are desired. Data quality goals are set in the goal definition and scoping phase. Data quality is measured by data quality indicators which are discussed in Chapter 5.5. While data quality is a critical issue, it is not the only aspect of quality of information since many decisions with respect to boundary definitions are linked to data quality requirements. Therefore, data quality assessment is an iterative process where checks are continually made to determine if data meet quality requirements. If it is found that data are unavailable or of inadequate quality to meet study objectives, the research team must either collect additional data to improve data quality so the study goal is met or revise the study goal to reflect the realities of the data. Researchers must recognize that data quality requirements may differ for different parts of the system and that one of the goals of the study may be to identify inadequacies in data so research can be directed to these areas.

Chapter 3. Goal Definition and Scoping: The Initiation Phase

3.1 Introduction

Decisions at the start of a study that define its scope and boundaries are perhaps the most critical. These decisions provide a clear understanding of the purpose of the study, the system(s) to be investigated, the audience, and intended use of the results. Results are dependent on definition of the system function, functional unit, and boundaries. These decisions are also critical for determining the specificity and quality required of data and the approach used. These latter are often determined from the application or intended use of the results but in many cases there may be options ranging from a very generic study to one that is very product specific and detailed.

Initiation includes:

- Defining the goal and purpose of the study, intended audience and application.
- Identifying the expertise required and organizing a study team.
- Defining the function of the system(s) studied and the functional unit.
- Defining boundaries

  Often it is useful to distinguish between the **study boundaries** and the **system boundaries**. Study boundaries include both the general issues to be dealt with in conducting the study and the physical system boundary to be analyzed. System boundaries refer to specific technical and practical limits of the process, product or product use activity under study and are covered further in Chapter 4.2. In the context of environmental-performance research on large integrated systems, decomposition of the overall system into many **subsystems** with consistent boundary conditions is essential.

- Defining specificity and quality required of data and checking that these data requirements can be fulfilled.
- Establishing the study process
- Establishing a validation or review process by appointing a reference panel and/or a review team to ensure quality and credibility of the study.

3.2 Goal of Study

3.2.1 Purpose and Intended Applications

Define clearly the purpose of the study and the intended use and users of the results. Definition of purpose should include both what will be done (ex. to compare alternative wall insulation materials) as well as the reason the study is needed (ex. to provide information for eco-labeling). The best way to handle this is to provide a clear statement on the intended applications and users of the results.

These definitions must be stated in the final report so readers will clearly understand why different assumptions and procedures were used.

3.2.2 Function(s) of the Studied System(s)

A "product" provides a consumer with a specific benefit or service and it is this function of a product that is of prime concern. LCA procedures are intended to provide information on impacts associated with the benefit or service provided over its full life-cycle from acquisition of raw materials, to creation of the benefit or service, and through use and final disposal. There is little meaning in comparing two or more products unless they are serving the same function. The only exception may be where the study objective is to compare different functionality such as durability (ex. untreated wood versus treated wood versus concrete). A clear understanding of the function being studied in relation to the study goal is of key importance in defining the system(s) to be studied.

The concept of comparing systems fulfilling identical functions may require consideration of more than one function in the analysis. This may occur where the production of a product serving the function of interest also involves production of other products and functions. Multi-functionality may be treated by either expanding the study boundaries to include all functions or by allocating resources, emissions, etc. between the main function and the co-functions not included in the study. These procedures are discussed further in Chapters 4 and 6.

3.2.3 Functional Unit

The functional unit is defined in terms of the main function(s) of the system(s) being studied and is a well-defined <u>measure</u> of the function that the system(s) deliver to the consumer. All data used in and reported by the study must be related to the functional unit. Defining the functional unit is a key issue since it will strongly affect the results and how they are communicated and interpreted. This definition may need to consider product efficiency, longevity, and performance requirements (quality standards).

3.2.4 Average or Marginal Analysis

As in economics, in which there is a clear distinction between situations where average versus marginal cost analysis is appropriate, care must be taken in deciding whether the study should have the perspective of average or marginal production and use of the functional unit. Some studies may have characterization of the typical product reaching a consumer as an objective and production-weighted industry averages are useful. Standard procedures for LCA (SETAC 1993) are often interpreted and applied on the assumption that the study objective will be met by characterizing the average conditions surrounding the functional unit. As an example, averages may be the proper basis for various environmental labeling methods for products.

However, if the objective is to examine expansion of industry production, replacement of an old technology with a new technology, or substitution between materials, processes or products, then only the changes due to the expansion, replacement, or substitution are relevant. In other words, the marginal, not average, effects must be measured. If an analysis using LCA is to be useful in the context of expansion, replacement, or substitution comparison, it must be able to correctly measure and predict the true environmental effects of the process or product change. If substitution of steel for wood studs is being evaluated, and the LCA recommends the steel stud as the environmentally preferable product, the real world change in environmental effects causec by switching from wood to steel studs must match the LCA results. If this does not occur then LCA has no utility in comparing these alternatives and misleads the public and policy makers. Gilbreath (1996) documents examples of LCA studies that incorrectly used average product profiles and developed misleading claims on which product was environmentally preferable.

Consider switching from a wood product to one made of steel or plastic. Where does the additior raw ore, crude oil, natural gas or coal come from and what are the effects of extracting the additi increment of these resources and transporting it to a mill or refinery? Since manufacture of steel products is very energy intensive, the relevant question to ask is "what energy generation resourc must be expanded in order to meet the expansion of steel production when it replaces wood?" Fr statistics on the U.S. energy grid (Chapter 7) one can see that shares of hydro and nuclear are declining and that shares based on fossil fuels have been increasing. Thus it is likely that additior energy to expand steel products must be generated almost exclusively from fossil fuels and henc environmental emissions associated with energy in producing additional steel studs should be ba on emissions from fossil fuels only and not the average emissions of the existing grid mix.

Since study objectives may raise issues in which either average profiles or marginal analysis are required, analysts must carefully define the objective of the study in order to ensure that the correct approach is used and ensure that data definition and collection be accomplished in such a way that the correct type of analysis is facilitated.

3.3 Study Scope

Scoping involves identifying and defining the system(s) to be studied, boundaries, data requirements, assumptions and limitations. Specific issues include

- choice of product or service to be studied
- boundaries of the technical system
- boundaries of the impacts to be considered
- data quality requirements

3.3.1 Choice of Product or Service to be Studied

Most studies either examine a single product or compare alternatives, and hence those included must be representative. Each alternative should be carefully described and justified to give the audience and users the opportunity to judge how representative the chosen alternatives are with respect of the goal of the study, thus helping to avoid misinterpretation and misuse of the results. In comparative studies, special care must be taken to define the reference product or service usec as the benchmark against which others are compared. Finally, analysts must ensure that the

Chapter 4. Inventory

Life-cycle inventory (LCI) is a detailed description of the functions and boundaries of the system, data collection, calculations, and sensitivity analysis. This Chapter focuses on detailed definition of the system and boundaries, Chapter 5 on data collection and quality, and Chapter 6 on modeling, particularly dealing with allocation and recycling.

4.1 Define the Product or Service System

Definition of the product or service system encompassing the functional unit is necessary to ensure that the system(s) being studied are fully described and that all relevant life-cycle stages are included at sufficient detail to meet the study objectives.

4.1.1 Identify System Function(s)

The overall system functions that are related to the goal of the study are initially described in goal definition and scoping (Chapter 3). In the LCI phase, these functions and systems are refined to the level of resolution and detail needed to accomplish the study objectives. This detailing is critical since it defines the life-cycle elements that are included. The initial detailing includes identifying and defining:

- identical main functions provided by the product(s) and system(s)
- where there are different additional functions that are integrated with the main functions such as quality, durability, or hidden services. As an example of a hidden service, use of waste paper for insulation also provides a waste management service.
- where co-products are provided by the system(s) that need to be considered in order that all parts of the life-cycle relevant to the study goal are included. For example, production of both steel and wood studs involves co-products (e.g. wood chips for paper) from each process.

Detailed definition of systems and functions often reveals that alternatives considered provide somewhat different and/or multiple functions and that an approach must be designed to accommodate these differences. Two common ways to do this are 1) refining boundaries to compare multifunctional systems, and 2) allocating resources, energy, and environmental changes among the multiple functions and co-products.

4.1.1.1 Refine Boundaries to Compare Multifunctional Systems

Boundaries may be revised to reflect all functions provided by adding subsystems to one or more alternatives. This multifunctional approach may be needed because the multiple functions are not separable in the user sense or because available data does not permit separation. The use of waste paper as insulation simultaneously involves both insulation value and reduction of waste management. In this case, expanding the boundaries to include both functions provides a more accurate description of the real world. Changing boundaries may be done by either:

- Adding subsystems to provide the additional functions, thereby making all alternatives directly comparable over the broader functional perspective. If waste paper insulation is compared to glass fiber insulation, a waste paper disposal subsystem is added to both the paper and glass fiber insulation systems.
- Subtract the subsystems that provide the extra functions from the relevant alternatives. In this case, subtracting the waste paper disposal subsystem from the paper insulation system makes it comparable to the glass fiber system (without waste paper disposal).

Although exact numerical results from using the additive and subtractive methods will be different, the results will be the same qualitatively since the systems are compared on an equitable basis. Each method has advantages and disadvantages. The additive method is often more transparent and understandable to the audience but creates more complex systems to study; the subtractive system may often be much simpler with less data collection but results, such as "negative" values due to avoided emissions, may be more difficult to interpret and communicate properly.

4.1.1.2 Allocate Resources, Energy, and Environmental Changes Among the Multiple Functions and Co-products.

In many cases, expanding boundaries to include multiple functions and co-products leads to a study that is too complex or which cannot be completed within time and cost constraints. Functions and products that are not the main objectives of study are often treated by placing them outside the study boundaries by allocating a portion of the resources and energy consumed and environmental changes caused by overall system to them. Chapter 6 presents commonly used allocation methods.

4.2 Defining System Boundaries

After deciding how to deal with functionality issues, the next step is to define system boundaries in detail using expert knowledge of the systems under study. Boundary definition is partly based on subjective decisions made during the scoping phase and partly with objective procedures designed to not lose important information and sensitivity as boundaries are finalized. Clear definition of boundaries is necessary as a prelude to data collection activities in the inventory. Boundary definition includes all ancillary material flows that could affect the ability of the analysis to address the study objectives. Section 4.2.4 discusses decision rules often used in deciding which ancillary materials and processes are significant to overall results and must therefore be retained within the study boundary.

4.2.1 Geographic Boundaries

The choice of geographic boundary of a study is an important decision since it defines the area for which the results should be representative and since inventory data and interpretation are often highly dependent on the geographic context. A specific objective of some studies may be to investigate differences between regions. Examples include differences in building codes that affect materials use, housing consumption of energy, and flows of resources, products, and environmental changes between regions. Energy data should be carefully examined with respect to geographic boundaries since environmental burdens associated with the production and consumption of energy are highly dependent on the specific type of energy generation which often varies greatly between regions.

4.2.2 Temporal Boundaries

While the life-cycle of many products, such as production, use and disposal of packaging, are of very short duration, others have life-cycle stages that may be very long. Housing is a good example. The time required to produce lumber and other building materials and to construct a house may take only 1-2 years, but the period of occupancy and associated energy consumption, repair and maintenance may be very long before the house is demolished and replaced. The temporal aspects of short life-cycle systems may be so short that they can be safely ignored and the temporal boundary of such studies may simply be a quest to acquire data of a common, current age for the alternatives. When one or more life-cycle stages becomes sufficiently long, it may be both impossible and illogical to obtain data from current operations. For example, one should not use energy consumption data collected from today's energy billing for the house of average age in the U.S. and apply it to a new house built with the latest energy efficient materials and methods.

When certain life-cycle stages involve long periods of time, system boundaries must be carefully defined to avoid bias associated with changes over time. Frequently there may be a need to segregate and separately study different age classes or cohorts of housing, forest stands, etc. and forecast the behavior of each through time. At any specific moment, these age class behaviors can be summed to present the expected weighted average at that time. This is a significant departure from traditional LCA studies which collect and present empirical data from existing operations. When system boundaries require consideration of long-term behavior, life-cycle inventories must be augmented by forecasting techniques that will project how cohorts change through time and summarize how these changes in the aggregate affect results and conclusions. Chapter 8 presents further discussion of this situation in the case of forestry, wood products production, and housing construction, occupancy, and disposal, a sequence that may often last 1-2 centuries.

4.2.3 Technosphere/Biosphere Boundaries

These boundaries are determined by decisions on where the boundary for biomass production is set in defining the "cradle" aspect of resource extraction and when decomposition processes in **landfills** become regarded as part of nature. These boundaries may become important in quantifying how much carbon sequestration and **greenhouse gas** emission is attributed to the system being studied and how much to natural processes. Inclusion of these processes and their emissions will also strongly affect the time horizon in defining the temporal boundaries of the study.

4.2.4 Streamlining Life-Cycle Boundaries

Life-cycle boundary definition also includes decisions as to where to cut off upstream, downstream, and ancillary subsystem detail. While in theory all subsystems associated with the studied system and main flows are included, contributions by some to environmental impacts may be so small as to have negligible influence on study results and conclusions. These practical limitations affect the data collection process, computational complexities, and time and cost of the study. Some studies restrict the scope to completely exclude upstream or downstream stages of the life-cycle. For example, many past studies of wood products begin with harvesting of mature trees and exclude all aspects of growing and tending the forest, building road infrastructure, etc.. Other studies terminate at the point where the product or functional unit is received by the consumer and ignore all downstream activities associated with use, repair, maintenance, and disposal. These partial LCA's should be viewed with caution since important characteristics of and differences between systems may be missing. This section describes decision rules commonly used to streamline studies.

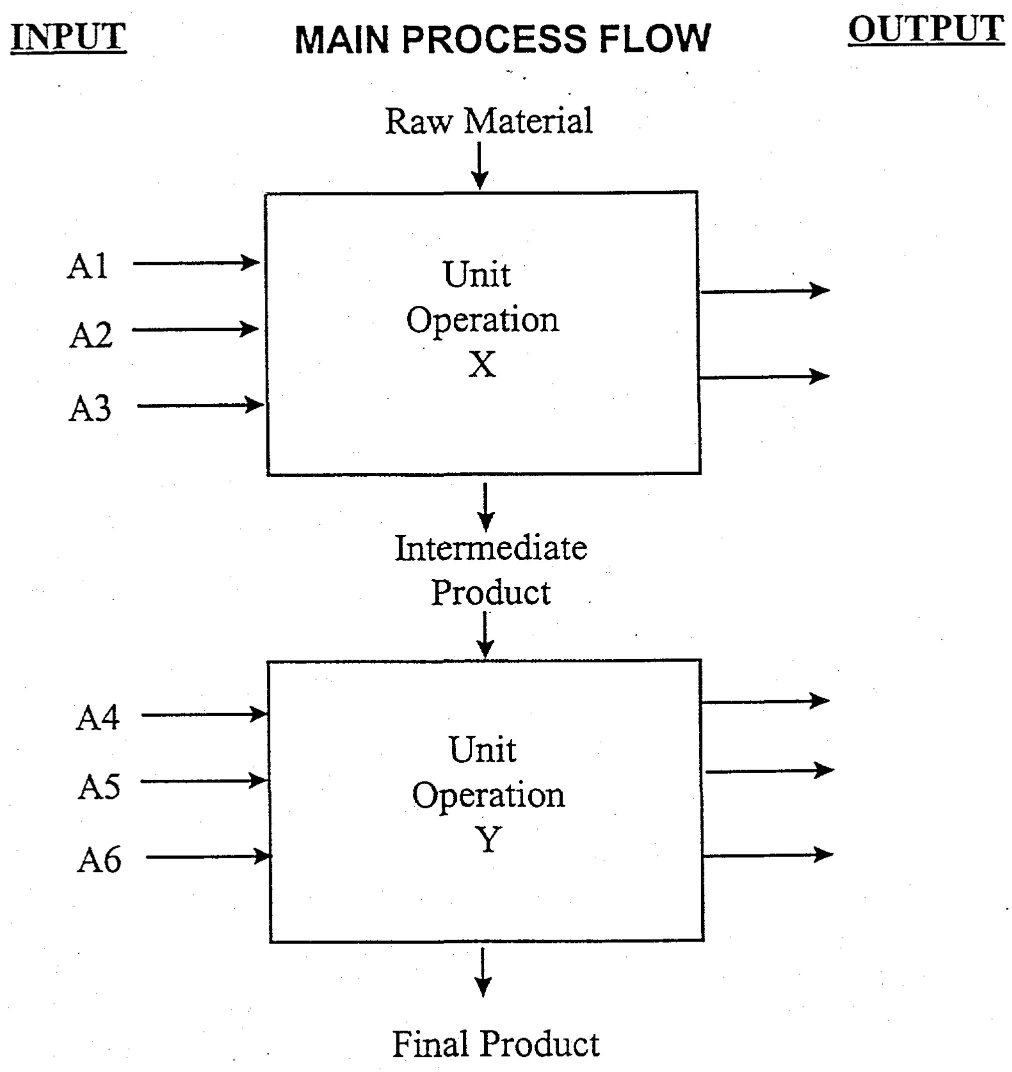
4.2.4.1 Perform a Data Availability Survey (DAS)

A Data Availability Survey (see Chapter 5.3) is an initial list of primary and ancillary material inputs, a list of environmental changes produced by each unit process with a description of the source and type of data that is available, and an assessment of the quality of each piece of data that is needed to meet the study objectives. A DAS should be conducted before beginning any streamlining decisions.

Information developed by the DAS allows construction of an outline table where the analyst can list and assess the mass and energy contribution, economic importance, and environmental relevance of raw materials and ancillary materials and can make a determination of which are negligible with respect to the study objectives and, hence, are candidates for placement outside the system boundary. Often preliminary data from the literature, consultation with experts, or a preliminary data collection survey can be quickly obtained and converted to percentage contributions for mass, energy and economic contribution. Yes/No indicators can often be used to indicate whether there are significant environmental changes associated with each material.

Figure 4-1 illustrates a simple process where 2 main unit operations comprise the main process flow. Operation X transforms raw material into an intermediate product using ancillary materials A1-A3 and operation Y uses ancillary materials A4-A6 to convert the intermediate product to a **finished product**. Once identified, the materials flows form the basis for a matrix in which each is evaluated with respect to its contribution to overall mass, energy, economic importance, and environmental relevance.

Figure 4.1. Streamlining Boundaries of a Simple System



Material	% of Mass	% of Energy	% of Cost	Environmental Relevance
Raw material	85.1	28.0	45.0	Yes
Intermediate product	included in raw material	60.3	25.0	Yes
Ancillary materials:				
A1	5.2	6.1	16.0	Yes
A2	0.1	<0.05	2.0	No
A3	0.1	0.1	4.0	Yes
A4	3.0	0.5	1.0	No
A5	4.0	3.0	7.0	Yes
A6	2.5	2.0	<0.05	No
Total	100.0	100.0	100	

The analyst can use the matrix tabulation to decide which ancillary materials should be included in the study. Those which represent a minor overall contribution to mass and energy use, have a small economic importance, and have no environmental relevance to the study objectives are candidates for exclusion. This form of scoping study can be conducted at whatever level of detail is required. The analyst should document the decisions by providing a justification for each and describing the decision rule applied. The remainder of this section describes some commonly used decision rules which may, of course, be used in combination to arrive at a decision.

4.2.4.2 Using Mass Contribution To Exclude Ancillary Materials

The use of mass contribution as the basis of the decision to exclude ancillary materials has been used frequently. Many studies have excluded materials that contribute less than some fixed percent of the mass of a given unit operation or some fixed percent of the overall mass of the system. If a 5% cut-off was used, ancillary materials A2-A6 would be excluded in the Figure 4-1 example. From a data quality point of view, preference should be given to rules that take into account the cumulative contribution to the system studied rather that the contribution of any one material. Such a rule might require that all raw materials that have a cumulative total of more than some fixed percent of the total mass in the system be included. With this rule, one might decide that the materials to be included shall total more than 99% of the total mass in the system. With this rule, ancillary materials A4-A6 must be included while A2 and A3 are potential candidates to exclude.

Another method of streamlining while maintaining quality of the study is to distinguish between ancillary materials that require data from primary sources and those that could be adequately represented by secondary data. A decision rule could be to require primary data be collected for all materials that have a cumulative mass contribution greater than say, 90%. Using this rule and given that the raw material must be primary data, one option would be that A1 be required to be source from primary data. Other options could allow A1 to be from Secondary data sources by requiring some combination of A4, A5, and A6 to be from primary sources. The distinction is important, since treatment of secondary ancillaries is less rigorous.

Rules using fixed percentages such as those described above should be carefully reviewed in studies where systems are being compared since the fixed percentages imply the assumption that the same degree of cut-off has the same effect on all of the systems being studied.

4.2.3.3 Using Energy Contribution or Economic Importance To Exclude Ancillary Materials

While mass is an important indicator of the significance of ancillary materials, using it alone as a criterion may result in the loss of valuable information because some ancillaries with small mass may be very energy intensive, very costly, labor intensive, or responsible for major environmental changes. It is recommended that the procedure used with mass contribution be repeated using energy and economic value as criteria, each with appropriate thresholds.

4.2.4.4 Using Environmental Relevance To Exclude Ancillary Materials

Literature searches and expert advice should be sought to identify any conceivable changes that affect the environment. One can then develop a decision rule for including an ancillary material based on its environmental relevance contingent on the study objectives. This could be as simple as Yes/No as shown in the example or using estimates of percentage contributions.

4.2.4.5 Factors Normally Not Quantified in LCA

A number of factors are normally not considered in LCA are:

- Capital Equipment and Infrastructure

A question is often raised regarding the inclusion of capital equipment as an ancillary input to any unit process. The energy and resources used to construct buildings, manufacturing equipment, transport vehicles, highways and bridges, etc. should be considered. However, for most situations, capital equipment is allocated over the production of so many units of production during its productive lifetime that the resource use, energy, and environmental changes per unit of production are very small. This situation should always be verified.

- Accidents

Except when there may be large differences in systems being compared or where they are a stated study objective, accidents or the risk of severe accidents, such as oil spills, are not included in LCA studies. In many cases, lesser minor malfunctions of processes are likely to be included within average annual operating data.

- Personnel Issues

Personal activities of workers, such as sanitary effluents, lunchroom trash, energy use, air-conditioning, etc. and their **transportation** to and from work are generally excluded from consideration. In many cases, the consequences of these activities are either very small or would occur whether or not the product is manufactured. Excluding these ancillary activities may be justified in many cases although the analyst should examine these questions and determine if there are important effects of differences between systems being studied.

4.3 Life-Cycle Flow Diagrams

All subsystems included in the study must be defined at the required level of detail before any data collection can proceed. Systems and subsystems should be defined by process flow diagrams (process trees) at the appropriate level of detail required by the study. Initially, it may be helpful to view an LCI a generic "model" composed of the following major stages or subsystems that can be disaggregated into greater detail as needed:

Raw materials acquisition: All of the activities required to gather and obtain a **raw material** or energy source. In the case of biomass materials, this also includes all activities associated with growing the biomass to the time of its harvest. In addition, this stage includes the harvesting and transportation of the raw material to the point of material manufacture, but does not include any material processing activities.

Manufacturing: Which includes

- **Materials Manufacture:** The activities that convert a raw material into a form that either can be used directly by the consumer (e.g. lumber) or used as **intermediate products** consumed by other processes to fabricate a finished product or package. Transport of intermediate products is included.
- **Product Conversion and Fabrication:** The processes that convert raw material or intermediate materials to fabricate a finished product. The fabricated product may be distributed to other industries (beverage bottles, cardboard boxes, lumber, pallets, etc.) or to the consumer (filled bottle, constructed home). This step often involves a consumer product that will be distributed for retail sales but the product could also be distributed for use by other industries.
- **Filling/Packaging/Distribution:** Processes that prepare the final products for shipment and that transport the products to retail outlets. Although these activities may require a change in the location or physical configuration of the product, they do not involve a transformation of materials.

Use/Reuse/Maintenance: Begins after the products have been **distributed** and/or assembled for the intended **use** and includes any activity in which the product or package may be reconditioned, maintained, or serviced during its **useful life**.

Recycle/Waste Management: Begins after the product, package, or materials has served its intended purpose and either enters a new system through recycling or enters the environment through a **waste management system**.

This organization of LCI components differs from that presented in the SETAC procedures (1993) and is due to the fact that this document is written from the perspective of guiding the assembly of information in performing a study rather than from the perspective of how results might be presented. Therefore, transportation activities are disaggregated, rather than presented as a single aggregate stage, so each transportation activity is associated with its specific life-cycle stage.

This model also considers materials manufacture, product fabrication, and filling/packaging/distribution to be included in the manufacturing stage. Separating these activities into sub-stages reflects the fact that they are often performed by different organizations. The separate treatment also reflects the very different nature of these operations.

Finally, **recycling** and waste management are combined into one stage since these activities often simply represent a splitting of the flow of material between these two streams.

Chapter 5. Define Data Sources & Categories, Data Quality, and Data Collection Procedures

5.1 Data Types and Classification

The purpose, scope and boundary of the inventory help the analyst determine the level or type of information that is required. Even if the analyst can obtain actual industry data, the form and degree of detail in which it is presented (range of values, industry average, specific plant, best available technology, etc.) can be easily determined if the purpose or scope has been well defined. Generally, most publicly available life-cycle studies present industry averages and it is recommended that these also include provision for a measure of variability in the form of ranges or standard deviation. Several types of data are often used in life-cycle studies, including:

- a specific make, model, and age of machine where the principal variation is due to materials processed, operator, maintenance, and random variation between machines.
- a single machine center or unit operation where variation expands to include different makes, brands, and ages.
- similar machine centers or unit operations that are combined from multiple facilities or locations, commonly within the same company. These aggregate data may not be representative of the industry average.
- industry average data derived from a representative sample of different companies and believed to statistically capture the typical unit operation and variation across all technologies, inputs to and outputs from the operation, and company management.
- generic - data whose **representativeness** and variability may be unknown but which are qualitatively descriptive of a unit operation.

This classification assumes individual machine centers or unit operations. For some studies, it may be sufficient to obtain data that aggregate several or all unit operations of a process. For example, rather than detailing lumber recovery yield and energy use according to each machine center in a sawmill, it may be adequate to gather lumber yield and processing energy for the mill as a whole rather than for each process step.

When the purpose of the study is to find ways to improve internal operations, it is best to use data specific to the system that is being examined. These types of data are usually the most accurate and helpful in analyzing potential improvements of a system. However, private data are often proprietary and often must be protected from disclosure by some means.

Industry-average data may be preferable when the study results are to be used for broad application across the industry, especially in studies for public use. Although composite or aggregate data may be less specific to a given facility, they are generally more representative of the industry as a whole. Means and standard deviations can provide valuable information on the "typical" situation as well as the variation normally to be expected. Such **composite data** can often be made publicly available, are more widely usable and more general in nature.

Complete and thorough life-cycle studies often require use of data considered proprietary by either the manufacturer of the product, upstream suppliers, or the LCA practitioner conducting the study. While confidentiality issues are not relevant for companies using their own data for internal studies. use of proprietary data can be a critical issue for studies conducted for external use and whenever facility-specific data are collected from external suppliers or customers for internal studies. Consequently, studies often contain insufficient documentation of source data to permit technically sound external review. Lack of technically sound data or its documentation adversely affects credibility of the life-cycle study results and the methods used in creating them. When collecting data and reporting results, the protection of proprietary data should be weighed against the need for a complete and detailed analysis or disclosure of information. Some form of selective confidentiality agreements for entities performing life-cycle studies, as well as formalization of peer review procedures, is often necessary for inventories that will be used publicly. Industry data may need an intermediate, confidential review before being aggregated to provide disclosure protection in a document to be released to the public.

5.2 Data Sources

5.2.1 Introduction

Many sources may be used in collecting data and whenever possible, it is best to obtain well-defined industry data for production processes. Manufacturing processes often change and become more efficient over time hence it is important to collect current data. Data can be specific for a facility or more general entity and still remain current. Data sources can be categorized as either primary, secondary, or pseudo-data from models.

5.2.2 Primary Data Sources

Primary data sources include industry data for a specific facility that may or may not be accessible and other LCA specific study data. Examples include independent or internal reports, periodic measurements, accounting or engineering reports or data sets, specific measurements, and machine specifications.

Industry trade and technical associations may be useful, without providing specific data, in reviewing and confirming the accuracy, representativeness and age of collected data.

5.2.3 Secondary Data Sources

Examples of secondary data sources include government and industrial databases, averaged industrial data, product specifications, bibliographic databases, database clearinghouses, government reports, open literature publications, other life-cycle inventories, and **end-user** surveys.

Government documents and databases provide data on broad categories of processes and are publicly available. Most government documents are published on a periodic basis although the data contained may be several years old. In addition, the data may be less specific and less accurate than industry data for specific facilities or groups of facilities. However, depending on the purpose of the study and the specific data objectives, these limitations may not be critical. All studies should note the source and age of data. Examples of useful U.S. government documents include

- U.S. Transportation Energy Data Book, Oak Ridge National Laboratory
- U.S. Department of Commerce Census of Manufactures
- U.S. Bureau of Mines Census of Mineral Industries
- U.S. Department of Energy Monthly Energy Review
- U.S. Environmental Protection Agency Toxic Release Inventory (TRI) Database
- U.S. Environmental Protection Agency Compilation of Air Pollutant Emission Factors

Technical books, reports, conference papers, and articles published in technical journals can also provide information and data on processes. Data presented in these sources are often older and may either be too specific or not specific enough. Many may give theoretical data rather than real or actual process data. Such data may not be representative of actual processes or may deal with new technologies not widely used. In using such sources, the analyst should consider the date, specificity, and relevancy of the data.

Market researchers often conduct surveys designed to obtain information from a representative sample of end users which can provide current information on the use of a product or a service. These surveys often answer questions such as

- number of uses or longevity of product or service until it is discarded.
- what other materials and what quantities of them are used in conjunction with product use and/or maintenance?
- how frequent is the need for product repair or maintenance?
- what other uses does the product have beyond its original purpose?
- what does the consumer do with the product when it is disposed of?

Often the consumer will not be able to provide specific information on inputs and outputs but often can provide insights on consumer practices from which inputs and outputs can be derived.

5.2.4 Pseudo-Data from Models

Frequently, data may be difficult to collect from actual operations and data from models that simulate the operation may be used as a proxy. In forestry, forest stand growth simulators are commonly used to estimate stand growth and yield, distribution of species and tree sizes, and tree and wood quality characteristics. Models may be used to either estimate output of activities on the current forest estate or to project how a forest will respond over time to various treatments. Data from models should be clearly differentiated from data collected from actual operations.

5.2.5 Geographic Specificity of Data

An important consideration in defining and developing data sources is the geographic specificity required. Natural resource and environmental consequences occur at specific sites but there are broader implications. There may be important differences between the specific geographic areas from which raw materials and energy resources are taken, the location where processing activities and their environmental changes occur, and where the consumptive and disposal activities and environmental changes occur.

5.2.6 Data Time Period

Another issue relating to data sources is the time period for which data are collected. This time period should be long enough to smooth out short term variations (routine shutdowns, startup activities, normal seasonal fluctuations in operation, etc.) in production at a facility. Often data are available for a fiscal year of production which is usually sufficient to cover many of these variations. Also, data from various sources should be comparable in age to provide consistency within a particular system and in comparisons between systems.

5.3 Data Categories

This section describes in more detail the data requirements to quantify the inputs and outputs associated with the various life-cycle stages and unit operations. In describing and communicating data it is useful to organize the many individual species of data into larger categories as shown in Table 5.1. In each case, the inputs and outputs will be sufficiently detailed to show all significant requirements and related environmental changes. A more comprehensive listing along with precise definitions will be completed by CORRIM II researchers as part of the first modules of research funding which are designed to provide the pre-test on data development and priorities prior to a comprehensive examination of all products and processes.

5.3.1 Inputs

Table 5.1a presents broad data input categories and within each lists sub-categories and examples that should be included. This list is not intended to be exhaustive and may be expanded and refined further by CORRIM II researchers.

5.3.1.1 Primary raw material inputs

Primary raw materials are refer to the principal material in the main flow of the system under study. In CORRIM II research, the primary raw material in most cases will be wood either in the form of a tree or log, intermediate wood products used to build subassemblies, etc. Where applicable, a distinction should be made between wood harvested from forests and wood materials that have been recycled. A distinction at the species level should also be maintained; this may simply be softwood versus hardwood, or possibly commercial species groups (Douglas-fir, hem-fir, red oaks, etc.). There may also be a need to further distinguish grades of quality that may affect allocation and design considerations.

In the case of some substitute. composite. or hybrid products or assemblies there may be a need to consider other primary raw materials such as ores for steel. concrete. and minerals or fossil fuels used for plastics manufacture. These are differentiated from wood in that CORRIM II will rely on secondary sources of information for them.

5.3.1.2 Ancillary material inputs

Ancillary materials are inputs such as fertilizers and chemicals used in forest nurseries and silviculture and adhesives, fasteners and finishes that are used in the manufacture of wood products and in the construction of assemblies. In general CORRIM II will rely on secondary sources of information for ancillary materials.

5.3.1.3 Energy inputs

Gross energy inputs will be used. Utilization factors, which reflect the primary energy needed to produce and deliver energy to the unit process, will be developed by CORRIM II researchers for the individual subregions.

5.3.1.4 Environmental inputs

Environmental inputs to be included include CO_2 removed from the atmosphere by photosynthesis and chemically stored in the tree and surface and ground water consumed by various processes. Inputs of solar energy, soil minerals, and other factors may be optionally considered.

5.3.1.5 Economic inputs

Economic inputs include the quantity and cost of labor, capital cost, and costs of energy and materials consumed by the processes. The quantities of energy and materials will be measured under the material and energy categories previously listed. These economic measures, vital to benefit cost analysis, will be obtained from primary survey instruments and secondary sources.

5.3.2 Outputs

Table 5.1b presents broad data output categories and within each lists sub-categories and examples that should be included. This list is not intended to be exhaustive and may be expanded and refined further by CORRIM II researchers.

5.3.2.1 Products and intermediate material outputs

These refer to outputs that consist of the main flow of the process under study hence outputs of one unit operation typically become inputs into the next unit operation in the sequence of life-cycle stages. As an example. veneer is an intermediate output from logs that may be assembled into plywood or laminated veneer lumber (LVL). The LVL and plywood may be used with little further processing or they may be further manufactured into the flange and web materials in manufacturing a composite beam.

5.3.2.2 Co-product outputs

This refers to salable products and **intermediate materials** that are sold to other industries not part of the main flow and which therefore are typically transferred outside the system boundaries along with their share of material, energy, environmental and economic characteristics of the unit process in which they were created.

5.3.2.3 Energy outputs

Some unit operations may convert a fraction of the raw material inputs into fuel that is converted to energy, some of which may be sold and exported to the utility grid. Additionally, some solid waste may be incinerated for energy as an alternative to other forms of disposal.

5.3.2.4 Environmental outputs

There are many possible changes that processes may create in the environment. Some such as removal of CO_2 from the atmosphere and reduction of greenhouse gases, may be considered to be beneficial, while others, such as emissions of chemical compounds to the air and water and creation of solid waste may be detrimental or create nuisance problems. In other cases, such as bio-diversity, a change may be beneficial to some species groups and detrimental to others.

Unlike many life-cycle studies which only focus on those changes which appear to be detrimental or a nuisance, CORRIM II will take an approach which will include both potentially positive and potentially negative changes.

Environmental outputs are further classified according to those affecting the atmosphere, water, and landscape. The latter includes both solid waste disposal and changes in land use, and vegetation structure and habitats that affect wildlife and amenity considerations.

5.3.2.5 Economic outputs

The prices of products, co-products and energy sold and costs associated with disposal of wastes will be collected either from primary or secondary sources.

Table 5.1 Data Categories

A. Inputs

Category	Example
Primary Materials	-trees and logs (species & grade) -lumber, plywood, other products (species and grade) -subassemblies (floor, wall, roof, etc.) -metallic minerals (iron ore, etc.) -non-metallic minerals (sand, gravel, gypsum, etc.) -fossil fuels used in plastics, fertilizers, adhesives
Ancillary Materials	-metal fasteners -adhesives -finishes -fertilizers -forest chemicals -other
Energy	-electricity (hydro, thermal, nuclear, other) -natural gas (including LPG) -coal -refined petroleum -wood (hog fuel, spent pulping liquor, wood wastes) -other
Environmental	-carbon dioxide uptake in photosynthesis -water (surface, ground, other) -soil nutrients -other
Economic	-employment -costs (labor, energy, materials) -other

Table 5.1 Data Categories (cont.)

B. Outputs

Category	Example
Products finished intermediate	-logs -lumber -veneer -panels (plywood, OSB, etc.) -engineered products (glulams, composite beams, LVL, etc.) -millwork (windows, doors, etc.) -assemblies (floors, walls, roofs, etc.)
Co-products	-pulp chips -other
Energy	-electricity -other
Environmental	
air	-carbon dioxide, carbon monoxide, methane (from both biomass and non-biomass sources) -sulfur oxides -nitrogen oxides -volatile organic compounds -particulates and fumes
water	-biochemical oxygen demand -suspended solids -dissolved solids -pH -polynuclear aromatic hydrocarbons -other
land	-land use -solid waste (extraction, primary processing, secondary processing, construction, post-consumer) -forest structure, habitat classification -other
Economic	-prices -costs (solid waste disposal) -other

5.4 Data Availability Survey

A Data Availability Survey (DAS) is an initial list of primary and ancillary material inputs to and a list of outputs and environmental changes produced by each unit operation with a description of the source and type of data that is available and the quality of each piece of data that is needed to meet the study objectives.

5.4.1 Use of Templates to Simplify Analysis

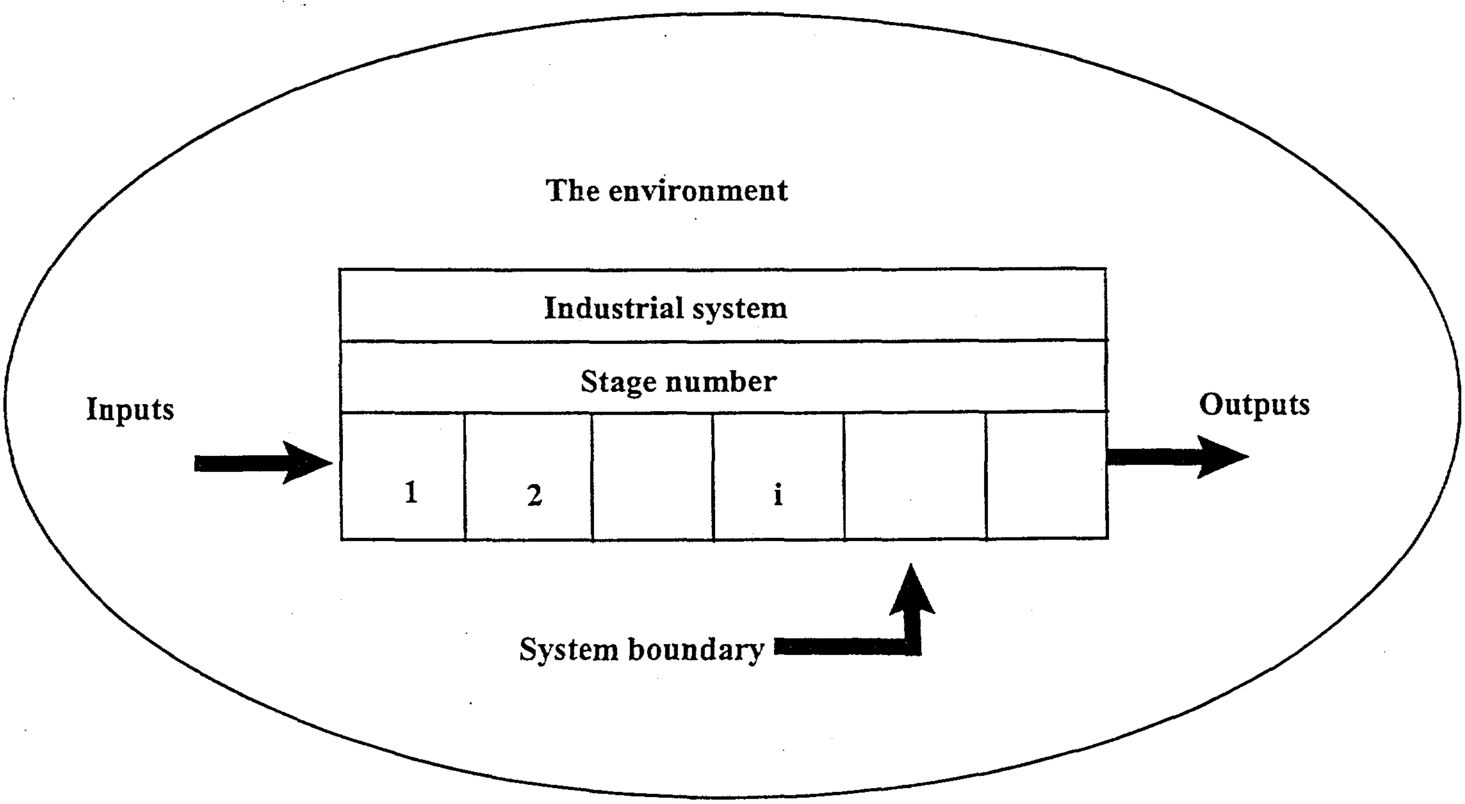
To analyze the inputs and outputs of the life-cycle stages, one must be able to describe and comprehend the relationships of a complex industrial system which is a collection of operations that act together to perform some function (Figure 5-1).

The "environment" encompasses the industrial system within a systems boundary established for the Life-cycle Assessment. The system boundary encloses all the relevant operations of the specific industrial system under examination. All inputs and outputs related to the system are derived from or released into the environment. Thus the environment acts both as the source of inputs to the industrial system as well as the sink for all outputs from the various stages, whether they be useful products or environmental releases.

The first step in analyzing such a complex system is to develop a systems flow diagram for the product, process, or activity being studied. Figure 5-2 is an example for plywood which includes tree growing, harvesting and transporting logs to the mill, conversion of the log into veneer and by-products, assembling the veneer into plywood panels, and packaging and distributing plywood to a retail outlet where the final customer obtains and uses the product. This flow diagram illustrates the main unit operations and process flows as well as ancillary materials including fertilizers used to grow the trees and adhesives applied to veneer to make plywood. These ancillary materials also have flows that can be traced back to their origins.

The task of identifying these ancillary flows as well as other inputs and outputs is aided by use of a template which guides the collection of data. A generic template, such as shown in Figure 5.3, visually depicts the material and energy accounts describing a defined unit operation. It indicates which categories of data are necessary to construct the energy and materials input/output analysis that is at the core of life-cycle analysis. The generic template can be readily transformed into data collection sheets such as the Data Availability Survey sheet in Figure 5-4 and can be easily amended to include economic information such as costs, labor requirements, etc.

Figure 5.1. Conceptual View of an Industrial System



Source: Canadian Standards Association, 1994

Figure 5.2. Life-Cycle of Plywood

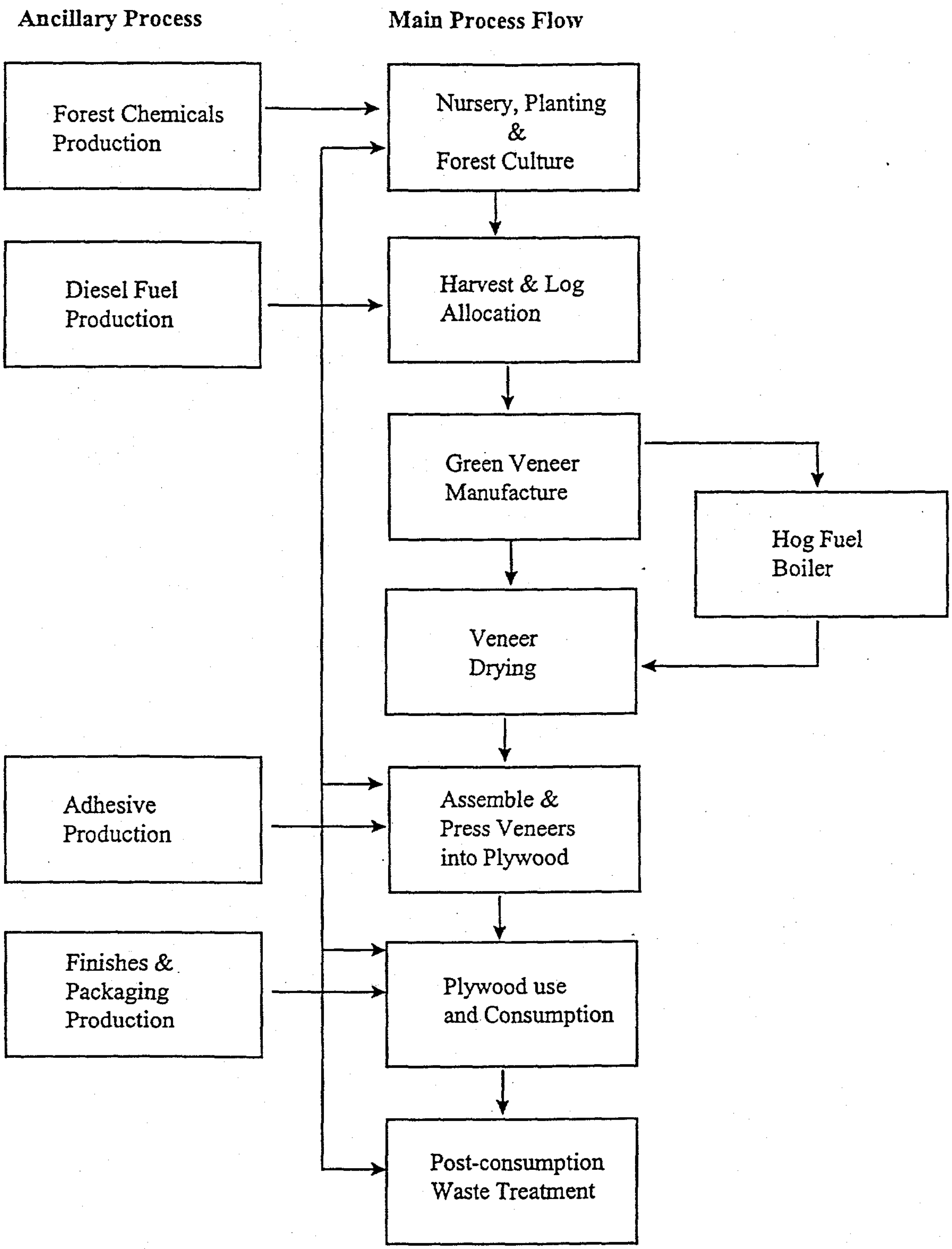
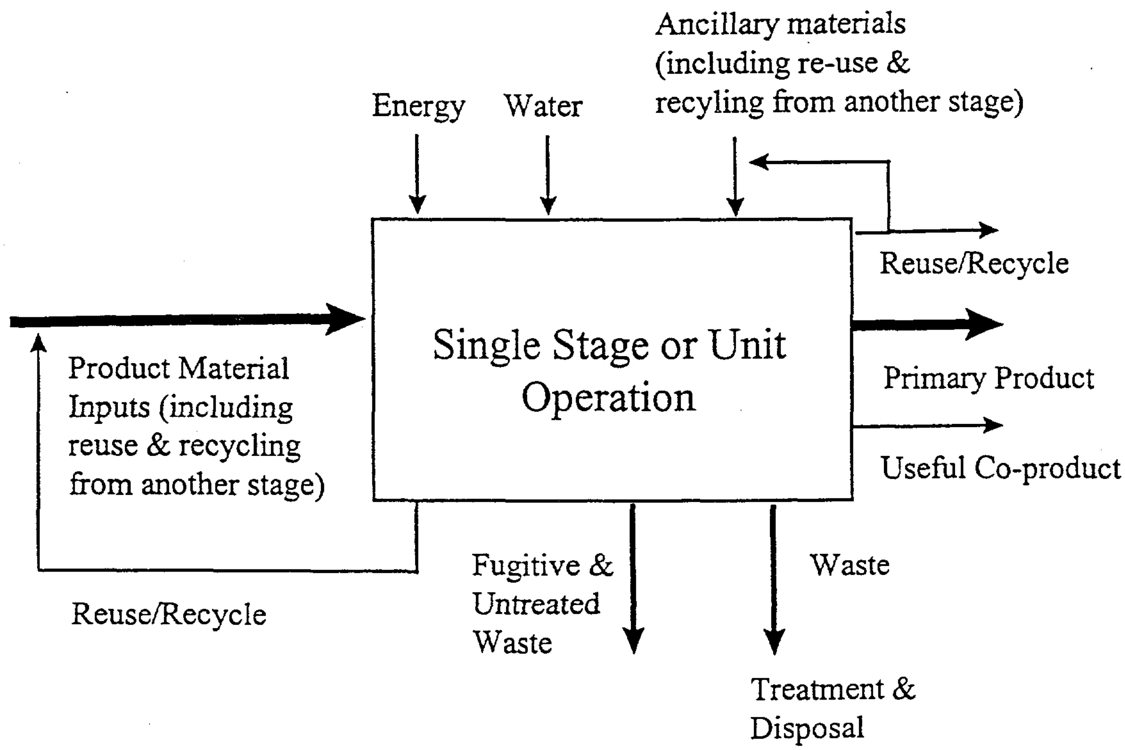
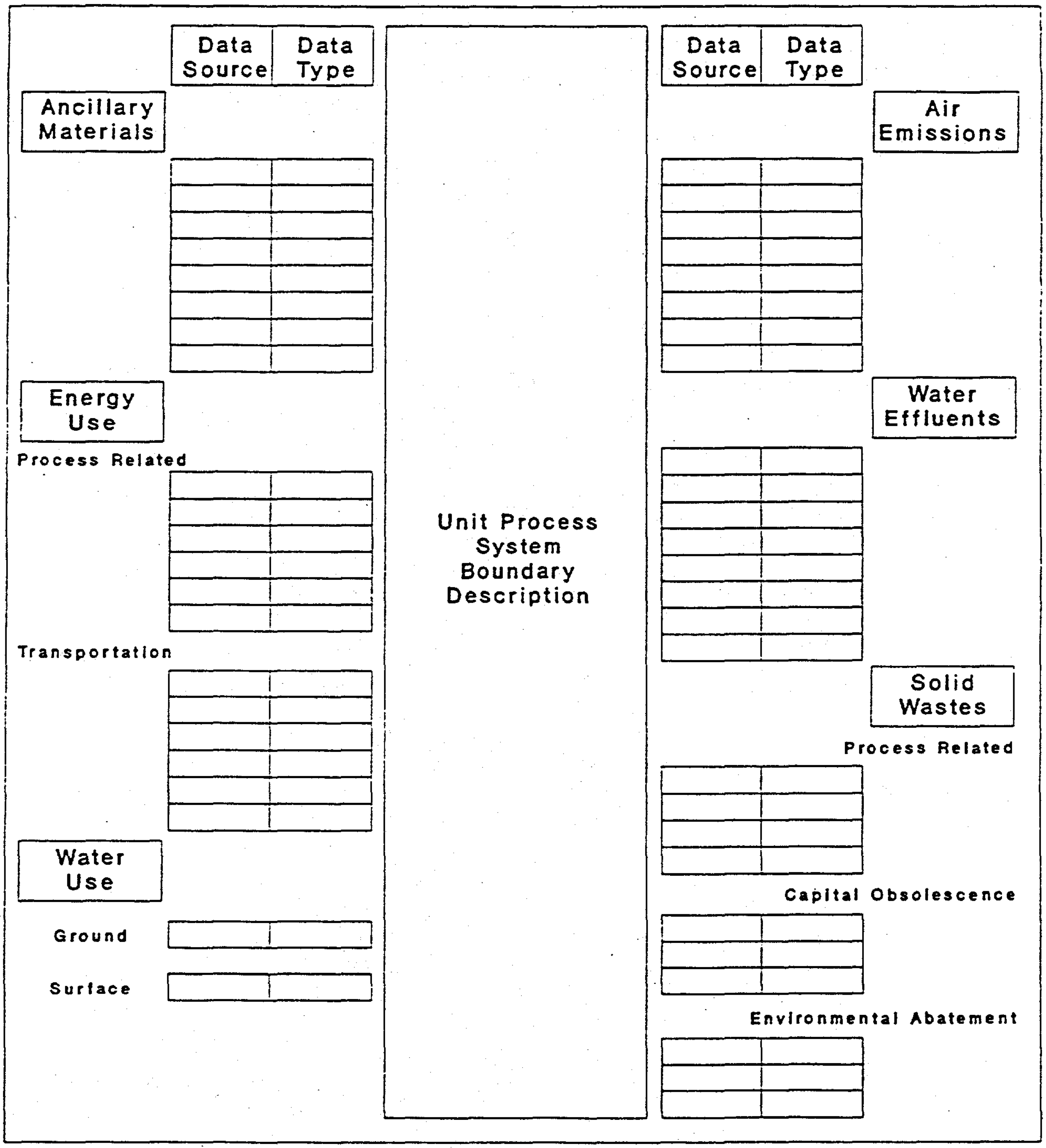


Figure 5.3. Input/Output Templates for a Unit Operation



Source: Adapted from Keoleian & Menerey, 1993

Figure 5.4. Data Availability Survey



Source: Canadian Standards Association, 1994

5.4.2 Perform the Data Availability Survey

Once the systems flow diagram has been developed, inputs and outputs for each unit operation in the main process flow must be established. A Data Availability Survey (DAS), such as shown in Figure 5-4, is a valuable tool for defining and structuring the collection of this information. For each unit operation, a section of the DAS is constructed and completed based on the study team's knowledge of the unit process, information from technical experts and reference materials, or input from facilities where those unit processes are carried out. Within each section, the data sources and data types should be indicated for each data category listed. This should be evaluated in the context of data quality that will be required for the particular unit process to determine if the available information will be adequate to meet the study objectives.

5.4.3 Unit Operation Boundary Description

Completion of the data availability survey begins by defining the unit operation boundaries which define the context for which data on the unit operation will be gathered. This description includes discussion of the raw or intermediate material(s) entering the unit operation, the specific operations and transformations conducted on these materials, and the precise delivery location of outputs. For each input and output, an indication is given of the source and type of data and quality required of it. Also included in the description are any data exceptions or exclusions. The next unit operation description begins where the previous description ends. The following sections discuss specific treatment of ancillary materials, energy, water, emissions and solid waste.

5.4.3.1 Ancillary Material Inputs

The next step is to list all each of the "significant" ancillary material used within the unit operation. See Chapter 4 for decision rules for including ancillary materials. For each, an indication is given of the expected data source (ex. purchasing records), type and quality.

5.4.3.2 Energy Use

Next, all primary fuels and purchased electricity used in the unit operation are listed. Care must be taken to avoid double counting, such as listing a primary fuel used and steam or electricity generated on-site from it. In these cases, the primary fuels are preferred.

Both energy associated with the process equipment and on-site transportation should be listed. Transportation of raw, intermediate, and ancillary materials and products to and from the site are not included at this point; they are best identified after all unit operation and material flows have been finalized.

One must also consider the relevance of "overhead" energy that is associated with the overall process (lighting, heating, etc.) but which is not identified with a specific unit process.

5.4.3.3 Water Use

It may be useful to segregate water use into different source categories such as groundwater or that obtained from surface waters.

5.4.3.4 Changes in the Environment

For environmental emissions and discharges, historical practice has been to use levels specified by regulatory statutes because of limitations in data availability. The DAS should list all perceived or known, reportable and monitored environmental changes and determine the nature of data that is available. Aggregation and classification should be done later when the material flows and data categories are finalized and will be driven by the study objectives, data available, and the type of impact evaluation to be performed. The following paragraphs define recommended practice for air emissions, water effluents, and solid waste.

Emissions to air reflect actual discharges through existing emission controls (such emissions are sometimes referred to as **"fugitive" emissions**) and are reported in units of weight.

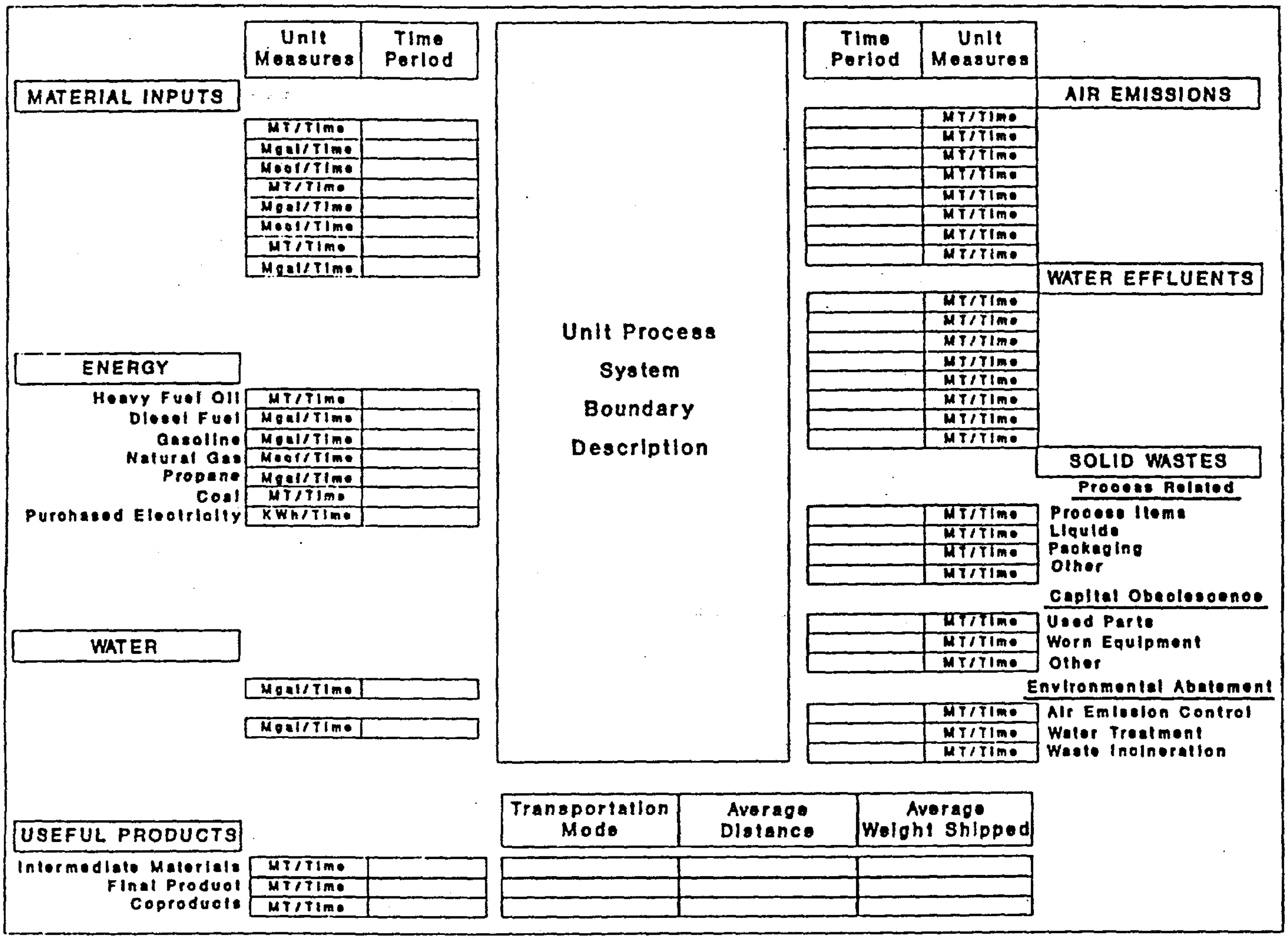
Effluents discharged to water reflect actual discharges present after existing wastewater treatments and are reported in units of weight.

Solid waste is all material disposed from all sources within the defined system and are most commonly reported by weight to some type of landfill. Solid wastes include materials discarded from the process (process waste), worn out equipment or parts (obsolescent capital), and solid matter from air and water pollution controls and from incineration.

5.4.4. Unit Process Data Input Sheet

Once the DAS is completed for all unit operations of the system, an analysis of the data categories identified is performed to decide which data categories to include and develop data input sheets. The DAS can also be very helpful for developing a single listing that can be applied to all of the main and ancillary flows and develop standardized data collection sheets, such as the example in Figure 5-5 derived from the Figure 5-3 **template**, that simplify data collection, database management, and modeling. The data input sheet is developed for each reporting site for each unit operation and each life-cycle stage investigated. Depending on the complexity and boundaries of the system being studied, the number of data input sheets can become very large.

Figure 5.5. Unit Operation Data Input Sheet



Source: Canadian Standards Association, 1994

5.5 Gathering the Data

5.5.1 Materials

Acquiring raw materials or energy resources involves disturbing the environment via harvesting of trees, using land for crops, in drilling for oil and gas, or mining for minerals and coal. **Resource requirements** should be quantified and included in the life-cycle inventory along with statistics that are available to quantify effects such as runoff of pesticides and fertilizers from agriculture, etc.

In analyzing the use of animal or plant products, the feed to produce the animal product or the seed, fertilizers, pesticides and fuels in growing the plant crop are the main raw materials to the system. Environmental changes are associated with all aspects of growing, tending, and harvesting these animal or plant products and hence all of these activities should be included in the system.

A number of issues surface in collecting materials data. The first is to decide on units of measure to be used. While most life-cycle studies use standard SI units as the common basis for summarization, SI units may not always be the most convenient basis for data collection due to lack of familiarity with the SI system by industry personnel. In many cases it will be most convenient to collect data from industrial operations using conventional measures that are familiar to operational personnel and to develop and apply conversion to a standard basis as part of database management and modeling. In forestry and the forest products industry, there are many unique measures for raw materials and products. Logs may be measured according to one of several board foot or cubic log rules. Lumber is measured in board feet, panel products in square feet, and other products in terms of either wet or dry weight. Often, there are regional differences in specific measures that are applied. It is recommended that data be gathered in customary units and that a group of experts from each region and/or industry sector develop appropriate conversion factors. This approach will minimize miscommunication and conversion errors during data collection and will facilitate and separate the verification and validation of original data from that of conversion factors during expert reviews.

5.5.2 Energy

Energy within a life-cycle inventory involves energy requirements for each unit process and can be very important since use of energy is often a major source of pollution. Energy is often quantified according to three categories: process energy, transportation energy, and inherent **energy of materials.**

5.5.2.1 Process Energy

Process energy is that consumed to operate the unit operations and machinery including boilers, blowers, pumps, dryers, saws, etc. It also includes the power supplied to a conveyor to carry material within the same unit operation. It does not include power supplied to a conveyor to transport material between unit operations; this is considered to be transport energy.

Within each unit operation, energy input data should be expressed as quantities of specific fuels (kwh electricity, cubic feet of natural gas, gallons of diesel, etc.) which are later converted to energy equivalents using conversion factors. This conversion to primary energy values includes combining both combustion and pre-combustion (energy of fuel acquisition) values; the latter being an expansion of the boundary to consider the energy that must be expended to acquire the fuel raw materials (e.g. coal mining and transport to a conversion plant), process the fuel into usable fuel, and delivering the usable fuel to the consuming process. In the case of electricity, delivery includes **transmission line losses**. Energy sources must also be carefully identified, including whether energy was generated off site or on-site, whether regional or national electric grid information is appropriate, and the use of peak versus off-peak hour generation since the type of incremental energy generation may be very different than the overall average mix. Careful consideration must be given to identifying possible energy and environmental credits associated with generation and export of on-site energy or use of off-peak capacity. Chapter 7 presents further discussion of energy.

5.5.2.2 Transportation Energy

Transportation energy is the energy required for modes of transportation such as trucks, rail, barges and ships, pipelines, etc. that move material from between unit processes or stages of the life-cycle. On-site transport such as conveyors, fork lifts, and other vehicles must be carefully labeled as to whether the associated energy is internal to the **unit operation** of interest and hence is process energy or is external to the unit operation in the sense that it is transportation between unit operations.

As in the case of process energy, transportation energy data should be expressed as quantities of specific fuels (kwh electricity, cubic feet of natural gas, gallons of diesel, etc.) which are later converted to energy equivalents using conversion factors. This conversion to primary energy values again includes both combustion and pre-combustion values. Chapter 7 provides further discussion and details.

5.5.2.3 Inherent Energy of Materials

Inherent energy of materials reflects the fact that many materials have an energy content and could, at some stage, be incinerated for their fuel value. It is important to include these inherent energy values from a thermodynamic balance point of view.

This energy category accounts for those products or materials that divert energy resources such as natural gas, oil, or coal to non-energy materials such as plastics or adhesives. In these cases the inherent energy (also called fuel-related inherent energy, latent energy of materials, or feedstock energy) is equivalent to the combustion value of the fossil fuel that was diverted. While these diversions from primary energy resources are straightforward, controversy has arisen in the case of wood and other biomass materials which have inherent energy but which are not considered to be primary fuel resources although **residues** from processing them are often incinerated for energy. Since the objective of a life-cycle study may be to examine the alternative of incinerating products made from these materials after they have served their useful life, it is recommended that any material that has inherent energy value be tracked as a distinguishable energy category as the uses of this latent energy of materials may be an important consideration in assessing the environmental performance of products. Chapter 7 presents further discussion of inherent energy values.

5.5.3 Water

Water requirements should be measured in gallons or liters and identified according to source with the minimum categorization being surface versus groundwater. The former may also be differentiated into drinking versus non-drinking water, stream, lake, impoundment or sea water, etc. depending on the study objectives. It is important to remember that water use competes with other consumptive uses and can affect navigation, aquatic habitats, etc.

5.5.4 Environmental Changes

Atmospheric emissions are reported in units of weight per unit product output. It is recommended that emissions data be gathered in the most specific form possible. Emissions include:

- **regulated emissions** that are monitored by regulatory agencies; amounts reported are actual emissions after passing though existing emission control devices
- fugitive emissions, often of those that are regulated, that are released from valves, storage areas, etc. directly to the atmosphere and do not pass through control devices.
- Other emissions such as carbon dioxide, water evaporation, etc. that are typically not regulated or monitored. Some of these may be important from an environmental point of view, such as the role of carbon dioxide in the greenhouse-effect, and should be included in data gathering.

Liquid and **waterborne** discharges are also reported in units of weight and expressed per unit of product output. As in the case of atmospheric emissions, most data is available and has been gathered for those that are included in current monitoring regulations and measure the quantities actually discharged from treatment facilities.

Solid waste includes all solid material that is disposed from all sources in the system and is typically reported by weight. These wastes are sometimes expressed in terms of volume of space occupied using landfill bulk density factors. It may be necessary to gather data in both forms to achieve consistency. At a minimum there is a distinction between industrial, post-consumer, and fuel related waste since they are often collected and treated at different facilities and with different methods.

Industrial solid waste refers to that generated during the production of a product and its packaging and is often categorized as:

- process related solid waste which is generated in the actual process and includes trim and scrap materials that are not recycled.

- capital obsolescence solid waste which is major worn-out equipment and parts that are replaced during the time period for which the inventory is gathered and may be prorated according to their useful life.
- environmental solid waste which includes slugs and solids from pollution control equipment.

Post-consumer solid waste refers to the product and **packaging** that has fulfilled its intended use and is discarded into the municipal solid waste stream which may then be segregated into that which is eventually recycled, reused, incinerated, or placed in a landfill.

Fuel related solid waste includes ash and other solids (mineral extraction waste, solids from utility air pollution controls) from the production and combustion of fuels for operating manufacturing processes and transportation.

Mine tailings, overburden, logging slash and agriculture field residues are not regulated as solid waste but may be useful to consider depending on the study objectives.

Finally, there are many other changes to the environment that have not been traditionally included in life-cycle inventories. These include such things as measures of habitats and biological diversity. Suitable alternatives for expressing and measuring these characteristics must be developed.

5.5.5 Products

Products are defined by the particular unit process. The sequence of unit operations leads to a final product which serves a role in performing the functional unit. Most unit operations produce an intermediate product that continues on the main flow that leads to the final product and functional unit and co-products that become inputs to systems other than the main system under study. The question of how to segregate and allocate data and results between the products on the main flow and the co-products is discussed in Chapter 6.

5.5.6 Complete the Data Input Sheets

After these issues and questions have been resolved, the decisions should be incorporated into instructions for completing the unit operation data sheets. These should be pre-tested using a focus group of industry personnel to clarify the instructions before they are completed by each operating facility chosen for sampling.

Care must be taken to include all significant ancillary flows; data for these are often available from purchasing records. Any of the decision rules for inclusion of ancillary materials must be clearly explained and understood by the person filling in the data sheets.

Care should also be taken to make sure that information is not lost by being included in an ambiguous "other" category. Instructions should request that all items be clearly specified.

5.6 Data Quality

The quality of data will greatly affect the study results and because these studies are very data intensive, development of a set of uniform quality criteria is essential for selection, integration and reporting. The basic requirements for data quality should be specified based on the study objectives. It is also important to understand desired versus achievable accuracy and precision considering **random** and statistical error, situations where judgments and estimates are necessary because data are missing, proprietary, too old, or too variable to be useful. From a data perspective a study can be viewed as having two key parts:

- a set of measurement data that may or may not be amenable to standard statistical analysis
- a set of assumptions and decision rules that dictate how the data are integrated to describe the system.

Life-cycle practitioners (SETAC, ISO, EPA) are developing a set of quantitative and qualitative data quality indicators (DQI's). Although the final system of DQI's has not been finalized, some of those commonly in use are described in the remainder of this section.

5.6.1 Quantitative DQI's

In addition to providing measures useful in assessing data quality, these quantitative DQI's are useful inputs in performing sensitivity analyses.

5.6.1.1 Precision

Precision measures the spread or variability of the values around their mean. The mean, standard deviation, and range of reported values are calculated and reported for each data category for each unit operation.

5.6.1.2 Completeness

Completeness measures the degree of coverage of the population by the sample from which data was collected. This may include percentage of facilities, percentage of production, etc.

5.6.1.3 Others

In addition to the above, the following may be used

- distribution - the actual frequency distribution on values within the data set
- homogeneity - a measure of how the data values lie within a specific statistical distribution
- correlation - patterns and structures within the data set; perhaps between geographic areas or over time
- uncertainty - statistical tests performed on the data sets

5.6.2 Qualitative DQI's

5.6.2.1 Consistency

Consistency is a term used to describe how uniformly the study methodology is applied to the various components of the study. Three key aspects of consistency are:

- Communication which can be facilitated by developing a clear understanding of what data is being requested, how it is to be measured, how it will be reported, and how it will be used. The DAS, described in Chapter 5.3, is very useful in developing this understanding. Data collection is also facilitated by using a standardized data collection sheet that should include a glossary describing what is to be included within each data category, directions on where and how to measure the data, instructions on sampling/analysis that may be needed, and unit of measure to use. All communications between the study team, the sample location, and those actually gathering the data should be written to provide clear and permanent documentation of how issues were resolved.
- Verification and critical review to determine if the communications were effective in gathering what was needed.
- Integration using a computer model. Each unit operation should be treated in the same fashion and steps should be taken to thoroughly document all aspects of computer model logic.

5.6.2.2 Applicability/Suitability

This refers to the relevance of data sets to the study objectives. It reviews data sources, types, and age as well as the technology employed in the unit operations that were measured to assess if these caused deviation from the stated study objectives.

5.6.2.3 Representativeness

This is an assessment of the degree to which data present a true and accurate portrayal of the typical or marginal conditions that were to be addressed by the study. It may involve comparison with other studies and reports.

5.6.2.4 Comparability

Comparability documents the degree to which the boundaries, data categories, assumptions, data sampling, and quality assurance allow for comparison of results and conclusions reached from different components of an analysis. A high level of similarity, hence comparability is desired but this may be compromised by limitations on proprietary aspects as well as other differences.

5.6.2.5 Anomalies and Missing Data

All cases of extreme and missing values in a data set should be identified with an explanation of probable cause and how they were subsequently treated. In many cases, anomalies and missing data can be checked with the original source to seek explanation.

5.6.2.6 Reproducibility

This describes whether there is sufficient data and methodological detail to allow an independent party to carry out the study analysis and reproduce the study results. Cases with proprietary data may lack sufficient transparency to allow this to be done in the public arena. This may be handled by having an independent third party certify that the results are reproducible, assuming, of course, that suitable agreements with respect to the proprietary data can be developed with the certifier.

5.6.2.7 Documentation

Documentation of all decisions and procedures associated with defining the objectives and scope of the study, data specificity and quality, system boundaries and flow diagrams, unit operations, data availability surveys, data input sheets, and treatment of ancillary materials will greatly facilitate subsequent assessment of the quality of the study results. This documentation will also be useful in communicating study requirements to those providing data and in presenting how the study was conducted to critical reviewers and those who commissioned the study.

Chapter 6. Modeling

6.1 General Modeling Approach

Because of the many calculations and decision rules that may be required in a typical life-cycle inventory, most of these will be performed through use of a computer program. The program should be designed to perform the normalization and allocation calculations described in the next sections and implement decision rules that finalize the overall system boundary. These rules include those associated with deciding which ancillary materials are to be included within the system boundaries (see section 4.2). Recycling, which is also described later in this chapter, is regarded as simply another set of unit operations.

The integration model should be designed to facilitate sensitivity analysis both in terms of alternative computational methods (more than one method for co-product allocation may be justifiable) and in terms of effects of variability and uncertainty in unit process data.

In addition to facilitating sensitivity analysis, the integration modeling involves data manipulations, called normalization, that allow merging of the unit operations together into the overall system being studied. Normalization involves two steps:

- Express the data for each unit process in terms of a standard quantity of output. The most widely used basis of expression is weight in SI units (e.g. 1000 kg). In the case of wood products, care must be taken with regard to moisture content and the recommended practice is to express wood products in terms of oven-dry weight. For example, the forest harvesting unit operation would convert volumes of logs from cubic feet, board feet, or green weight to oven dry weight. This step would also normalize all features of the harvesting operation on a per 1000 kg basis.
- Express the data from the sequence of unit operations in terms of the life cycle of the functional unit being examined. This involves re-expressing the results of the sequence of unit operations in terms of the functional unit that is the basis of study, carefully taking into account shares of inputs and outputs attributed to co-products.

6.2 Co-product Allocation

Many processes produce multiple outputs of which only a subset are of interest in the context of study objectives. A study of performance of housing designs requires the lumber manufacturing unit operation but, in addition to producing lumber, sawmills also produce large quantities of chips and sawdust that are sold for manufacture into paper or particleboard. The term co-product refers to outputs other than the primary product of interest. Co-products are of interest only because, up to some point in the unit process, they share inputs with the primary product of interest and also share in producing environmental changes. Beyond the point of sharing, co-products are of no further interest as their subsequent transport and processing are outside the boundaries of study. The conversion of the sawmill chips into paper and subsequent use and disposal of paper is outside the boundary of a study focusing on house construction.

Although each system must be examined on a case-by-case basis to decide on the appropriate co-product allocation method, the most commonly used approach is based on mass of materials. However, in the case of chemicals manufacture, it may be necessary to write balanced chemical equations and trace the chemical stochiometry from raw chemicals into the products. In other situations, the heat of reaction may be a more appropriate basis for allocating energy. Some have also argued that the selling price of co-products should be used as the basis for allocation.

There are some situations where it is difficult to decide on the relevance of an allocation. Examples are

- one or more co-products may have such low economic value relative to its mass as to question the need for allocation.
- when is an output a co-product rather than a waste?

When logs are processed for wood products, is bark a co-product or a waste? For some manufacturers, bark has value for conversion to process energy or sale for landscaping but for others bark is a solid waste problem. This often depends on the mill size and its location relative to markets. In mining, the desired high value mineral may be a very tiny fraction of the ore and the discarded material may have a very low selling value for use in some other application. In these cases, co-product allocation must be very carefully examined and the decision to either ignore allocation or use a special method must be explained.

Detailed examples of specific co-product allocation methods are available in the LCA references listed in the Bibliography. Since allocation alternatives that may be used may produce greatly different results, the choice of a specific method in a given situation should be carefully reviewed. If more than one method is justifiable, consideration should be given to using each of them in order to understand the sensitivity of study results and conclusions.

6.2.1 Industrial Scrap

Industrial scrap refers to trim scraps, reject and off-specification materials from a process that are collected and used as inputs to other processes. Many scrap pieces of lumber can be salvaged, have defects removed, and be finger-jointed together to make other products. These scraps are distinct from post-consumer waste, and must be carefully reviewed to determine how they should be treated. A sawmill producing studs may salvage trim scraps that may either be sold to another industry (such as millwork) or it may have a process to reassemble these scraps to make additional studs. In once case the scrap is a co-product that exits the boundary while in the other case the scrap is input to another unit process that produces additional primary product.

6.2.2 Transportation

Transportation can become involved in allocation problems particularly where backhauling occurs. If a truck delivers paper to a consumer and returns empty, it is clear that the round trip is charged to paper delivery. However, if the truck delivers paper and then picks up another material (perhaps paper for recycling) for delivery to the paper mill or elsewhere then only the segment associated with paper is charged to paper and the balance to the second material.

6.3. Recycling

Recycling reduces the amount of waste entering landfills and the requirements for virgin raw materials. Two alternative recycling systems commonly occur; closed-loop and open-loop.

6.3.1 Closed-Loop Recycling

Closed loop recycling occurs when a product is recycled into a process that produces the same product again. Examples are aluminum cans, glass bottles, and many paper products. In cases such as aluminum cans, closed loop recycling can theoretically repeat indefinitely. The analyst must be careful to consider various losses that may occur in order to estimate the true net recycle rate. These losses include fractions not collected for recycling and rejects that may occur during unit operations of the recycling process.

In other cases, such as many paper products, two additional phenomena may occur. First, wood fibers degrade after several uses to the point where they are no longer useful for making paper, hence the number of iterations through the recycling loop is finite. Second, recycled paper is often converted into a lower paper grade. This case of recycling into lower grades begins to take on characteristics of open-loop recycling in the next section.

The LCA References listed in the Bibliography provide excellent examples of mathematical formulation of closed loop recycling.

6.3.2 Open-Loop Recycling

In **open-loop recycling**, an initial product, made from virgin material, is recycled into a second product which may in turn be recycled into a third product. This is sometimes referred to as chain or cascade recycling. Examples include plastic containers that are recycled into fibers for carpeting or clothing, plastics recycled into plastic lumber, and used wood building materials that are converted into pulp chips or particles for particleboard.

In addition to carefully accounting for fractions that are not collected for recycling and rejects during the various recycling steps, care must be taken in allocating the material inputs, energy and environmental changes associated with the recycling among the products.

As an example, a hypothetical Product 1 is manufactured and after use, a fraction is collected and recycled to manufacture Product 2. Recycling product 1 reduces solid waste associated with Product 1 and reduces demand for virgin raw material needed for Product 2. Assume that Product 2 is disposed of after use with no recycling. Correct allocation of inputs and outputs among these products is best treated by expanding the study boundaries to encompass the systems for both Product 1 and Product 2. While this is the preferred option, it may not be feasible within the time and financial constraints of a study. In this case, there are several possible methods for allocating inputs and outputs among the products, including:

- allocation based on the percentage of the two products produced.
- allocate disposal credits to the product being recycled.
- divide the effects of recycling equally between the two products.

The LCA References listed in the Bibliography provide excellent examples of mathematical formulations of open-loop recycling and various allocation methods. These various allocation methods tend to be somewhat arbitrary and the selection of one may affect results and conclusions. When one of these allocation methods is chosen, it is important to clearly define the method used, justify its use, and use it consistently. It is also desirable to test the effect of using an alternative method with sensitivity analysis.

6.3.3 Composting

Composting is a disposal alternative where organic materials, including paper and solid wood products, are removed from the solid waste stream and converted into a soil amendment that can replace topsoil, fertilizer, etc. In this context, composting is a form of open-loop recycling.

Chapter 7. Energy Data & Associated Environmental Emissions

7.1 Introduction

Energy is obtained from many sources including coal, hydropower, natural gas. oil, nuclear, wind, solar, biomass, and incineration of waste. Fuels are often interchangeable and utilities and manufacturers select among them based on their energy content and cost. However, other factors such as emissions to the environment have a role in the choice of energy sources. For this reason, inventory should characterize the energy requirements according to the basic sources of energy. In the case of electricity, the inventory should consider both the overall electricity consumed as well as the mix of basic sources (coal, hydro, nuclear, etc.) that produce the electricity.

7.2 Measurement Unit for Energy

The standard units of energy for CORRIM II will be British thermal units (BTU's) and joules. It is recommended that both units be presented in all CORRIM II analyses and reports. Appendix 7.1 provides conversion factors for converting various energy units to these standard units.

7.3 Energy Content of Materials

Many materials have an energy content and from a thermodynamic perspective it is important that an overall energy balance is maintained within each subsystem.

7.3.1 Materials Produced from Primary Energy Resources

The energy content of materials whose alternative and often primary use in the case of coal, oil and natural gas, is fuel for generation of energy is referred to as fuel-related energy, latent energy, inherent energy, embodied energy[1], or feedstock value. An example where a primary energy resource has been diverted to a material is plastics which are formed from petroleum and natural gas. This decision to divert an energy resource into a material and thereby reduce finite energy fuel reserves, is treated by assigning a "diverted energy" value to these materials. This assigned value is the equivalent of the fossil fuel combustion value of the diverted energy resources plus the process and transportation energy associated with manufacture of these materials.

7.3.2 Secondary Energy Materials

Other materials such as wood and biomass that are not customarily used as primary energy resources also have inherent energy. In some processing industries, by-products from

[1] Many references also use the term embodied energy to refer to the cumulative energy invested in the material or a products by the time of use.

manufacturing these materials are incinerated to produce **process energy** and hence reduce demand for primary fuels. Furthermore, the finished products from these materials may be incinerated for energy after disposal at the end of their useful lives. For these reasons, it is recommended that the energy content of these materials be tracked. It is also recommended that the various categories of materials with inherent energy be kept separate so that differences and trade-offs can be explicitly identified in study results.

7.3.3 Higher Heating Value

Higher heat value (HHV) is the gross heat of combustion chemically embodied in a material. It does not reflect thermal yield available after considering losses due to moisture content of the fuel, inefficiency of combustion systems, etc. It is recommended that HHV be assigned as the inherent energy stored in materials as these data are readily available and not subject to variation in factors that affect thermal yield. HHV information will be necessary for materials such as wood or plastic that can be incinerated to produce energy. Appendix 7.2 provides HHV values for various materials. Conversion from HHV to usable thermal yield should be treated by including combustion/incineration as a unit operation within the product life-cycle.

7.4 Pre-Combustion Energy (Energy of Fuel Acquisition)

When fuels are combusted into energy, this is only a portion of the total energy since energy was also expended to extract, transport, and process the fuel prior to actual combustion of the fuel into energy. This additional energy is called pre-combustion energy. Including pre-combustion energy is necessary to portray the true demand of the system under study and effectively extends the system boundary to include activities associated with the creation of energy. Appendix 7.3 provides pre-combustion data for various fuels. Pre-combustion energy may be distinguished according to source, e.g., fossil fuel or biomass.

7.5 Electrical Energy

Important considerations when examining electricity are the source(s) of fuel used to generate the electricity and the efficiency associated with the generating system. Utilities use fossil fuels (coal, oil, natural gas), hydropower, nuclear power, wind, geothermal, biomass, and post-consumer waste to generate electricity. Electricity generation may also involve the use of process steam for parallel and co-generation facilities. Accurate estimation of electrical energy use and associated environmental effects raises a number of issues and difficulties in relating the actual electricity consumed by a single manufacturer or product to the actual fuel used.

Although a consumer pays a particular utility, it does not necessarily obtain power from the nearest plant. When electricity is generated by a given facility and fed into power lines, it is no longer distinct from electricity from any other facility. Individual facilities of a utility may use different fuels and electricity from them is commingled in the transmission lines of that utility which are interconnected with neighboring utilities to form regional and national grids. Life-cycle inventories are commonly based on the average fuel mix of regional or national grids. In many cases, where an industry is widely scattered, the average mix of the national grid may be reasonable but there may be exceptions when major regional differences exist, when there are important shifts in fuels from peak to off-peak generation, or when regional differences are part of the study objectives.

The efficiency of the electricity generating and delivery system must also be considered. The efficiency of a specific generation system or grid would be obtained by comparing actual fuels consumed to the actual electricity delivered for useful work. This would incorporate both boiler inefficiencies and transmission line loss. As an example, the theoretical conversion from kilowatt hours (kwh) to megajoules is 3.61 but the U.S. EPA estimates an average conversion of 11.3 MJ/kwh to deliver electricity from the national grid which an average efficiency of about 32%.

Nuclear and hydropower present special problems. There is no measure of nuclear power directly equivalent to the heating values of conventional fuels so nuclear power is commonly measured at its fossil fuel equivalency. Pre-combustion energy associated with mining and processing of nuclear fuels plus the extra energy required for shielding nuclear plants are added to the fuel equivalency value. In the case of hydropower where water has no inherent energy value per se, the conventional method is to assign the theoretical energy equivalence of 3.61 MJ/kwh with no pre-combustion energy added.

Appendix 7.4 presents annual data on the U.S. electric generation grid since 1978. Conversion of electricity consumption at a manufacturing facility to demand from the electrical generating grid must include

- transmission line losses
- conversion efficiency of the generating plant
- combustion efficiency of the fuel used (moisture content effect)
- pre-combustion energy for delivered fuel resources

Appendix 7.4 also provides electric generation facility efficiency data.

7.6 Transportation Energy

Transportation energy includes truck, rail, barge, ocean vessel, etc. The energy associated with transporting products varies with

- quantity of the product.
- size and fuel efficiency of the "vehicle."
- load factor; load as a percent of capacity.
- whether or not back-hauling occurs.
- route; city vs rural highways, etc.

Appendix 7.5 presents a set of average data for transportation modes that may be refined by further data collection by CORRIM II.

7.7 Environmental Emissions Associated with Energy Use

Combustion of fuels generates air emissions and solid waste. Appendix 7.6 summarizes current data on environmental releases associated with various fuels.

Appendix 7.1: Energy Conversion Factors

	btu	erg	foot-lb	gram-calories	hp-hr	joule	kilogram calories	kilogram meters	kilowatt hours
btu	1	1.055×10^{10}	778.3	252	3.931×10^{-4}	1054.8	0.250	107.5	2.928×10^{-4}
erg	9.480×10^{-11}	1	7.367×10^{-8}	0.2389×10^{-7}	3.725×10^{-14}	1×10^{-7}	2.389×10^{-11}	1.020×10^{-8}	0.2778×10^{-13}
foot-lb	1.286×10^{-3}	1.356×10^{7}	1	0.3238	5.050×10^{-7}	1.356	3.24×10^{-4}	0.1383	3.766×10^{-7}
gram-calories	3.968×10^{-3}	4.187×10^{7}	3.0880	1	1.560×10^{-6}	4.187	1×10^{-3}	0.427	1.163×10^{-6}
hp-hr	2547	2.685×10^{13}	1.98×10^{6}	641190	1	2.685×10^{6}	641.2	2.737×10^{5}	0.746
joule	9.480×10^{-4}	1×10^{7}	0.738	0.239	3.726×10^{-7}	1	2.389×10^{-4}	0.102	2.778×10^{-7}
kilogram calories	3.968	4.187×10^{10}	3088	1000	1.560×10^{-3}	4187	1	426.9	1.163×10^{-3}
kilogram meters	9.294×10^{-3}	9.804×10^{7}	7.233	2.342	3.654×10^{-6}	9.804	2.342×10^{-3}	1	2.723×10^{-6}
kilowatt hours	3413	3.600×10^{13}	2.655×10^{6}	859850	1341	3.6×10^{6}	860.5	3.671×10^{5}	1

Source:

Briggs, D.G. 1994 Forest Products Measurements and Conversion Factors - with special emphasis on the U.S. Pacific Northwest. Contribution No. 75, Institute of Forest Resources, College of Forest Resources, University of Washington, Seattle, WA.

Appendix 7.2: Higher Heating Values

Fuel	Heat Content. btu/lb	physical state
methane	23878	gas
natural gas	21600	gas
gasoline	20750	liquid
fuel oil	19400	liquid
petroleum. crude	19300	liquid
coal. anthracite	14920	solid
coal. high-temperature	14030	solid
charcoal	13780	solid
ethanol	12780	liquid
lignite	12230	solid
peat	10250	solid
wood. softwood	9000	solid
wood. hardwood	8300	solid

Sources:

Briggs, D.G. 1994 Forest Products Measurements and Conversion Factors - with special emphasis on the U.S. Pacific Northwest. Contribution No. 75, Institute of Forest Resources, College of Forest Resources, University of Washington, Seattle, WA.

Young, R.A., McGovern, J.N., Rowell, R.M. 1990. Wood for fiber, Energy and Chemicals. Ch 23 of R.A. Young & R.L. Giese Introduction to Forest Science, 2nd ed. John Wiley.

Appendix 7.3: Pre-Combustion Energy for Fuels (MJ)

Fuel	Unit	Delivered	Precombustion	Total
Heavy fuel oil	1 kg	36.4	6.1	42.6
Diesel	1 liter	38.7	6.5	45.2
Gasoline	1 liter	34.9	5.9	40.8
Natural gas	1 cubic meter	38.4	3.2	41.6
Propane	1 liter	25.5	4.3	29.8
Coal	1 kg	19.9	0.8	20.7
Wood	1 kg	8.5	0.81	9.7

This list may be expanded and regionalized as needed. The units and data values are illustrative and taken from Canadian Standards Association Plus 116 (1996)

Appendix 7.4:

Electricity Generation Efficiencies and Precombustion Energy (joules)

Fuel	Efficiency Percent	Precombustion Energy
Fuel Oil	33	43.9
Natural gas	33	7.1
Coal	33	93.2
Hydroelectric	95	0
Nuclear	35	0

Includes 8% transmission line loss. This list may be expanded and regionalized as needed. The units and data values are illustrative and taken from Canadian Standards Association Plus 116 (1996)

U.S. Electric Utility Net Generation of Electricity

	Electric utility net generation of electricity by energy source												
	Fossil fuels				Renewable energy				Percent of total energy from				
Year	Coal	Natural gas	Oil	Nuclear	Hydro.	Geotherm.	Other	Total	Coal	Gas	Oil	Nuclear	Hydro.
	(billion kWh)								(%)				
1978	975.7	305.4	365.1	276.4	280.4	3.0	0.3	2,206.3	44.22	13.84	16.55	12.53	12.71
1979	1,075.0	329.5	303.5	255.2	279.8	3.9	0.5	2,247.4	47.84	14.66	13.51	11.35	12.45
1980	1,161.6	346.2	246.0	251.1	276.0	5.1	0.4	2,286.4	50.80	15.14	10.76	10.98	12.07
1981	1,203.2	345.8	206.4	272.7	260.7	5.7	0.4	2,294.8	52.43	15.07	9.00	11.88	11.36
1982	1,192.0	305.3	146.8	282.8	309.2	4.8	0.3	2,241.2	53.19	13.62	6.55	12.62	13.80
1983	1,259.4	274.1	144.5	293.7	332.1	6.1	0.4	2,310.3	54.51	11.86	6.25	12.71	14.38
1984	1,341.7	297.4	119.8	327.6	321.2	7.7	0.9	2,416.3	55.53	12.31	4.96	13.56	13.29
1985	1,402.1	291.9	100.2	383.7	281.1	9.3	1.4	2,469.8	56.77	11.82	4.06	15.54	11.38
1986	1,385.8	248.5	136.6	414.0	290.8	10.3	1.2	2,487.3	55.72	9.99	5.49	16.65	11.69
1987	1,463.8	272.6	118.5	455.3	249.7	10.8	1.5	2,572.1	56.91	10.60	4.61	17.70	9.71
1988	1,540.7	252.8	148.9	527.0	222.9	10.3	1.7	2,704.3	56.97	9.35	5.51	19.49	8.24
1989	1,553.7	266.6	158.3	529.4	265.1	9.3	2.0	2,784.3	55.80	9.58	5.69	19.01	9.52
1990	1,559.6	264.1	117.0	576.9	279.9	8.6	2.1	2,808.2	55.54	9.40	4.17	20.54	9.97
1991	1,551.2	264.2	111.5	612.6	275.5	8.1	2.1	2,825.0	54.91	9.35	3.95	21.68	9.75
1992	1,575.9	263.9	88.9	618.8	239.6	8.1	2.1	2,797.2	56.34	9.43	3.18	22.12	8.56
1993	1,639.2	258.9	99.5	610.3	265.1	7.6	2.0	2,882.5	56.87	8.98	3.45	21.17	9.20
1994	1,635.1	291.0	91.3	639.4	243.6	7.0	2.0	2,909.4	56.20	10.00	3.14	21.98	8.37

Source:

Energy Information Administration. 1995. Monthly Energy Review. U.S. Department of Energy. Washington, D.C. (March) Table 7.1 page 95. Table & graph prepared from this source by Gilbreath (1996)

Appendix 7.5: Transportation Energy

Mode	Fuel	Gal/Ton-mile
Ocean vessel	Heavy fuel oil	0.00106
Barge	Heavy fuel oil	0.00241
Rail	Diesel	0.00313
Truck (bulk)	Diesel	0.00943

The units and data values are illustrative and taken from Canadian Standards Association Plus 116 (1996)

Appendix 7.6: Emissions Data for Fuels

The units and data values in the following pages are illustrative and taken from Canadian Standards Association Plus 116 (1996). These may be regionalized and expanded.

Table B5
Emissions Data for Primary Fuels

Precombustion Factors (Per Fuel Unit)

	Heavy fuel oil barrels	Diesel barrels	Gasoline barrels	Natural gas MSCF	Propane Mgals	Coal tons
Air emissions (lb)						
Particulates	1.04E-01	9.64E-02	8.69E-02	1.22E-02	1.51E+00	3.98E+00
SO_x	1.29E+00	1.20E+00	1.08E+00	1.22E-02	1.88E+01	1.28E+00
NO_x	8.61E-01	7.99E-01	7.20E-01	8.78E-02	1.25E+01	6.88E-01
CO	7.42E-02	6.89E-02	6.21E-02	0.00E+00	1.30E+00	2.46E-01
CO_2	1.56E+02	1.45E+02	1.30E+02	5.62E+00	2.27E+03	1.20E+02
Organics	8.76E-01	8.12E-01	7.32E-01	4.44E-01	2.16E+01	2.95E-01
Solid Waste (lb)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.44E-01
Net Water Use (Mgal)	7.14E-02	6.63E-02	5.97E-02	0.00E+00	1.04E+00	4.85E-01
Water Effluent (lb)						
TSS	1.48E-02	1.38E-02	1.24E-02	0.00E+00	2.16E-01	1.08E+00
Oils/Grease	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dissolved Metals	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Organics	1.93E-01	1.79E-01	1.61E-01	0.00E+00	2.59E+00	0.00E+00
BOD	1.48E-02	1.38E-02	1.24E-02	0.00E+00	2.16E-01	0.00E+00

Precombustion Factors (Per MMBtu)

	Heavy fuel oil	Diesel	Gasoline	Natural gas	Propane	Coal
Air Emmissions (lb)						
Particulates	1.65E-02	1.65E-02	1.65E-02	1.18E-02	1.65E-02	1.91E-01
SO_x	2.05E-01	2.06E-01	2.06E-01	1.18E-02	2.05E-01	6.14E-02
NO_x	1.37E-01	1.37E-01	1.37E-01	1.42E-01	1.37E-01	3.30E-02
CO	1.18E-01	1.18E-02	1.18E-01	1.42E-02	1.42E-02	1.18E-02
CO_2	2.48+01	2.48E+01	2.48E+01	9.56E+00	2.49E+01	5.78E+00
Organics	1.39E-01	1.39E-01	1.39E-01	4.55E-01	2.36E-01	1.42E-02
Solid Waste (lb)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.65E-02
Net Water Use (Mgal)	1.14E-02	1.14E-02	1.14E-02	0.00E+00	1.14E-02	2.33E-02
Water Effluent (lb)						
TSS	2.36E-03	2.36E-03	2.36E-03	0.00E+00	2.36E-03	5.19E-02
Oils/Grease	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dissolved Metals	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Organics	3.07E-02	3.07E-02	3.07E-02	0.00E+00	2.83E-02	0.00E+00
BOD	2.36E-03	2.36E-03	2.36E-03	0.00E+00	2.36E-03	0.00E+00

Table B6
Emissions Data for Power Plants

	Fuel oil	Natural gas	Coal	Nuclear
	Factors without Fuel Precombustion Burden (Per MMBtu Heat Input)			
Air Emissions (lb)				
Particulates	7.87E-02	3.48E-03	4.89E-02	
SO_x	8.89E-01	7.67E-04	1.84E+00	
NO_x	3.67E-01	4.49E-01	8.87E-01	
CO	3.93E-02	4.60E-02	3.17E-02	
CO_2	1.69E+02	1.09E+02	2.53E+02	
Organics	6.56E-03	2.30E-03	5.24E-03	
Solid Waste (lb)	0.00E+00	0.00E+00	1.15E+01	
Net Water Use (Mgal)	1.14E+00	1.14E+00	1.14E+00	1.08E+00
Water Effluent (lb)				
TSS	9.13E+00	9.13E+00	9.13E+00	8.70E+00
Oils/Grease	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dissolved Metals	9.61E-02	9.61E-02	9.61E-02	9.15E-02
Organics	4.80E-02	4.80E-02	4.80E-02	4.58E-02
BOD	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Factors with Fuel Precombustion Burden (Per MMBtu Heat Input)			
Air Emissions (lb)				
Particulates	9.52E-02	1.57E-02	2.40E-01	
SO_x	1.09E+00	1.26E-02	1.90E+00	
NO_x	5.04E-01	5.91E-01	9.20E-01	
CO	5.11E-02	4.60E-02	4.35E-02	
CO_2	1.94E+02	1.18+02	2.59E+02	
Organics	1.46E-01	4.57E-01	1.94E-02	
Solid Waste (lb)	0.00E+00	0.00E+00	1.15E+01	
Net Water Use (Mgal)	1.15E+00	1.14E+00	1.16E+00	1.08E+00
Water Effluent (lb)				
TSS	9.13E+00	9.13E+00	9.18E+00	8.70E+00
Oils/Grease	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dissolved Metals	9.61E-02	9.61E-02	9.61E-02	9.15E-02
Organics	7.87E-02	4.80E-02	4.80E-02	4.58E-02
BOD	2.36E+00	0.00E+00	0.00E+00	0.00E+00

Table B7
Emissions Data for Industrial Facilities

Factors without Fuel Precombustion Burden (Per MMBtu Heat Input)

	Fuel oil ind. boiler	Diesel ind. boiler	Diesel ind. eng.	Gasoline ind. eng.	Natural gas ind. boiler	Propane ind. boiler	Coal ind. boiler
Air Emissions (lb)							
Particulates	7.87E-02	1.44E-02	2.42E-01	5.17E-02	4.87E-03	5.52E-03	1.09E-01
SO_x	8.89E-01	8.89E-01	2.25E-01	4.25E-02	5.41E-04	6.13E-04	2.05E+00
NO_x	3.67E-01	1.44E-01	3.38E+00	8.16E-01	6.18E-01	7.01E-01	7.32-E01
CO	3.34E-02	3.61E-02	7.35E-01	3.15E+01	9.47E-02	1.07E-01	9.72E-02
CO_2	1.70E+02	1.63+02	1.63E+02	1.78E+02	1.09E+02	1.23E+02	2.53E+02
Organics	8.55E-03	1.80E-03	2.70E-01	1.06E+00	1.49E-02	1.69E-02	3.89E-03
Solid Waste (lb)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.15E+01
Net Water Use (Mgal)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water Effluent (lb)							
TSS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Oils/Grease	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dissolved Metals	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Organics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BOD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Factors with Fuel Precombustion Burden (Per MMBtu Heat Input)							
Air Emissions (lb)							
Particulates	9.52E-02	3.10E-02	2.58E-01	6.83E-02	1.67E-02	2.20E-02	3.00E-01
SO_x	1.09E+00	1.09E+00	4.31E-01	2.48E-01	1.24E-02	2.06E-01	2.12E+00
NO_x	5.04E-01	2.81E-01	3.52E+00	9.53E-01	7.61E-01	8.38E-01	7.65E-01
CO	4.52E-01	4.79E-02	7.47E-01	3.15E+01	9.47E-02	1.21E-01	1.09E-01
CO_2	1.94E+02	1.88E+02	1.88E+02	2.03E+02	1.18E+02	1.48E+02	2.59E+02
Organics	1.48E-01	1.41E-01	4.10E-01	1.19E+00	4.69E-01	2.53E-01	1.80E-02
Solid Waste (lb)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.15E+01
Net Water Use (Mgal)	1.14E-02	1.14E-02	1.14E+00	1.14E+00	0.00E+00	1.14E-02	2.33E-02
Water Effluent (lb)							
TSS	2.36E-03	2.36E-03	2.36E-03	2.36E-03	0.00E+00	2.36E-03	5.19E-02
Oils/Grease	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dissolved Metals	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Organics	3.07E-02	3.07E-02	3.07E-02	3.07E-02	0.00E+00	2.83E-02	0.00E+00
BOD	2.36E-03	2.36E-03	2.36E-03	2.36E-03	0.00E+00	2.36E-03	0.00E+00

Table B8
Emissions Data for Transportation

Factors without Fuel Precombustion Burden (Per MMBtu Heat Input)

	Ocean vessel heavy fuel oil	Barge heavy fuel oil	Rail diesel	Truck diesel
Air Emissions (lb)				
Particulates	1.34E-01	0.00E+00	1.80E-01	4.54E-01
SO_x	1.27E+00	2.14E-02	4.11E-01	3.24E-01
NO_x	3.73E-01	1.87E+00	2.67E+00	9.63E-01
CO	2.30E-02	6.68E-01	9.37E-01	7.30E-01
CO_2	1.70E+02	1.70E+02	1.63E+02	1.63E+02
Organics	4.56E-03	3.34E-01	6.78E-01	2.13E-01
Solid Waste (lb)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Net Water Use (Mgal)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water Effluent (lb)				
TSS	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Oils/Grease	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dissolved Metals	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Organics	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BOD	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Factors with Fuel Precombustion Burden (Per MMBtu Heat Input)

	Ocean vessel heavy fuel oil	Barge heavy fuel oil	Rail diesel	Truck diesel
Air Emissions (lb)				
Particulates	1.50E-01	1.65E-02	1.97E-01	4.71E-01
SO_x	1.48E+00	2.27E-01	6.17E-01	5.30E-01
NO_x	5.10E-01	2.01E+00	2.80E+00	1.10E+00
CO	3.48E-02	6.80E-01	9.49E-01	7.42E-01
CO_2	1.94E+02	1.94E+02	1.88E+02	1.88E+02
Organics	1.44E-01	4.73E-01	8.17E-01	3.52E-01
Solid Waste (lb)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Net Water Use (Mgal)	1.14E-02	1.14E-02	1.14E-02	1.14E-02
Water Effluent (lb)				
TSS	2.36E-03	2.36E-03	2.36E-03	2.36E-03
Oils/Grease	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dissolved Metals	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Organics	3.07E-02	3.07E-02	3.07E-02	3.07E-02
BOD	2.36E-03	2.36E-03	2.36E-03	2.36E-03

Chapter 8. Linking Life-Cycle Inventory and Benefit Cost Analysis in Forest Products

8.1 Introduction

In the past, most life-cycle inventories (Figure 8.1) were performed on non-durable products for which the time from resource extraction until post-consumer disposal was so short that the time dimension could be ignored. These inventories were performed at the individual plant level or with regional or national average statistics. Results from these inventories can be related to economics by altering the system with, say, a product design change that substitutes a more benign raw material, and comparing change in an LCI parameter with changes in revenues and costs. This type of analysis commonly occurs at the individual plant level and falls under the improvement analysis phase of Life-Cycle Analysis.

Applications to more durable products such as wood or steel often focus on processes and products up to the time when the consumer received the product (Figure 8.2). Inventories that stop at delivery to the customer exclude all aspects of consumer use of the product and its eventual disposal characteristics. In the case of wood, resource extraction is commonly assumed to begin with tree harvesting. These could be referred to as "stump-to-gate" studies in the case of products such as lumber, plywood, composite beams, etc. or "stump-to-structure" studies in the case of a completed new home with a "for sale" sign. Commonly, the total time from harvest to completed house is short enough, about 2 years, that the temporal dimension is generally ignored. Although useful, these are incomplete life-cycle assessments and a number of difficulties appear when boundaries are extended to include activities associated with consumer use and disposal and, in the case of wood, extended to include the forest processes that grow wood.

8.2 Extending Through House Occupancy and Disposal

When the boundary definition is extended to incorporate house occupancy and forest processes, the time dimension becomes great and presents difficulties. This section considers extending the wood product system to include occupancy, use, and eventual disposal of a house and the next section considers extending the system to include the forestry processes of growing wood.

If the functional unit of study is a single family home, the new house is occupied and (1) consumes energy throughout its life, (2) periodically requires certain maintenance (painting) and replacement (re-roof) activities, (3) involves other repair and remodeling changes as owners modify it according to style changes (new doors) cycles and (4) is eventually torn down and the materials recycled, reused or disposed to the earth. Figure 8.3, in which the "stump-to-structure" subsystem in Figure 8.2 is represented by the "S/S" block, simplifies occupancy into three phases:

Figure 8.1. General Flows in a "Cradle-to-Grave" LCA of a System

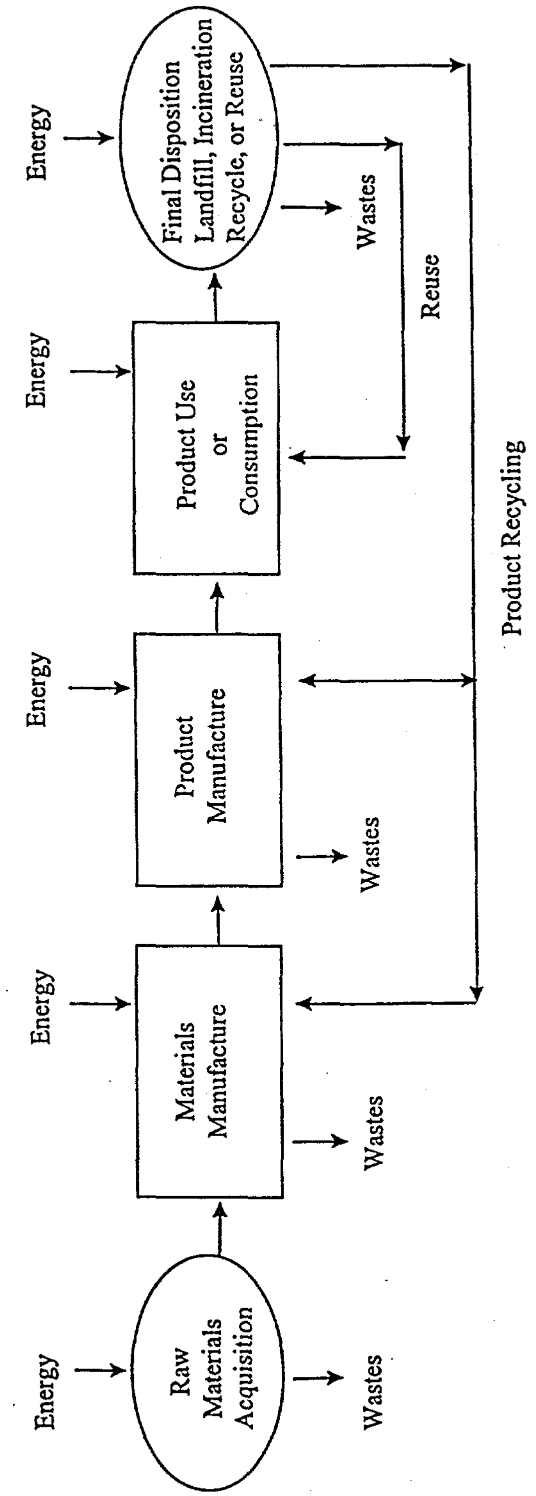
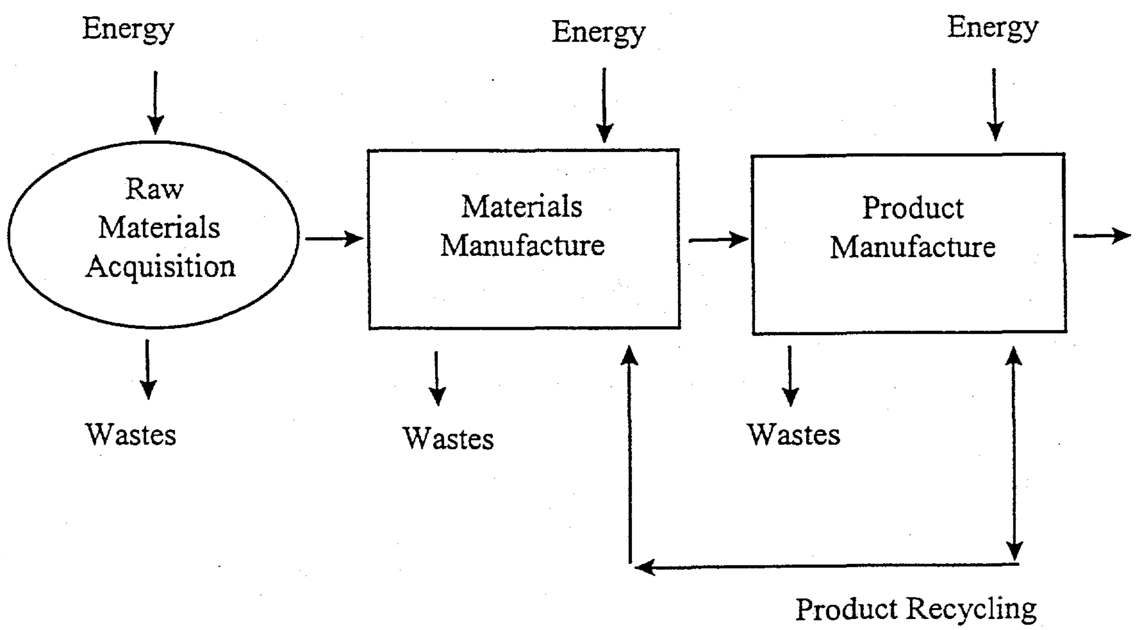


Figure 8.2. An Incomplete LCA: "Stump-to-Gate" or "Stump-to-Structure"



- **young**: relatively little maintenance, replacement, or remodeling occurs during the early use of a new home.

- **middle-aged:** the first cycle of maintenance and replacement activities begins, hence there is demand for materials to accomplish them as well as disposal issues for the replaced materials.

- **old-aged**: maintenance and replacement cycles may intensify as the house becomes outdated and homeowners undertake various remodeling steps.

Figure 8.3 Extension Through House Occupancy and Disposal

S/S	y	m	o	d
	o	i	l	I
	u	d	d	s
	n	d		p
	g	l		o
		e		s
				e

h .... time ....T

Theoretically, the home could remain in place indefinitely but at some point it is likely to be demolished with final disposition of materials.

If the "Stump-to-Structure" stage is regarded as the present point in time, extension through occupancy, use, and disposal requires forecasting the timing of maintenance cycles as well as materials that will be used. Although one may be able to develop reasonable forecasts of maintenance cycles, forecasting changes in roofing materials or insulation retrofits that may be available 20 years hence seems very tenuous. Even more uncertain would be forecasts of the longevity of a structure until demolition and changes in technology that may profoundly affect disposal options whenever demolition occurs. A forecast assuming no change in technology and materials or disposal methods from present practice may be just as uncertain. In any case, the concept of basing an LCI on empirical data is violated and highly uncertain forecasts are required.

8.3 Extending to Forestry Processes

Figure 8.4 presents a "cradle-to-grave" configuration for forest products with forestry activities included. This includes planting seed in nurseries; planting seedlings on forest land; tending the forest with pruning, thinning, and fertilization; and eventual harvest of the mature trees. This process lasts "h" years and, in many situations "h" may be at least 25 years and may often be more than 100 years.

In this view, harvested logs are no longer a raw material; instead logs are an intermediate product. Raw materials are CO_2, water, and solar energy used in photosynthesis, land, and fertilizers and fuels associated with the silviculture and harvesting activities.

Figure 8.4 Extension to Include Forestry Processes

N	P	PTF	PTF'	M	S/S	Y	M	O	D
N	P	Prune	Prune	m	S/S	y	m	o	d
u	l	Thin	Thin	a		o	i	l	I
r	a	Fert	Fert	t		u	d	d	s
s	n			u		n	d		p
e	t			r		g	l		o
r				e			e		s
y									e

0 .... h .... h+2 .... T

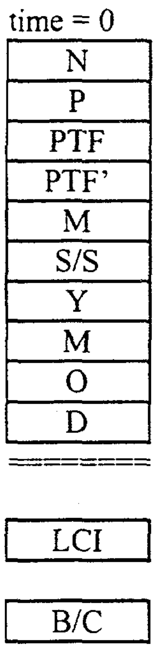
This configuration portrays a true "cradle-to-grave" perspective for forest products; seeds are planted, the forest is grown on some land with eventual harvest, production and use of a home, and finally, disposal. This entire process might last 2 centuries. The problem with this perspective is that it creates some logic issues and violates the tenet that LCI is based on empirical, not forecast data. At any time chosen as the present, data for all activities beyond that time point are forecast data that must rely on assumptions regarding changes in technology and design. If the present is assumed to be the time of planting seed, can we assume that today's building codes, design practices, and materials will be relevant when the home is built from these trees at h+2 years in the future? If not, what will be the relevant codes, designs, and materials? If thinnings are conducted, is it logical to pool them with the final harvest as inputs into the "S/S" stage? In the real world, no mill will store thinnings from a stand for 15 or 20 years in order to process them with the logs from the final harvest of that stand. Thus, the LCI analyst must consider the stream of events and impacts associated with using each thinning separately from the stream of events and impacts associated with the final harvest.

To illustrate a different type of problem, consider the final disposal of the house. The disposal, materials recovered, and emissions to the environment of a new house that will not be built until far into the future, and which will not be torn down until much later, are likely to be very different than the problems associated with tearing down and disposing of materials from the today's obsolete houses. A question to be raised is "are we really interested in the cumulative impacts associated with planting seeds in a nursery and, perhaps 200 years into the future, tearing down and disposing of a house made from them?

8.4 A Different Perspective

The difficulties with the time-line approach can be overcome by recognizing that all stages of the cradle-to-grave forest product system shown in Figure 8.4 also occur simultaneously in the current or any other time period (Figure 8.5). Today, nurseries are producing seedlings for planting on lands that were just harvested. Today there exists a mix of forest age classes receiving silvicultural treatments (pruning, thinning, fertilization), and today mature stands are being harvested. Logs from thinning and final harvest activities on the today's forest estate feed today's industrial processes to yield products, subassemblies and housing developed with known, current technologies and design methods.

Figure 8.5 Simultaneous Activity Perspective of the "Cradle-to-Grave" Forestry System



Finally, owners of homes produced in the recent past are dealing with relatively minimal upkeep and repair; owners of, say, 15-30 year old homes, are involved in many replacement (roof, siding, etc.), upkeep, and remodeling activities using current materials and code requirements; owners of much older homes are dealing with the unique problems they present; and some of the existing housing inventory is being demolished and replaced. The environmental impacts of demolition of today's obsolete homes reflect the actual materials of the past that were used to build and maintain them. This includes problems such as lead-based paints and asbestos that will not be used in future designs but are impacting current disposal and recycling options and will continue to have an impact in the near future.

Summation of activities performed on today's stocks of forest lands and housing, coupled with today's processing, construction, and demolition and disposal methods, provides a more realistic "bottom line" inventory report on the current status of resource and energy consumption and releases to the environment. Furthermore, empirical data can be collected on each of these activities because they are occurring now. Thus all data is empirical in the true spirit of a life-cycle inventory. Similarly, it is relatively easy to collect data on current costs of labor, capital, raw materials (both virgin and recycled) and energy associated with each activity and on market prices for products.

8.5 Scenario Analyses: Policy Changes and Economic Linkages

If one wishes to study the effect of a policy change, such as lengthening forest rotation cycles to store additional carbon, this can be easily accommodated. Implementing such a policy would alter forest practices whereby each of today's age classes in Figure 8.5 becomes the start of a process where that class evolves over time in response to practices that would implement the policy (Figure 8.6). Thus, the young stands that were just thinned and fertilized in the present will evolve toward maturity over time under the influence of this policy.

As the forest evolves, it yields logs from thinning and final harvest at any point in time that are processed by industry into products, subassemblies, and houses. The changes in forestry to accommodate the policy may alter the quantity, size, and quality of the logs available to industry thereby forcing changes in processes, products, and designs which create new homes for occupancy. Concurrently, maintenance, replacement, repair/remodel, and demolition/disposal is continuing on older homes produced in previous periods. Thus the effect of a policy produces changes in the forest which in turn have lagged effects on the characteristics of materials which later may affect technologies used, products, and design. By forecasting these changes to a time of interest in the future and summing the columns for the time periods, one can obtain inventory summaries and summarize the costs, revenues, and other benefits that occur. These "bottom line" summaries can then be compared in terms of change in physical parameters of interest and in terms of economics.

8.6 Conclusion

This approach, in which cradle-to-grave aspects of forest products are regarded as occurring simultaneously, allows analysts to develop a valid life-cycle-inventory status report on the current situation, develop economic measures of the current situation, and then use forecasting techniques and sensitivity analysis to estimate how changes in any system element lead to changes in environmental and economic measures over time.

This perspective provides a means for reconciling difficulties with temporal aspects of life-cycle inventories associated with forestry and housing and provides a means by which the tool of life-cycle inventory can be used in conjunction with the tools of economic analysis. It is also consistent with the approach commonly used by individual firms in applying and combining life-cycle inventory and improvement analysis methods in identifying cost-effective ways to provide products with improved environmental performance.

Figure 8.6 Scenario Analysis Extension

				N=>
			N=>	***P=>***
		N=>	***P=>***	***PTF=>***
	N=>	***P=>***	***PTF=>***	***PTF'=>***
N=>	***P=>***	***PTF=>***	***PTF'=>***	***M=>***
P=>	**PTF=>**	**PTF'=>**	**M=>**	**S/S=>**
PTF=>	**PTF'=>**	**M=>**	**S/S=>**	**Y=>**
PTF'=>	**M=>**	**S/S>**	**Y=>**	**M=>**
M=>	**S/S=>**	**Y=>**	**M=>**	**O=>**
S/S=>	**Y=>**	**M=>**	**O=>**	**D**
Y=>	**M=>**	**O=>**	**D**	
M=>	**O=>**	**D**		
O=>	**D**			
D				

0 .... time .... T

LCI_0	LCI_1	....	....	LCI_T
B/C_0	B/C_1	....	....	B/C_T

Large bold represents pathways (left to right) from present age classes of forest lands and housing. Bold italic represents pathways based on future plantings after stocks of existing forests are harvested.

The approach does not include translation of specific emissions to the environment into environmental impacts or hazards and does not include application of costs or values that may be associated with these hazards. Presently, this translation of emissions into impacts and hazards and associated values is not scientifically well-defined. There are many problems associated with interactions among emissions, non-linear behavior, definition of thresholds and dose-response relationships, and dependency of these on very detailed spatial and temporal conditions.

Rather than attempt to resolve these scientific and valuation issues, CORRIM II will focus on monitoring how changes in forest, manufacturing and design, and consumption processes affect use of materials and energy and change associated releases of emissions. CORRIM II will also identify the costs and benefits associated with the process modifications. Comparing how alternative strategies for changing the resource and environmental effects of the processes also affect their economic characteristics will help ensure selection of policies that have carefully weighed both economic and environmental considerations.

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Glossary

Ancillary material - a material used by the process manufacturing a product but is not used directly in the formation of the product

Atmospheric emission - discharge of emissions to the air subsequent to emission control devices. Includes point sources such as smokestacks and non-point or area sources such as release of carbon dioxide from a forest fire.

Biomass - biological material, usually expressed in terms of weight; some forms of biomass may be used as an energy source.

Closed loop recycling - a recycling system where the material is remanufactured into the same product (e.g. aluminum can into aluminum can)

Completeness - the percentage of data available for analysis relative to the total potential data in existence

Composite data - data from multiple facilities performing the same operation that have been averaged or pooled

Composting - waste management option for organic materials where they are subjected to controlled biological decomposition into a relatively stable humus product that can be handled, stored, and/or applied to the land

Co-product - a marketable product from a process that is not the primary product of interest. This includes materials often defined as industrial scrap (waste) that is later used in a different manufacturing process

Co-product allocation - a method of adjusting material and energy inputs and environmental changes associated with a process or activity to the main product and co-products such that each is credited or debited with its proper share

Distribution - transfer of manufactured products between producer and end-user; includes movement of products within a warehouse or retailing facility

Ecosystem - the interacting system of a biological community and its surrounding environment

End-user - individuals, businesses and institutions that actually use (unpackage, consume, operate, prepare for their use, and eventually dispose of) a finished product

Energy of material - the fuel value contained in raw materials used to make a product; also known a latent energy or inherent energy

Environmental change - changes to the environment caused by the activities associated any specific stage or the overall life-cycle of a product. Changes may represent emissions and discharges of pollutants to air, water, and land, solid waste, effects on biodiversity, carbon release and sequestration and so forth.

Environmental profile - a listing of the environmental changes associated with a system or life-cycle stage. These may be aligned as those having perceived negative (debits) or positive (credits) effects of the system under study.

Equivalent usage ratio - a method of comparing two or more products on an equivalent basis such as comparing alternative beverage containers on the basis of quantity consumed by a consumer for a specific time period.

Finished product - the product produced by the system under study that is consumed by the end-user.

Fugitive emissions - emissions that do not flow through pollution control devices. These are often regulated emissions that escape during processing, storage and handling activities, leaks from equipment, etc. and are often difficult to measure.

Global warming - the hypothesis that certain atmospheric constituents are causing an increase in the earth's temperature

Greenhouse - the hypothesis that certain atmospheric gases trap heat in the atmosphere thus causing to global warming. These constituents, such as carbon dioxide, are often referred to as greenhouse gases

Higher heating value - the gross heat of combustion of a material or fuel

Impact assessment - a component of life-cycle assessment (LCA) which attempts to determine the magnitude and significance of environmental impacts according to the goal, scope, and objectives defined in a study. It is used to translate impact indicators into estimates of the response of environmental receptors and the corresponding consequences incurred by the receptors

Improvement assessment - a component of life-cycle assessment (LCA) concerned with identifying and evaluating opportunities to improve environmental performance of a process of product over its life-cycle

Industrial scrap - byproduct materials of value produced by a manufacturing process and either reused within the same process or sold as raw material to another manufacturer; often referred to as industrial waste

Inherent energy - see energy of material resource

Intermediate materials - materials or products manufactured from raw materials that are further manufactured before the finished product is completed.

Inventory analysis - see life-cycle inventory

Landfill - land based sites for deposition of solid wastes. Sanitary landfills are sites for nonhazardous solid waste where the waste is spread in layers, compacted, and covered. Secure landfills are sites for hazardous waste and are selected and designed to minimize the risk of their release into the environment

Life cycle - the stages of a product life, beginning with producing and acquiring the raw material; including all manufacture, consumer use and maintenance, and transportation; and ending with any or several waste management options, including recycling.

Life-cycle assessment (LCA) - a concept and method for evaluating the environmental performance of a product or activity by analyzing its entire life cycle. The method includes study initiation and life-cycle inventory, impact assessment, and improvement assessment.

Life-cycle inventory - the identification and quantification of resource and energy use and all environmental changes associated with the life cycle of a product or activity.

Life-cycle stages - the sequence of major stages that a product or service passes through over from its development and acquisition from the land until it is eventually disposed back to the land (cradle to grave). Four major stages, common to all products are acquiring raw materials and energy, manufacturing, consumption (including reuse and maintenance), and waste management (including recycling).

Mass balance - a mathematical expression where the sum of all inputs equals the sum of all outputs, including accounting for any conversion to energy.

Nonrenewable resource - a resource that cannot be replaced in the environments as fast as it is being consumed

Open loop recycling - also called secondary recycling, recycling where a product made from one type of material is recycled into a different type of product; the latter may or may not be recycled.

Packaging - often segregated into three categories. Primary packaging is that which is in contact with the product, secondary packaging is that which contains one or more primary packages; and tertiary packaging is that which contains one of more secondary packages. For example, pop-tarts have a foil wrap (primary packaging), four of which are sold together in cardboard packs (secondary packaging), which are shipped in bulk corrugated boxes (tertiary).

Pollutant - any substance introduced into the environment with an adverse effect

Precombustion energy - the energy necessary to extract, transport, and process fuels into useful form. In the case of electricity this includes inefficiencies in power generation and transmission line losses. Also known as energy of fuel acquisition.

Process - an operation performed on one or more raw or intermediate materials as part of the formation of a product.

Process emissions - waste materials resulting from the raw materials, reactions, or equipment associated with a process.

Process energy - the energy necessary for each subsystem process which are quantified by source and type of fuel.

Random error - error that does not have a definite or systematic pattern or bias.

Raw materials - inputs to a subsystem including all material present in the product plus material lost due to emissions, scrap and off-spec, moisture lost to evaporation, etc.

Recycling - the life-cycle activity that divert material, called recycled material, from the waste stream and delivers it for manufacturing. Recycled content of a product refers to the fraction, usually by weight, that was derived from recycled material.

Regulated emissions - emissions regulated by government to limit amounts or concentrations of waste released to the environment.

Renewable resource - a resource that is being replaced at least as fast as it is being consumed.

Representativeness - the degree to which a sample is characteristic of a group of population.

Residues - process wastes (such as wood bark); commonly but not always solids.

Resource requirements - the amount of raw materials or natural inputs and energy used in a system.

Sensitivity analysis - a systematic evaluation of the effect on outputs and conclusions of variation in the inputs to a system.

Solid waste - volume or weight of solid products or materials disposed of in landfills, incinerated, or composted. Post-consumer solid waste is material that has served its intended use and has been deposited in the waste stream. Industrial solid waste - sludges, solids from air pollution devices, trip or scrap materials, ash from burning wood or coal, mineral extraction residues, etc. that have no value and are not recycled. Municipal solid waste is collected from residential, commercial, institutional, and industrial sources and includes durable and nondurable goods, containers and packaging, food waste, yard waste, an miscellaneous inorganic waste. It does not include municipal sludges. combustion ash. and nonhazardous industrial waste that may also be disposed of in municipal landfill or incinerators.

System - the set of operations that perform a desired function. In life-cycle analysis, the scope of the system is defined by the boundary conditions that are established. A subsystem is an individual step that is part of the defined process. See also unit operation.

Template - a guide used by analysts for collecting and organizing data. It describes the material and energy balance for a defined system or subsystem, and includes resource, energy, and transportation requirements and emissions and wastes generated by that subsystem.

Transportation - the process of movement of materials, energy, or water between operations at different locations. Transportation energy is the energy required for this movement and is converted from the conventional units of "ton-miles" by each mode (truck, rail, barge, ship, etc.) to energy units using the fuel efficiency of each mode.

Unit operation - also unit process, is an individual process within the defined system. See also subsystem.

Use - activities such as consumption of a product, operation of equipment, repair and maintenance, storage, preparation of a product for use.

Useful life - the length of time from when the product is delivered to the end user until it is discarded.

Waste - an output with no marketable value that is disposed of to the environment (air, water. or land).

Waste management system - the process for treating or handling waste prior to its disposal to the environment.

Waterborne waste - also waterborne discharge, refers to discharges of pollutants to water after treatment processes.

Appendix I: ISO 14040

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Possible Additional Chapters to Develop and Include in the Future

Chapter 10. Forestry, Timber Production, and Harvesting

Chapter 11. Conversion Processes

Chapter 12. Design of Assemblies and Structures

Chapter 13. Use, Maintenance, and Repair

Chapter 14. Demolition and Disposition of Materials

APPENDIX B

RESEARCH MODULES—CONTENT

INTRODUCTION

The following presents a description of the 22 research modules that encompass the proposed research effort by CORRIM II on the life-cycle analyses of forest products. For each research module a statement of objectives, justification, research statement, and specification of inputs, outputs and procedures are provided. A chart showing the timeline, budget, and relationship of the modules is presented in Figure VI.1 of the report.

The Phase I research modules are constrained in regional resource and product coverage to provide for a thorough evaluation phase of procedures before undertaking more complex sourcing, processing, construction and use in a Phase II sequence of modules. Research modules are also clustered by group such as Cluster A (from forest resources to structural components) which provides the basic building blocks for comparison to the 1976 CORRIM study. The clusters of modules make it possible to integrate results to serve specific analysis objectives. Cluster B extends Cluster A to a complete building structure. Cluster C includes process and product substitute alternatives. Cluster D includes all life stages for buildings. Cluster E incorporates nonstructural products. Cluster F considers infrastructure uses including bridges and marine facilities. Cluster G provides for comprehensive analyses of all uses with consistent linkages to alternative global sources.

PHASE I:

Cluster A (modules #1- 4): Environmental-performance improvement for forest resources from the Northwest and Southeast regions through product processing, and construction of these products into floor, wall, and roof components. This cluster will provide a consistent comparison of performance values to CORRIM I results which will reflect changes that have occurred over the last two decades (#1 Forest Resources I, #2 Processes I, #3 Structures Ia, and #4 Data Management).

1. Forest Resource I: Northwest/Southeast

The forest regions and resources identified for study in the Forest Resources I Module are selected to be representative of the regions producing the largest annual volumes of timber in the U.S. They are the Northwest softwood and Southeast softwood and hardwood regions.

Objective and Output of Module:

- Provides environmental, energy and resource data on the growth, management, harvesting and reforestation of timber under five general scenarios of management intensity for the Northwest and Southeast regions of the United States

- Develops case studies to represent a typical range of forest management objectives and stand and site conditions
- Provides environmental performance measures including indices of stand structure diversity, habitat and fragmentation for each of the case study scenarios
- Provides inputs for the Processing and Biomass modules from the case study scenarios

Justification:

Removal of wood biomass from the forest and the activities associated with growth, removal, and re-establishment of trees need careful analysis to determine the total life-cycle impacts and sustainability of the use of biomass-based products. Life-cycle impacts are not stationary and will change over the next 100 years based on both past and prospective technologies, evolving forest management procedures and population demands. Time becomes a critical element of this analysis since the period from initial planting or forest establishment to removal can range from five years for short rotation intensive culture to 100 years or more for selectively managed natural forests. Inputs and outputs of the life-cycle process include both quantitative and qualitative measures of the environment and timber removed. To some, the qualitative (largely environmental) factors are of great importance to the life-cycle impacts of utilizing wood biomass and, to the degree possible, these factors need quantitative descriptions developed. Understanding the time dependent linkages between technology changes and management practices and their effects on these factors is essential to improve forest management alternatives that enhance the critical environmental features, but are also cost effective.

Research Statement:

Research is needed to identify harvest and forest management technologies that enhance critical environmental factors (environmental design systems) associated with forest management alternatives that are designed to produce timber. This will be accomplished by characterizing the life-cycle inputs and outputs of representative forestry operations. A wide variety of forest management and harvesting options currently exist, but the total environmental and economic impacts of these options over the life cycle of the forest are not well understood. A limited number of scenarios, representing the range of environmental and timber objectives, will be structured and analyzed through existing models. These options include:

(1) High timber output at low cost, while maintaining low environmental impacts—a scenario likely to involve areas intensively managed for timber and will involve such forest management activities as fertilization, thinning, harvest regeneration cuts and reforestation through planting

(2) High outputs of environmental factors at low cost, but with continued production of timber—a scenario likely to involve selective removals of trees to maintain health, diversity and density of the forest. Reforestation will generally occur naturally

(3) Joint objectives for timber and environmental factors on the same acre—a scenario that may include intensive forest management activities designed to achieve an objective for both timber and biodiversity. Activities such as thinning, snag and debris retention could be involved to achieve a desired level of structure diversity and mix of species

(4) Short rotation intensive culture for the production of biomass—a scenario involving fast growing species that are managed with water and chemical inputs to achieve maximum growth of fiber in the minimum amount of time

(5) No forest management with no wood removal—a control scenario that in one instance will involve historic disturbance patterns (wildfire, wind etc.) and in the other instance involve intervention-affected disturbance patterns (results of natural fire exclusion, etc.)

Outputs will be developed from existing models and synthesized to provide an indication of the life-cycle impacts of this range of forest operations. Some of these outputs are measurable in conventional units of measurement. Some environmental outputs will need to be expressed as indices comparable to the input values. All measures will be developed or calculated as responsive to selected management alternatives and primary resource inputs.

Inputs:

- Stand structure and location as described by slope classification, site classification moisture relationship (wet or dry site), age classification (even aged, uneven aged, mature) and species mix. Analysis will be restricted to a distinct number of cases that represent the most common combination of conditions of a region.
- Harvesting options with a regional average transport distance to the processing point and the harvest system selected from mechanized or non-mechanized, ground-based, cable or aerial harvesting system, or alternative harvesting technologies. The harvesting system selected will also be matched to options on road location and density.
- Natural disturbances with associated risk factors for wildfire, insect and disease, wind and storm damage, and floods and related slope instability. Impact and costs of mitigation and control measures will also be noted.
- Forest management treatments to existing forest stands to include thinning, pruning, fertilization, herbicide and pesticide treatments, harvest prescription, debris and snag retention and reforestation.
- Pre-treatment measurements of environmental factors that include water quality index, water quantity outflow per acre, an air quality index for factors related to fire, snags and down woody material, fuel loading, a biological diversity index as measured by a habitat index and stand structures (diameter, trees per acre, canopy, etc.), an index of fragmentation, carbon storage per acre, and volume of standing biomass per acre.

- Cost basis (simplified/standardized tax accounting) to include material costs, labor costs, cost of capital, and taxes.
- Product options and values to include outputs in lumber grades, pulp wood grades and engineered products.
- Harvesting inputs for harvest and transport to gate of processing, including energy requirements per acre by option, and other materials used.

Outputs:

Output tables of stand level variables will be expressed on a per acre basis. Outputs that do not lend themselves to per acre expressions will be expressed as a regional impact. Some outputs will stand by themselves as measures of impact from forest operations. In these cases they will be compared to values and indicators before treatment and when appropriate to a baseline scenario. Others will serve as input to the processing modules of the project. The outputs include the following:

- Product volumes by quality, product, and species categories
- Energy used by form
- Carbon balance
  - amount released and amount stored
  - input to products
- Water quality indicator
- Water quantity measurement
- Air emissions
- Biological diversity index as measured by habitat and stand structure
- Fragmentation index
- Snags and down woody material
- Production costs
- Economics from marketed products to include net present value, rural jobs, tax receipts

Procedures:

The combination of forest stand conditions and treatment options in any given region are infinite. The first step in analysis for this module will be to develop a fixed number of options for analysis based on the five alternatives defined earlier and stand and slope conditions typical of a region. Phase I of the module will analyze conditions in the Pacific Northwest and Southeast United States. Phase II will consider conditions in the interior west and north central United States and Canada. These will represent the most likely scenarios to meet timber market and environmental objectives and will also reflect a range of treatment options from no management or recovery from a site to intensive management. The site and stand conditions will also be limited to reflect those most likely to be selected for removal of biomass material. A select number of case studies will be developed for each region.

Existing models will be used to develop relationships before and after treatment. Moc are generally available to predict growth and yield of the biomass over time, to predict watershed impacts in terms of sediment flow and water quantity, and to assess fire risl forest stands. Other work has been done in some regions to develop indicators of habi and biological diversity. Where necessary, additional indicators will be developed fro model output. Results of these models will be synthesized to develop output tables fo selected number of treatment options and locations.

Important outputs characterizing the impact of technology management alternatives w include amount and quality of timber for markets, carbon stored and input to product flows, energy used by form, measures of biodiversity (habitat indices and stand structures), net present value to the landowner, jobs tax receipts, expenditures, and cap requirements. These will establish a life-cycle footprint for each management alternat as a function of time.

Brief summary statements in the format of Agenda 2020 RFPs are provided for each module.

Summary Statement in Agenda 2020 Format: Research is needed to synthesize dat on the environmental and energy impact of providing timber and logs for the manufac of forest products used in construction applications.
A comprehensive analysis of the impact of forest resource management from stocking through the delivery of logs to manufacturing operations is needed for the primary wo producing regions of the United States — the Northwest and Southeast United States. This analysis should consider all pertinent inputs and outputs, including development life-cycle inventory analysis of environmental and energy measures for comparison to use of other resources or management alternatives. The analysis should include a rang of management alternatives and their impact on harvest, forest inventory, carbon sequestration, forest structure distributions and linked habitat indices, and other co-products of forest management. The resultant data and analysis should facilitate identification of cost effective strategies for reducing the impacts of forest production the environment or to meet existing or proposed environmental requirements.

2. Processes I: Primary Products

This study analyzes the manufacturing processes for structural building materials made fr wood resources in the Northwest and Southeast regions. The focus of the study is to con a life-cycle analysis of the environmental, energy, and resource impacts associated with t manufacture of the raw materials into products. The Forest Resource I module will prov input values for the raw materials and other modules will use the output of this module fo their inputs.

Summary Statement in Agenda 2020 Format: Research is needed to synthesize dat on the environmental, energy, and resource impact of manufacturing structural wood products such softwood lumber, softwood plywood, oriented strand board (OSB), laminated veneer lumber (LVL), parallel strand lumber (PSL), I-beams, and trusses–materials used in the construction of residential and light commercial structures.

A comprehensive life-cycle inventory analysis is needed of the environmental, energy and resource impacts of wood use as a structural material and as an alternative to othe materials. The study should address the impact from the resources entering the manufacturing operations through to the shipping of the product, considering all pertir inputs and outputs. The specific products and related processes that need to be analyz are softwood lumber and plywood, oriented strand board, parallel strand lumber, laminated veneer lumber, I-beams, glulam and trusses–all structural components used the construction of walls, floors, and roofs of residential and light commercial structu The analysis should include a comparison to the 1976 CORRIM data to determine if t has been progress for given functional uses. The resultant data and analysis should facilitate identifying cost effective strategies for reducing the impacts of processing a product use on the environment.

3. Structures Ia (and #5 Structures Ib): Structural Components and Subassembli

This study addresses the environmental performance impacts of constructing those components (Module Ia) and subassemblies used in a structural shell (Module Ib) typ found in buildings. Typical materials used for light-frame floors, walls and roof incl softwood lumber, softwood plywood, oriented strand board, laminated veneer lumbe parallel strand lumber, lumber, I-beams, glulam and trusses. Included in this are jois studs, sheathing, and their combination into wall, floor and roof assemblies common i both residential and light commercial construction.

Objective and Output of Module:

- Provides environmental, energy, and resource impact data on the manufacture floor, wall, and roof components for residential and light commercial structu (both site-constructed and factory-built)
- Provides environmental, energy, and resource impact data on the manufactur representative single residential structure designs (both site-constructed and f built analyzed) comprised of floor, wall, and roof components—no windows, roofing, or siding
- Provides input data into the Structures II module
- Provides input data into the Integrated Modeling modules
- Provides benchmark data for these products which will enable future compar of process improvements or to new processes

- Provides a comparison of energy and resource impacts to the 1976 CORRIM study for the floor, wall, and roof components
- Compares fossil versus biomass fuel dependency
- Provides a measure of resource use efficiency

Justification:

A major use of wood and wood-based materials is in structural components for residential and light commercial buildings. Individual components (i.e., joists, studs, sheathing, etc.) are combined structurally to form various "subassemblies" such as floors, walls, and roofs. Floors and roofs can be comprised of individual components (e.g., joists or rafters) or of other systems (e.g. trusses). These subassemblies are combined to form a complete (or full) structural system (see Structures Module II). An understanding of the environmental impacts in producing structural components and their use in structural subassemblies is an essential step in the development of environmental performance measures for using wood.

Inputs:

- Solid wood products
  - lumber
  - glued laminated lumber
  - wood trusses
- Composite wood products
  - LVL
  - parallam
  - composite beams
  - plywood
  - OSB
  - particleboard
- Other essential materials
  - connectors (nails, bolts, glues)
  - gypsum
  - insulation
- Type of construction
  - site-constructed
  - factory-built (modular construction, prefabricated trusses, etc.)
- Governing design criteria
  - energy efficiency
  - architectural
  - structural

- Water
- Energy
- Capital
- Labor
- Transportation

Outputs:

Based on available data, several typical (representative) designs will be analyzed in detail. The analysis will yield the following data:

- Quantity of the individual components
- Quality of the structural assembly
- Emissions to air (CO, CO_2, CH_4, NOx, SO_2, particulate, VOC, formaldehyde), land, water
- Energy
- Solid waste
- Material (products, byproducts)
- Transportation
- Relative cost of alternatives considered

Procedures:

The first step in the analysis will be an evaluation of available components and the relative quality, environmental performance, life expectancy and cost of these components. The second step will be the evaluation of structural assemblies (floors, walls, and roofs) comprised of the aforementioned components, again including an assessment of the relative quality, environmental performance, life expectancy and cost. An important aspect of this is the inclusion of life-safety and performance criteria in the life-cycle evaluation procedure. The results will be reported for each component and assembly type category discussed above. Regional categories may be introduced if such factors are deemed significant. A standard situation will be analyzed, that is, the assumption will be made that all the materials and technologies are properly used and applied.

Summary Statement in Agenda 2020 Format: Research is needed to synthesize data on the environmental, energy, and resource impact of constructing residential and light commercial structures using wood and other products.
A comprehensive life-cycle inventory analysis is needed of the environmental, energy, and resource impacts for structural use of wood in the construction and occupancy of residential and light commercial buildings. The study should address the impact of constructing the shell of these buildings from joists, studs, sheathing and their combination to form the wall, floor, and roof subassemblies. The scope of the study should include all pertinent inputs and outputs associated with the construction of these shells, both factory-built and site-constructed. (Consideration of the nonstructural materials such as doors, windows, roofing, plumbing, and electrical will be considered in other modules). The analysis should include resource and energy impact comparisons to the CORRIM 1976 data for similar built structures, as well as the comparisons of impacts with alternative materials such as steel, concrete, and plastics. The resultant data and analysis should facilitate identifying cost effective strategies for reducing the impacts on the environment of constructing residential and light commercial buildings.

4. Data Management and #7 Integrated Modeling I, #17 Integrated Modeling IIa and #21 Integrated Modeling IIb)

This study serves as a repository of all data collected in the various research modules and provides a means to model the life-cycle analysis of all the forest products and alternative materials considered. This module ties together the objectives of the various research modules to provide a comprehensive life-cycle analysis and enable sensitivity studies to be conducted.

Objective and Output of Module:

- Provides environmental impact and energy and resource usage data from the manufacture and use/disposal of wood resources and wood-based composite products, as well as alternative materials
- Provides a repository for all data collected in a pre-defined format that is compatible with life-cycle analysis methodology using CORRIM II protocol
- Provides baseline data for all processes, products, and uses studied
- Provides life-cycle and cost-benefit models for studying various process, product, and use scenarios
- Provides input data for life-cycle assessments
- Provides data for calculating resource efficiency

Justification:

A critical component of CORRIM II research will be to design, maintain, and update a database that integrates the information collected by all the research modules and to develop a modeling system based on this database that supports a wide variety of synthesis studies and analyses. Examples of the types of synthesis studies and strategy questions that may be performed are:

- Evaluation and quantification of wood products and wood-using systems. What are the opportunities for improving their associated characteristics such as sustainability, recycling and reuse, energy efficiency, and carbon sequestration?
- Examination of how changes in forest culture and wood use affects the Nation's energy requirements. How might the production of wood biomass for energy impact the supply of wood products and overall energy balance?
- Assessment of the relationship between carbon emission requirements, forest culture, and forest product use. How might the demand for forest products be affected by emission requirements? How might a carbon tax influence the choice of building materials? What are the opportunities for and consequences of trading carbon credits?
- Examination of ways to conserve wood. To what extent might reuse and recycling of wood offset declining federal timber supplies? Is incineration for energy a viable alternative to reuse and recycling? How might innovative designs improve efficiency in use, energy conservation, and product durability?

Research Statement:

These modules have two objectives. First, to provide a repository of research data for all modules in a pre-defined format that will enable the life-cycle analysis of forest products and second, to provide integrated modeling of case studies. The database management will collaborate with all other research module teams to assure consistency and compatibility in the design of data collection procedures. Appropriate units of measure will be developed for data collection along with conversion factors for converting information gathered from various forestry and forest products sectors to a common basis. As for data management the goal is to provide for continuous data entry with quality control checks to identify errors and suspect data. Because of the sensitivity of some of the data, appropriate security will be provided for proprietary data. The database will be an active database, with data being entered as new information is collected. It will be the responsibility of the research team for this module to provide on-line integrative support to CORRIM II researchers on other modules. A modeling team will evaluate a variety of existing techniques and models for summarizing life-cycle information. They will develop specifications for an integrative model capable of synthesizing and analyzing life-cycle information needed by CORRIM II researchers to answer questions such as those outlined in the justification.

Procedures:

A database/programming professional(s) will be hired to assist with selection of a database software system, to assist with the design of data collection instruments and development of measurement standards and conversion factors, and to assist with the creation of integrative model specifications and development. Second, a modeling team will be assembled to review and evaluate existing life-cycle modeling systems, to develop specifications for the CORRIM life-cycle model, and to design and implement the CORRIM life-cycle model. A preview of these possibilities is provided in section IX of the main report.

Summary Statement in Agenda 2020 Format: Research is needed to develop a database that organizes all of the data collected by the various research modules and develop the integrative modeling that relies on this database and provides synthesis and analytic capability measure environmental performance across the life cycle for all stages of processing and regions.
Data management capabilities include design of data collection sheets, data input and security protocols, and development of conversion factors in a convenient computerized format. Integration across stages of processing requires development of a modeling system that uses the database information to link results from several stages of processing, perform appropriate calculations and summarization and deliver output information in convenient summary form. The database and modeling must be designed to permit analyses on a regional basis and recognize the temporal dimensions of forest growth and longevity of products and structures. The modeling system must be designed to permit easy comparison of technology and management alternatives and substitutions, and permit the analyst to perform sensitivity analysis in the search of management and technologies with improved environmental performance.

Cluster B (modules 5-8 with Cluster A): Environmental-performance improvement for Northwest and Southeast forest resources through the completion of building structures (#5 Structures Ia, #6 Industrial Products, #8 Nonstructural Products I, and #7 Integrated Modeling I)

5. Structures Ib

This study extends the floor, wall, and roof, components of structures in Structures Ia to a structural shell (Module Ib) typically used in wood and wood-based buildings (see #3 & 5 Structures I).

6. Industrial Products: Treated and Untreated

This study analyzes the manufacturing processes of untreated and preservative or fire retardant treated wood used for industrial purposes. Such applications include, but are not limited to, utility poles, piling, railroad ties, cooling towers and other products that are used in industrial applications. The focus of the study will be to conduct a life-cycle analysis of the environmental, energy, and resource impacts associated with the production, use, and disposal of these products, including the chemicals employed for these processes. Other research modules will identify input values for the wood employed for these processes, and other modules will use the output of this module for their inputs.

Objective and Output of Module:

- Provides environmental, energy, and resource impact data on the manufacture of industrial wood products including pallets, utility poles, piling, and railroad ties
- Provides benchmark data for these products that will enable future comparisons with process improvements or with new processes
- Identifies the role of industrial wood preservation in recycling chemical waste products generated by other industries
- Shows fossil fuel versus biomass fuel dependency
- Provides a measure of resource use efficiency

Justification:

Industrial products represent nearly 50% of the total volume of preservative treated wood produced each year. These products are primarily treated with creosote, pentachlorophenol, or one of the inorganic arsenicals. All of these materials have come under scrutiny from the Environmental Protection Agency and their use is tightly controlled to minimize the potential risks during treatment and use. In addition, large industrial users employ considerable quantities of untreated wood for items such as pallets, packing, and other uses where resistance to biodeterioration is not a consideration. For this module, the life-cycle analysis will be based upon resources from the Northwest softwood, Southeast softwood and hardwood regions. The data from this module will be used as inputs in the Infrastructures and Integrated Modeling I modules. Eventually these units will be combined in the Structures II module to analyze the impacts of residential, light commercial and industrial structures.

Research Statement:

Research is needed to synthesize from available sources the environmental impacts resulting from the production of treated and untreated wood employed in industrial applications. The intent of this research is to document the impact of manufacturing materials that will be used in industrial applications such as water cooling towers, bridges, electric transmission or distribution lines, docks, railroads, and other large scale applications. Data will be collected and analyzed on chemical production, impregnation processes, internal waste handling procedures and disposal of treated or untreated wood products at the end of their useful life for two distinct regions of the country: the Northwest and the Southeast. Environmental, energy, materials and economic data related to the production of these products will be done in a manner consistent with the new CORRIM II protocol for measuring life-cycle impacts while also providing cost/benefit analysis comparisons with alternatives.

Inputs:

- Raw materials (types and amounts)
- Ancillary materials (coatings, fasteners)
- Water or oil (solvent)
- Energy (types and sources)
- Capital
- Labor
- Transportation
- Disposal

Outputs:

- Material (products/byproducts)
- Emissions to air, land, water (CO, CO_2, NH_4, Cu, Cr As, polycyclic aromatic hydrocarbons, pentachlorophenol)
- Solid waste (sludge, sawdust, older treated wood)
- Waste energy by source
- Transportation

Procedures:

The study will assemble available data on all inputs and outputs from the raw material coming into the process to manufactured products ready for shipping. Industrial inputs related to the production of preservative components will be particularly important, but the possible inputs from waste mitigation strategies and other aspects of treatment mandated by Federal regulations should not be overlooked. Primary data will be used for assessing the impacts of production of treated and untreated industrial products, while secondary data will be used for comparative materials such as steel, concrete, fiberglass or plastic. The data will be analyzed on a process basis for treated wood products rather than on an individual commodity basis. This approach should minimize duplication of data and assist in the identification of process changes that can reduce environmental, energy and resource impacts.

Summary Statement in Agenda 2020 Format: Research is needed to synthesize the data on the environmental, energy, and resource impacts of treated and untreated wood used in industrial applications.
A comprehensive life-cycle inventory analysis is needed of the impacts of wood used in industrial applications in comparison with other materials. The study should address the impact from the resources entering the manufacturing process through to the shipping of the finished product, and should consider all pertinent inputs and outputs. Treated wood products that should be studied include wood used for railroad ties, cooling towers, marine structures, utilities, and bridges, but need not be limited to these materials. Untreated wood systems might include any of the array of materials used in non-soil contact applications for large industrial structures as well as materials such as pallets that are used for shipping purposes. The resultant data and analysis should facilitate the identification of cost effective strategies for reducing the impact of processing and product use on the environment.

7. **Integrated Modeling I** (see #4 Data Management and Integrated Modeling)

8. **Nonstructural Products I**

This study analyzes the nonstructural products made from wood or wood-based composites and used to enclose major openings, such as doors and windows, and to finish the interior surfaces of a residential or light commercial building. The focus of the study is to conduct a life-cycle inventory analysis of all the environmental, energy, and resource effects of producing these products from the point where typical raw materials enter the manufacturing operation through the processing plant and is shipped to its point of use. Other research modules will provide this module's raw material input values, while its output values will be used as inputs for other modules.

Objectives and Outputs of Module:

- Provides environmental impact and energy and resource usage data from the manufacturing of both solid and wood composite windows, doors, moulding, paneling, and other wall coverings and flooring
- Provides input data for the Structures II and Substitutes II modules
- Provides baseline data for these products' manufacturing processes
- Provides data for comparing energy and resource usage with these products relative to the 1976 CORRIM study
- Provides data for calculating resource efficiency

Justification:

Over half of all forest products manufactured go into residential and light commercial construction. A significant portion of these products' dollar value consists of items such as windows and doors that enclose building openings and of such products as paneling, flooring, and moulding that cover interior surfaces. This module's life-cycle inventory analysis will include manufacturing data from all national regions because its inputs are likely to be raw materials of standard industry grade and to be shipped and available in all regions. The assessment of these materials will be used as input values for the Structures II and Substitutes II modules. The data for this module will also be compared to the 1976 CORRIM report where possible to demonstrate any improvements in energy use and material balance (environmental impacts were not considered in the 1976 CORRIM study).

Research Statement:

Information is needed on the effects of using nonstructural, wood-based elements in residential and light commercial buildings. The purpose of this research is to develop knowledge on how manufacturing nonstructural wood-based building components affects environmental emissions, energy consumption, and material flows. Data will be collected and analyzed on the nonstructural product industry categories classified under Standard Industrial Classification Major Group 24, excluding wood kitchen cabinets, Industry Number 2434. Examples include windows, doors, moulding, paneling and other wall coverings, and flooring, both solid wood and composite materials. Environmental, energy, material, and economic data related to the production of these products will be collected in a manner consistent with the CORRIM II protocol for measuring life-cycle consequences. The information generated will also provide a basis for cost/benefit comparisons with alternatives products. The type of input/output factors considered, but not limited to, are:

Inputs:

- Raw materials (type and amount)
- Ancillary materials (e.g. adhesives, nails/fasteners, and finishes)
- Water
- Energy (type and source)
- Capital
- Labor
- Transportation

Outputs:

- Emissions to air (CO, CO_2, CH_4, NO_x, SO_2, particulate, VOC, formaldehyde), land, water
- Energy
- Solid waste
- Material (products, byproducts)
- Transportation

Procedures:

The study will use the outputs developed in the Processes II Nonstructural Wood/Non-Wood and Biomass Processing modules as raw material inputs to the manufacturing operation in this module. Relevant data will be developed from these inputs to a manufactured product ready for shipping. Several new analysis methods will be employed in collecting the CORRIM II data. Where possible, instead of compiling only aggregate data for a product, an analysis by machine center or operation will be performed within a manufacturing process. For example in the manufacture of wood flooring, data could be developed on the finishing process which might then be reused for the same or similar finishing process for wood panels. This should also prove helpful when analyzing new products or processes using known machine centers and when examining process or product modifications to determine any reductions in environmental, energy and resource impacts. A range or distribution of values for the inputs and outputs will also be used. This will produce a more realistic life-cycle inventory analysis. This module's output data will be presented in a form usable as raw material inputs to the Structures II and Substitutes II modules. The information produced from this analysis will also be used to compare these products with other substitute materials such as carpet, vinyl sheet goods, and plastic.

Summary Statement in Agenda 2020 Format: Research is needed to develop the environmental, energy, material, and resource impacts of manufacturing nonstructural wood-based products such as doors, windows, moulding, decorative paneling, and flooring used in the construction of residential and light commercial structures.
This requires a comprehensive life-cycle inventory analysis of the environmental, energy, and resource factors affecting the use of wood in nonstructural components. A comparison with similar non-wood-based components can than be performed with this information. The study should determine all the consequences from the time the raw material enters the manufacturing process until the finished product is shipped including all the pertinent inputs and outputs. The products and related processes to be analyzed are those used to enclose major openings, such as doors and windows, and to finish the interior surfaces, such as paneling, flooring, and moulding, of a residential or light commercial building. The analysis should include a comparison to the 1976 CORRIM data for similar processes where possible. The resultant data and analysis should facilitate identifying cost effective strategies for reducing the impacts of processing and product use on the environment.

Cluster C (modules #9-10): Alternative processes and product substitutions to extend the prior cluster to include substitute products and processes. (Cluster B plus -- #9 Substitution I (components), and #10 Biomass processing)

9. Substitution I: Alternative or Hybrid Structural Systems

Through structural optimization and enhanced design procedures, the use of hybrid structural systems is becoming more common. A hybrid system is one in which multiple materials, or material-based systems are combined into a single structural system. The specific application of any given material is based on its positive and negative attributes, as well as those of the other materials in the system. One rather traditional system, which is an example of a hybrid system, is the light-gage metal sheathed roof diaphragm with lumber framing members common to post-frame buildings.

Objective and Output of Module:

- Provides environmental, energy, and resource impact data on the manufacture of hybrid systems that can substitute for the components built in Structures I. Hybrid systems include the use of wood, agricultural materials, steel, aluminum, concrete, and plastics
- Provides input data into the Integrated Modeling modules
- Provides benchmark data for these products which will enable future comparison of product and process improvements
- Shows fossil versus biomass fuel dependency
- Provides a measure of resource use efficiency

Justification.:

A major area of development in structural systems is the use of hybrid systems, including those utilizing wood and wood-based materials as a structural and/or nonstructural component. The judicious combination of dissimilar materials into a system may open opportunities for better utilization of all materials. To further this, an initial estimate and understanding of these hybrid structural components and systems and their use in structural subassemblies and systems is critical to our ability to characterize the environmental impacts of using these materials.

Inputs:

- Solid wood products
  - lumber
  - glued laminated lumber
  - wood trusses
- Composite wood products
  - LVL
  - parallam
  - composite beams
  - plywood
  - OSB
  - particleboard

- Other materials
  - steel
  - aluminum
  - concrete
  - masonry
  - plastics
- Other essential materials
  - connectors (nails, bolts, glues)
- Governing design criteria
  - energy efficiency
  - architectural
  - structural
- Water
- Energy
- Capital
- Labor
- Transportation

Outputs:

Based on available data, several typical (representative) designs will be analyzed in detail. The analysis will yield the following data:

- Quantity of the individual components
- Quality of the structural assembly
- Emissions to air (CO, CO_2, CH_4, NOx, SO_2, particulate, VOC, formaldehyde), land, water
- Energy
- Solid waste
- Material (products, byproducts)
- Transportation

Procedures:

The results of Structures Modules I and II will be used a baseline for comparisons. The first step will be the evaluation of substitute materials and components for traditional wood-based products. The second step will be the evaluation of hybrid structural assemblies (floors, walls, and roofs), again including an assessment of the relative quality, performance, and life expectancy. An important aspect of this is the inclusion of life-safety and performance criteria in the life-cycle evaluation procedure. The results will be reported for each component and assembly type category discussed above. Regional categories may be introduced if such factors are deemed significant. A standard situation will be analyzed, that is, the assumption will be made that all the materials and technologies are properly used and applied.

Summary Statement in Agenda 2020 Format: Research is needed to synthesize data on the environmental, energy, and resource impact of substituting hybrid structural systems for conventionally built residential and light commercial structures. Hybrid systems consist of multiple materials or material-based systems that are combined into a single structural system. Non-wood materials as well as combinations of these materials with wood are to be considered for comparison.
A life-cycle inventory analysis is needed of the environmental, energy, and resource impacts of using hybrid structural systems as a substitute for conventionally built residential and light commercial buildings. The study should address the impact of these hybrid systems, including those utilizing wood and wood-based materials as structural system and/or structural components. The judicious combination of dissimilar materials into a system may open opportunities for better utilization of all materials in terms of their environmental impact. Hybrid structural materials and systems and their use in structural subassemblies and systems should be studied. Comparisons should be made to the impacts associated with conventionally built subassemblies and structures. The analysis should include resource and energy impact comparisons to the CORRIM 1976 data for similar built structural components. The resultant data and analysis should facilitate identifying cost effective strategies for reducing the impacts on the environment of constructing residential and light commercial buildings.

10. Biomass Processing for Energy

This study analyzes the impact of using biomass as a source of energy. Energy use impacts environmental as well as economic objectives and different energy sources have different influences on resource sustainability. Several extensions to the National Renewable Energy Laboratory's work on life-cycle analysis of dedicated biomass energy through harvesting, transport of fuel, product manufacture, transport to site, and product use are planned (Mann and Spath, 1997). The expanded analysis includes: (1) longer rotations with co-product outputs such as plywood core and (2) boiler technology. It is anticipated that these extensions may be species and therefore region dependent. Energy processing of paper, demolition wood and other wood sources in the waste stream will be considered as an alternative to recycling.

Objective and Output of Module:

- Provides quantitative data on the provision and use of biomass energy in the development of structural building materials when used as a dedicated feedstock or as a waste by-product, or a co-product (energy and solid wood products from the same biomass plantation).

- Provides environmental impact data on use of biomass energy and other forms of energy
- Provides data on the impacts of bioenergy use on resource sustainability
- Interacts on accumulation and use of data with Resource, Processing, and Structures modules

Justification:

Forest biomass is the primary source of energy in the manufacture of wood structural building materials. Much biomass energy is used for producing other items, particularly pulp and paper, and there is interaction between the manufacture of different products. Some biomass is directly harvested for in-plant energy use, but most consists of residues from the primary processing plant or other forest products processing plants. Processing biomass waste for energy is also an alternative to recycling. Some biomass is also used in generating electricity supplied to manufacturing plants through on-site or off-site generation. Around 80 percent of energy consumed in lumber manufacture may be derived from biomass sources. Judicial use of biomass energy extends beyond the benefits in forest products manufacturing operations to environmental benefits of renewable fuels, by reducing dependency on fossil fuels, and alleviating increased emissions of greenhouse gases, sulfur, and heavy metals. A life-cycle analysis of these energy inputs will provide a basis for improving efficiency of energy use, and more intensive and effective use of the biomass resource. Extensions to studies being completed on dedicating biomass forests for power generation will characterize the environmental impacts of co-product alternatives.

Research Statement:

Research is needed to determine the energy use and environmental impacts of biomass energy from all sources. Data will be collected and analyzed on the provision of fuel from the forest, wood residues, and electricity generation from biomass. Supplemental fossil fuel energy will also be analyzed. Environmental, energy, and economic data related to the production and use of energy will be measured in accord with the CORRIM protocol for measuring life-cycle impacts, and some cost/benefit analyses between biomass energy and alternative fossil fuel energy will be made.

The type of input/output factors considered, but not limited to, are:

Inputs:

- Biomass
- Ancillary fuels for harvesting, comminution, and transportation, including gasoline and diesel fuel
- Potential contaminants such as preservatives, paint, and plastic laminates
- Moisture
- Capital, including expenditures for maintenance
- Labor

Outputs:

- Energy in the form of solid, liquid, or gaseous fuels
- Chemicals
- Emissions to air, land, water (CO, CO_2, CH_4, NO_x, SO_2, O3, particulates, hydrocarbons such as VOCs, heavy metals and other inorganic components of ash)
- Co-products (chips and solid wood products)

Procedures:

Impact analysis data from the Biomass Processing for Energy module will be used to encourage plant profitability, conserve biomass, and otherwise improve environmental performance. Primary data will be used for biomass analysis, while secondary data will be used for fossil fuels analysis. The study will be conducted with all inputs and outputs. including various forms of biomass beginning with the tree or residue source through combustion and dispersion of combustion residues. Comparisons among methods of biomass energy procurement including conventional forest management operations, short rotation intensive silviculture, rotation extensions for joint wood product and energy production, salvage operations, and waste stream alleviation will be made. Basis for energy analyses will be high heating value (HHV) and efficiency of conversion to useful energy. Best case scenarios for current biomass energy use, incremental gains, and potential for future technology application will be provided. There will be close coordination with inputs and outputs of the Forest Resource I, Processing I, and Structures II modules.

Secondary impacts including fuel moisture contents, contaminants, and transport distance will be analyzed to obtain a better understanding of biomass energy application.

Special applications of biomass energy such as densification, gasification, or liquefaction, for process heat, electricity, or motor fuel will also be analyzed.

Summary Statement in Agenda 2020 Format: Research is needed on biomass energy processing for accumulating and analyzing energy from biomass data in comparison to other sources of energy.
A comprehensive life-cycle inventory analysis is needed for biomass energy processing to characterize the effects of energy generation from biomass and other sources on resource sustainability, emissions of pollutants to air, ground, and water, and emissions of greenhouse gases to the atmosphere. Sources of biomass energy procurement should include conventional forest management operations, short rotation intensive silviculture, rotation extensions for joint forest product and energy production, salvage operations, and waste stream alleviation. The resultant data and analysis should facilitate cost effective and environmentally desirable strategies for energy use in the life-cycle analysis of buildings.

Cluster D (modules #11 & 12): Extending the life-cycle analysis through the use and ultimate disposal of a building (Cluster C plus—#11 Life Expectancy and Durability, #12 Use, Maintenance and Disposal or Final Recycle).

11. Life Expectancy and Durability

This module addresses the life expectancy and durability of materials used in a structure made from wood resources in representative regions of the U.S. The focus of the study is to define life expectancy and durability and then characterize factors that impact the life expectancy and durability of materials used in a structure. The life of both product and structure will be studied at four levels of life service: the aesthetic life of a product, the service life of a product, the functional life of the structure (e.g., premature replacement due to a zoning change), and the structural life of the building. Durability influences both the service life of the product and the functional life of a structure, and therefore is a critical component in life-cycle analysis of the structure. The end result of the study module will be quantitative information on the four levels of service life for products and the structure that can be used as input variables by other modules.

Objective and Output of Module:

- Defines the life of a product and the structure, which includes for the product the aesthetic and service life, and for the structure the service and functional life. Wood materials to be considered in the structure are softwood lumber, softwood plywood, oriented strand board, laminated veneer lumber, parallel strand lumber, I-beams, and trusses. and wood siding. Other wood materials to be considered include hardwood flooring, windows, and doors.
- Determines those factors most important to increasing life expectancy. A methodology will be developed for measuring the impact of each factor on life expectancy of products and the structure as a whole.
- Provides input data for other modules including Structures I & II; Use, Maintenance, and Disposal or Recycle; and Nonstructural Products.
- Provides a measure of resource use efficiency

Justification:

The life-cycle assessment of residential and light commercial structures must consider the life expectancy of components and the total structure. Characterizing the life expectancy of components in a heterogeneous building system requires a uniform assessment process that can be applied to different configurations.

Research Statement:

Research is needed to determine what factors most influence material performance in the context of life expectancy of the structure. Ultimately, the intent of the research is to provide information on the life expectancy of residential and light commercial structures, including nonstructural components. Both wood-based and non-wood materials will be studied. The type of input/output factors to be considered, but not limited to, are:

Inputs:

- Product type
- Product quality (grade)
- Regional environmental influences
- Construction design/type/quality
- Aesthetic considerations of materials/structure
- Structure use (how we inhabit/use the structure during its life)
- Capital
- Labor
- Transportation

Outputs:

- Life expectancy and durability of the individual components, including life-safety and performance criteria
- Life expectancy and durability of the structure, including life-safety and performance criteria
- Relative cost of alternatives considered

Procedures:

Primary data will be used for structural and nonstructural wood materials; secondary data will be used for alternative materials used in the same application.

Summary Statement in Agenda 2020 Format: Research is needed to characterize the life expectancy and durability of materials used in residential and light commercial structures relative to alternative materials and configurations.
The life of the products and structures are to be assessed at four levels of life expectancy: the aesthetic life of a product, the service life of a product, the functional life of the building, and the structural life of the building. The study should include assessment of material performance factors, aesthetic considerations, and environmental inputs for representative regions of the U.S. Structural materials to be evaluated in the study include, softwood lumber, softwood plywood, oriented strand board, laminated veneer lumber, parallel strand lumber, I-beams, and trusses, and wood siding materials. Other wood materials to be considered include hardwood flooring, windows, and doors. The resultant data should include an assessment of factors influencing life expectancy for the list of materials for representative structures, including alternatives for increasing life expectancy. Data will be presented for both wood based structures and other configurations.

12. Use, Maintenance, and Disposal or Recycle

This module addresses the life cycle assessment of residential and light commercial structures in terms of environmental, energy, and economic impacts associated with their occupancy. Included in this analysis is energy use associated with heating/cooling, maintenance, and the disposal and/or recycling of materials in the structure. Replacement or maintenance of a material or structure can occur at any of its four levels of life service: the aesthetic life of a product, the service life of a product, the functional life of the structure, and the structural life of the building. The scope of the analysis applies life expectancy data for products and structures to the life cycle of a building including occupancy, maintenance and associated replacement of materials due either to aesthetics or service life, to the final disposal or recycling of materials.

Objective and output of module:

- Measures the environmental, energy, and economic impacts due to the occupancy of residential and light commercial structures. The analysis will consider use, maintenance, and disposal or recycle of the structure at its various life expectancies-aesthetic, functional, and structural. Structural wood materials considered in this module are softwood lumber, softwood plywood, oriented strand board, laminated veneer lumber, parallel strand lumber, I-beams, and trusses. Nonstructural materials to be considered include flooring, windows, doors, siding, roofing, and insulation. Alternative materials will also be analyzed.
- Determines the amount of energy consumed during the structure's life attributed to heating/cooling requirements, maintenance and disposal/recycle.
- Defines intermediate and final recycle options and final disposal costs for the materials described, including non-wood substitutes or alternatives that may be used in the structure.
- Provides output data on the environmental, energy and economic impacts of the use of residential and light commercial structures into the Integrated Modeling module.

Justification:

Research is needed on the life-cycle assessment of residential and light commercial structures in terms of the environmental, energy, and economic impacts associated with occupancy during their service life. Of specific national interest is the energy requirements of these structures during life expectancy for heating/cooling, maintenance, and final disposal or recycle of its materials. Final life costs are the last contributing factor in an overall life cycle assessment of a structure, but must also include intermediate costs associated with maintenance and remodeling of the structure during its life. Often materials are replaced due to aesthetics or functional reasons, long before structural life expectancy is exceeded.

Research Statement:

Research will determine what environmental, energy and economic impacts occur due to the occupancy of residential and light commercial structures in representative regions of the U.S. Various options will be explored for intermediate recycling of materials. Also explored will be the final disposal or recycle cost of materials for the structures. Energy consumption is another focus of the module. Energy required for heating/cooling a structure during occupancy depends on the structure's construction and building code requirements and will be incorporated into this analysis. The end result of the study module will be quantitative information on energy use, other environmental impacts and costs, during occupancy, maintenance, and final disposal of the structure that can be output to other modules. Inputs from other modules will be necessary for completion of this module, they include the Life Expectancy and Durability, Structures I and II, Nonstructural Products, and Substitution modules. The input/output factors to be considered are:

Inputs:

- Product aesthetic and service life
- Structure service and functional life
- Product type and quality (grade)
- Construction design/type/quality
- Building and energy codes
- Maintenance schedules
- Aesthetic considerations of materials/structure
- Regional environmental regulations regarding disposal of materials
- Disposal costs (including transportation and conversion costs)
- Demolition/replacement costs
- Energy costs
- Structure efficiency ratings for energy calculations
- Labor
- Transportation

Outputs:

- Environmental, energy and economic impacts of repair or replacement of materials at intermediate time frames
- Volume of materials repaired or replaced or removed
- Emissions to air, land, water
- Energy consumption during occupancy
- Comparison of alternatives considered

Procedures:

Primary data will be used for structural and nonstructural wood materials; secondary data will be used for alternative materials used in the same application.

Summary Statement in Agenda 2020 Format: Research is needed on the environmental, energy, and economic impacts of materials for the use, maintenance, and final disposal or recycle life stages of residential and light commercial structures.
The study should include an assessment of the factors affecting material performance, aesthetic considerations that influence intermediate repair or remodel activities, and final disposal or recycle of materials for representative regions of the United States. This requires a life-cycle analysis of the energy demands for heating/cooling for the life of the structure. Structural building materials to be evaluated include softwood lumber, softwood plywood, oriented strand board, laminated veneer lumber, parallel strand lumber, I-beams, and trusses. Nonstructural materials to be considered include flooring, windows, doors, roofing, and insulation. The resultant data should include factors that influence maintenance or remodel activities that generate a stream of reusable or recyclable materials, the type and volume of materials replaced during maintenance, and the final disposal or recycle costs of materials for the entire structure. Data will be presented for wood, alternative materials, and their combinations for use as building materials.

PHASE II:

Cluster E (modules 13-19): Comprehensive alternatives for structures including resource management, processing, product substitutes, structural systems and nonstructural products, including use and disposal (Cluster D plus -- #13 Forest Resources II, #14 Processes II - nonstructural, #15 Substitution IIa, #16 Structures II, #17 Integrated Modeling IIa, #18 Nonstructural Products II, and #19 Substitution nonstructural).

13. Forest Resource II (U.S. and Canada: Northeast, North-central, Inland West)

Other forest regions of the United States and Canada will be analyzed using procedures similar to those of Forest Resources I Module. These regions include hardwoods and softwoods of the Northeast and North-central United States and Canada, softwoods of the Inland-west region of the United States and Canada, and softwoods of the west coast of Canada and Alaska.

Objective and Output of the Module:

- Provides environmental, energy and resource data on the growth, management, harvest and reforestation of timber under five general scenarios of management intensity for the Northeast, North-central, and Inland-west regions of the United States and Canada and the west coast region of Canada and Alaska.
- Develops case studies to represent a typical range of forest management objectives and stand and site conditions.
- Provides environmental performance measures including indices of stand structure diversity, habitat, and fragmentation for each of the case study scenarios

- Provides input to the Processing and Biomass modules for each of the case study scenarios

Justification:

Removal of wood biomass from the forest and the activities associated with growth, removal, and re-establishment of trees need careful analysis to determine the total life-cycle impacts and sustainability of the use of biomass-based products. Life-cycle impacts are not stationary and will change over the text 100 years based on both past and prospective technologies, evolving forest management procedures and population demands. Time becomes a critical element of this analysis since the period from initial planting or forest establishment to removal can range from five years for short rotation intensive culture to 100 years or more for selectively managed natural forests. Inputs and outputs of the life-cycle process include both quantitative and qualitative measures of the environment and timber removed. To some, the qualitative (largely environmental) factors are of great importance to the life-cycle impacts of utilizing wood biomass and, to the degree possible, these factors need quantitative descriptions developed. Understanding the time dependent linkages between technology changes and management practices and their effects on these factors is essential to improve forest management alternatives that enhance the critical environmental features, but are also cost effective.

Research Statement::

Research is needed to identify harvest and forest management technologies that enhance critical environmental factors (environmental design systems) associated with forest management alternatives that are designed to produce timber. This will be done by characterizing the life-cycle inputs and outputs of representative forestry operations. A wide variety of forest management and harvesting options currently exist, but the total environmental and economic impacts of these options over the life cycle of the forest are not well understood. A limited number of scenarios, representing the range of environmental and timber objectives, will be structured and analyzed through existing models. These options include:

(1) High timber output at low cost, while maintaining low environmental impacts—a scenario likely to involve areas intensively managed for timber and will involve such forest management activities as fertilization, thinning, harvest regeneration cuts and reforestation through planting.

(2) High outputs of environmental factors at low cost, but with continued production of timber—a scenario likely to involve selective removals of trees to maintain health, diversity and density of the forest. Reforestation will generally occur naturally.

(3) Joint objectives for timber and environmental factors on the same acre— a scenario that may include intensive forest management activities designed to achieve objectives for both timber and biodiversity. Activities such as thinning, snag and debris retention could be involved to achieve a desired level of structure diversity and mix of species.

(4) Short rotation intensive culture for the products of biomass— a scenario involving fast growing species that are managed with water and chemical inputs to achieve maximum growth of fiber in the minimum amount of time.

(5) No forest management with no entries for wood removal— a control scenario that in one instance will involve historic disturbance pattern (wildfire, wind etc.) And in the other instance involve intervention-affected disturbance patterns (results of natural fire exclusion, etc.).

Outputs will be developed from existing models and synthesized to provide an indication of the life-cycle impacts of this range of forest operations. Some of these outputs are measurable in conventional units of measurement. Some environmental outputs will need to be expressed as indices comparable to the input values. All measures will be developed or calculated as responsive to selected management alternatives and primary resource inputs.

Inputs:

- Stand structure and location as described by slope classification. site classification moisture relationship (wet or dry site), age classification (even aged, uneven aged, mature) and species mix. Analysis will be restricted to a distinct number of cases that represent the most common combination of conditions of a region.
- Harvesting options with a regional average transport distance to the processing point and the harvest system selected from mechanized or non-mechanized, ground-based, cable or aerial harvesting system, or alternative harvesting technologies. The harvesting system selected will be matched to options on road location and density.
- Natural disturbances with associated risk factors for wildfire, insect and disease, wind and storm damage, and floods and related slope instability. Impact and costs of mitigation and control measures will also be noted.
- Forest management treatments to existing forest stands to include thinning, fertilization, herbicide and pesticide treatments, harvest prescription, and reforestation.
- Pre-treatment measurements of environmental factors that include water quality index, water quantity outflow per acre, an air quality index for factors related to fire, snags and down woody material, fuel loading, a biological diversity index as measured by a habitat index and stands structure (diameter, trees per acre, canopy, etc.), an index of fragmentation, carbon storage per acre, and volume of standing biomass per acre.
- Cost basis (simplified/standardized tax accounting) to include material costs, labor costs, cost of capital, and taxes.
- Product options and values to include outputs in lumber grades, pulp wood grades and engineered products.
- Harvesting inputs for harvest transport to gate of process point including energy requirements per acre by option, carbon emissions during harvesting, and other emissions during harvest.

Outputs:

Output tables of stand level variables will be expressed on a per acre basis. Outputs that do not lend themselves to per acre expressions will be expressed as a regional impact. Some outputs will stand by themselves as measures of impact from forest operations. In these cases they will be compared to values and indicators before treatment. Others will serve as input to the processing modules of the project. The outputs include the following:

- Product volumes by quality, product, and species categories
- Energy used by form
- Carbon balance
  - amount released and amount stored
  - input to products
- Water quality indicator
- Water quantity measurement
- Air emissions
- Biological diversity index as measured by habitat and stand structure
- Fragmentation index
- Snags and down woody material
- Production costs
- Economics from marketed products to include net present value, rural jobs, tax receipts

Procedures:

The combination of forest stand conditions and treatment options in any given region are infinite. The first step in analysis for this module will be to develop a fixed number of options for analysis based on the five options defined earlier and stand and slope conditions typical of a region. These will represent the most likely scenarios to meet timber market and environmental objectives and will also reflect a range of treatment options from no management or recovery from a site to intensive management. The site and stand conditions will also be limited to reflect those moist likely to be selected for removal of biomass material. A select number of case studies will be developed for each region.

Existing models will be used to develop relationships before and after treatment. Models are generally available to predict growth and yield of the biomass over time, to predict watershed impacts in terms of sediment flow and water quantity, and to assess fire risk in forest stands. Other work has been done in some regions to develop indicators of habitat and biological diversity. Where necessary, additional indicators will be developed from model output. Results of these models will be synthesized to develop output tables for a selected number of treatment options and locations.

Important outputs characterizing the impact of technology management alternatives include the amount and quality of timber for markets, carbon stored and input to product flows, energy used by form, measures of biodiversity (habitat indices and stand structures), net present value to the landowner, jobs tax receipts, expenditures, and *capital* requirements. These will establish a life-cycle footprint for the management alternative as a function of time.

Summary Statement in Agenda 2020 Format: Research is needed to synthesize data on the environmental and energy impact of providing timber and logs for the manufacture of products used in construction applications.
A comprehensive analysis of the impact of forest resource management from stocking through the delivery of logs to manufacturing operations is needed for other wood producing regions of the United States and Canada — the northeast, north-central, inland west, west coast of Canada and Alaska. This analysis should consider all pertinent inputs and outputs, including development of a life-cycle inventory analysis of environmental and energy measures for comparison to the use of other resources or management alternatives. The analysis should include a range of management alternatives and their impact on harvest, forest inventory, carbon sequestration, forest structure distributions and linked habitat indices, and other co-products of forest management. The resultant data and analysis should facilitate identification of cost effective strategies for reducing the impacts of forest production on the environment or to meet existing or proposed environmental requirements.

14. Processes II - Nonstructural

This study analyzes the manufacturing processes for nonstructural building materials made from wood. The focus of the study is to conduct a life-cycle analysis of all the environmental, energy, and resource impacts for the manufacture of the raw materials into products. Other research modules will provide input values characterizing the raw materials. Similarly other modules will use the output of this module for their inputs.

Objective and Output of Module:

- Provides environmental, energy, and resource impact data on the manufacture of hardwood lumber, hardwood plywood, underlayment and industrial particleboard, medium density fiberboard (MDF), hardboard, insulation board, wood/plastic composites, wood/cement composites
- Provides input data into the Nonstructural Module
- Provides benchmark data for these products which will enable future comparison of process improvements or to new processes
- Provides a comparison for energy and resource impacts for some of these products relative to 1976 CORRIM study

  - Shows fossil versus biomass fuel dependency

  - Provides a measure of resource use efficiency
- Shows impact of recycling upon material use

Justification:

Over half of all forest products manufactured go into residential and light commercial construction, either as building materials or as millwork, cabinets and furniture. A major portion of these products consist of nonstructural building materials in the form of hardwood lumber, hardwood plywood, underlayment and industrial particleboard, medium density fiberboard (MDF), hardboard, insulation board, wood/plastic composites, wood/cement composites. The emphasis of this module will be on the life-cycle analysis of the manufacture of these materials based on wood resources, with attention given to regional differences. The assessment of these materials will be used as inputs to the nonstructural modules that will assess the manufacture of windows, doors, cladding, roofing, cabinets, furniture, countertops, and other similar products. Some of the data for this module will be compared to the 1976 CORRIM report to demonstrate any improvements in energy uses and material balances that may exist (environmental impacts were not considered in the 1976 CORRIM study).

Research Statement:

Research is needed to synthesize from available sources environmental impacts resulting from the use of nonstructural wood material in buildings. The intent of this research is to document the impact of manufacturing nonstructural materials that will be used in construction of buildings and the materials that are placed in these structures. Data will be collected and analyzed on the production of hardwood lumber, hardwood plywood, underlayment and industrial particleboard, medium density fiberboard (MDF), hardboard, insulation board, wood/plastic composites, wood/cement composites. Environmental, energy, materials, and economic data related to the production of these products will be done in a manner consistent with the CORRIM II protocol for measuring life-cycle impacts, while also being able to provide cost/benefit analysis comparisons between alternatives.

The type of input/output factors considered, but not limited to, are:

Inputs:

- Raw materials (type, amount, and cost)
- Ancillary materials (adhesives, coatings, laminates, wax, oils, antifreeze, packaging)
- Water
- Energy (type and source)
- Capital
- Labor
- Transportation

Outputs:

- Emissions to air (CO, CO_2, CH_4, NOx, SO_2, particulate, VOC, formaldehyde), land, water
- Energy
- Solid waste
- Material (products, byproducts)
- Transportation

Procedures:

Primary data will be used for wood products processed for the structural materials, while secondary data will be used for alternative materials such as steel, concrete, and plastic. The study will be conducted of all inputs and outputs, from the raw material coming into the process to a manufactured product ready for shipping. Impact analysis data from the Forest Resource I and Processes I modules will be used as raw material inputs to the manufacturing operation. Several new analysis methods will be employed to enhance the value of the CORRIM data. They are (1) analysis of machine centers within a process and (2) the use of distribution or range values for the inputs and outputs. Analysis of the selected processes will be done not only by product, i.e. decorative hardwood plywood, but by machine center within a process as well. Examples of machine centers include such manufacturing steps as machining, drying, blending and hot pressing. Choosing the machine center approach has several benefits. First of all, it will save time and effort when analyzing other operations that have the same or similar machine center in their operation (i.e., veneer drying is done in both sheathing plywood and laminated veneer lumber processes). Secondly, information from machine centers may enable the analysis of new products and processes based on known machine centers. Information gathered using this approach should prove useful in examining process modifications and determining the amount of reduction in environmental, energy and resource impacts that may be realized through processing and product changes. The models developed should be more effective analysis tools.

Summary Statement in Agenda 2020 Format: Research is needed to synthesize data on the environmental, energy, and resource impact of manufacturing nonstructural wood products such as hardwood lumber, hardwood plywood, underlayment and industrial particleboard, medium density fiberboard (MDF), hardboard, insulation board, wood/plastic composites, wood/cement composites–materials used in the construction of buildings as well as the products that go into them.
A comprehensive life-cycle inventory analysis is needed of the environmental, energy, and resource impacts of wood use as a structural material and as an alternative to other materials. The study should address the impact from the resources entering the manufacturing operations to the shipped product at its destination of use, considering all pertinent inputs and outputs. The analysis should include a comparison to the 1976 CORRIM data for similar processes. The resultant data and analysis should facilitate identifying cost effective strategies for reducing the impacts of processing and product use on the environment.

15. Substitution IIa: Structures

This study develops the data and mechanism necessary to analyze the manufacturing processes for substitute products for those studied in Processing II--hardwood lumber, hardwood plywood, underlayment and industrial particleboard, medium density fiberboard (MDF), hardboard, insulation board, wood/plastic composites, wood/cement composites. A major focus will be on novel, new materials. A life-cycle analysis will be done of all the environmental, energy, and resource impacts associated with the manufacture these new products from their raw materials to the product exiting the operations. Other research modules will provide input values for the raw materials, whereas other modules will use the output of this module for their inputs.

Objective and Output of Module:

- Provides environmental, energy, and resource impact data on the manufacture of novel, new products that will substitute for conventional products of hardwood lumber, hardwood plywood, underlayment and industrial particleboard, medium density fiberboard (MDF), hardboard, insulation board, wood/plastic composites, wood/cement composites
- Provides input data into the Nonstructural modules which cover doors, windows, cladding, siding, moulding, cabinets, countertops, etc.
- Provides a comparison of data for these products to the conventional products or their processes
- Provides a measure of resource use efficiency

Justification:

Over half of all forest products manufactured go into residential and light commercial construction, either as building materials or as millwork, cabinets and furniture. A major portion of these products consist of nonstructural building materials in the form of hardwood lumber, hardwood plywood, underlayment and industrial particleboard, medium density fiberboard (MDF), hardboard, insulation board, wood/plastic composites, wood/cement composites. Most of these materials have been developed as substitutes for solid wood over recent decades. This trend of substitution of materials is likely to occur as new materials are developed. The emphasis of this module will be on the life-cycle analysis of the manufacture of wood-based, non-wood, and hybrid materials that will substitute for traditional materials. The output of this module will be used as inputs to the Nonstructural modules which assess the manufacture of windows, doors, cladding, roofing, cabinets, furniture, countertops, and other similar products.

Research Statement:

Research is needed to synthesize from available sources the impacts resulting from the use of nonstructural wood-based materials. Data will be collected and analyzed on the production of novel materials that can substitute for conventional materials such as hardwood lumber, hardwood plywood, underlayment and industrial particleboard, medium density fiberboard

(MDF), hardboard, insulation board, wood/plastic composites, wood/cement composites. Environmental, energy, materials, and economic data related to the production of these new products will be done in a manner consistent with the CORRIM II protocol for measuring life-cycle impacts, while also being able to provide cost/benefit analysis comparisons between alternatives.

The type of input/output factors considered, but not limited to, are:

Inputs:

- Raw materials (type, amount, and cost)
- Ancillary materials (adhesives, coatings, laminates, wax, oils, antifreeze, packaging)
- Water
- Energy (type and source)
- Capital
- Labor
- Transportation

Outputs:

- Emissions to air (CO, CO_2, CH_4, NOx, SO_2, particulate, VOC, formaldehyde), land, water
- Energy
- Solid waste
- Material (products, byproducts)
- Transportation

Procedures:

Primary data will be used for wood-based products processing for these new materials, while secondary data will be used for component/alternative materials such as steel, concrete, and plastic. The study will be conducted of all the inputs and outputs from the raw material coming into the process, to a manufactured product ready for shipping. Impact analysis data from the Processing II module will be used as raw material inputs to the manufacturing operation. Information gathered should prove useful in examining process/product modifications and determining the amount of reduction in environmental, energy and resource impacts that may be realized through processing and product changes.

Summary Statement in Agenda 2020 Format: Research is needed to synthesize data on the environmental, energy, and resource impact of manufacturing novel materials that may substitute for nonstructural wood products such as hardwood lumber, hardwood plywood, underlayment and industrial particleboard, medium density fiberboard (MDF), hardboard, insulation board, wood/plastic composites, wood/cement composite–materials used in the construction of buildings.
A comprehensive life-cycle inventory analysis is needed for the environmental, energy, and resource impacts of wood-based nonstructural material and its use as an alternative to other materials. An analysis of the comparisons will support the identification of alternatives that can improve environmental performance.

16. Structures II: Complete Structural Systems and Buildings

The combination of structural subassemblies, such as floors, walls, and roofs addressed in Structures Module I, result in a complete (or full) structural system. This complete structural system is the basic form of a building. It may include some basic architectural components (e.g., windows, doors, "nonstructural" cladding, etc.). The complete building will include, at a minimum, the structural system, plus various other components including architectural components (nonstructural partition walls, etc.), energy components (e.g., insulation, etc.), and permanent furnishings (e.g., flooring, cabinetry, etc.). The aim of this module is to study the complete structural system as a sum of components and subassemblies, as well as the addition of some basic components of a complete building (e.g., nonstructural partitions, flooring, etc.). Finally, included in this module is both light-frame and heavy-timber construction.

Objective and output of module:

- Provides environmental, energy, and resource impact data on the manufacture of residential and light commercial structures—includes windows, doors, roofing, insulation and siding (both site-constructed and factory-built will be analyzed)
- Provides environmental, energy, and resource impact data on the manufacture of alternative structures (materials) to conventional built structures
- Provides input data into the Integrated Modeling II module
- Provides benchmark data for these products which will enable future comparison of process improvements or to new processes
- Shows fossil versus biomass fuel dependency
- Provides a measure of resource use efficiency

Justification:

A major area of use for renewable wood and wood-based materials is as a structural component in residential and light commercial buildings. The combination of individual structural components (i.e., joists, studs, sheathing, etc.) and various "subassemblies" such as floors, walls, and roofs (see Structures Module I) into a complete (or full) structural system completes the application. Added to this, however, are various nonstructural, yet permanent components and subassemblies. The integration of structural and nonstructural components and subassemblies is critical to our ability to characterize the impact of the uses of these renewable materials.

Inputs:

- Categories
  - light-frame buildings
  - heavy-timber structures
- Additional materials (beyond Structures Module I)
  - other sheathing (wood- and non-wood-based materials): gypsum board, siding products (brick, stucco, aluminum, high-density fiberboard, wood-cement based boards, vinyl)
  - insulation
  - connectors (nails, bolts, glues)
  - flooring (vinyl, wood, carpets, ceramic-based)
  - paint
  - doors and windows
  - plumbing and electrical installation materials
- Transportation
- Labor
- Capital

Outputs:

Based on the available data, several typical (representative) designs will be analyzed in detail. The analysis will yield the following data:

- Quantity of the individual components
- Quality of the structure
- Emissions to air (CO, CO_2, CH_4, NOx, SO_2, particulate, VOC, formaldehyde), land, water
- Energy
- Solid waste
- Material (products, byproducts)
- Transportation
- Relative cost of alternatives considered

Procedures:

The first step in the analysis will be to utilize the results of Structural Module I to assess the integration of structural components and subassemblies into complete structural systems, including an evaluation of the relative quality and performance of various structural systems. Complete structural systems or buildings would be analyzed for two temperature climates (warm and cold) and built to code. A number of various construction methods (factory- and site-built) and material combinations would be selected as case studies for analysis. The second step will be the evaluation of these complete buildings comprised of the aforementioned structural building system and basic nonstructural components (e.g., partition walls, insulation, doors and windows, etc.), again including an assessment of the relative quality and performance. An important aspect of this is the inclusion of life-safety and performance criteria in the life-cycle evaluation procedure. The results will be reported for each structural and/or building type category discussed above. Regional categories may be introduced if such factors are deemed significant. A standard situation will be analyzed, that is, assumption will be made that all the materials and technologies are properly used and applied.

Summary Statement in Agenda 2020 Format: Research is needed to synthesize data on the environmental, energy, and resource impact of constructing residential and light commercial buildings consisting of all structural and non-structural components. The completed structures would include the structural systems, architectural components, energy components, and permanent furnishings.
A comprehensive life-cycle inventory analysis is needed of the environmental, energy, and resource impacts for constructing completed residential and light commercial buildings. The completed structures would include the structural system (joists, trusses, framing, and sheathing), architectural components (sheetrock, siding, roofing, windows, and doors), energy components (insulation) and permanent furnishings. Buildings should be analyzed for two temperature climates (warm and cold) and built to code. A number of various construction methods (factory- and site-built) and material combinations should be selected as case studies for analysis. The resultant data and analysis should facilitate identifying cost effective strategies for reducing the impacts on the environment of constructing residential and light commercial buildings.

17. Integrated Modeling IIa (see #4 Data Management and Integrated Modeling)

18. Nonstructural Products II

This study analyzes the nonstructural products made from wood or wood-based composites and used to furnish the interiors of residential and light commercial building. The focus of the study is to conduct a life-cycle inventory analysis of all the environmental, energy, and resource impacts resulting from the manufacture of these products from the point where typical raw materials enter the manufacturing operation to the point the product exits the plant. Other research modules will provide this module's raw material input values, while its output values will be used as inputs for another module.

Objective and Output of Module:

- Provides environmental impact, and energy and resource usage data from the manufacturing of both solid and wood-composite furniture and fixtures, and kitchen cabinets
- Provides input data for the Integrated Modeling II module
- Provides baseline data for these products' manufacturing processes
- Provides data for comparing energy and resource usage with these produces relative to the 1976 CORRIM study
- Provides data for calculating resource efficiency

Justification:

Over half of all forest products manufactured go into residential and light commercial construction. A significant portion of these products' dollar value consists of items such as fixed and freestanding cabinets, fixtures, and furniture for furnishing interior spaces. This module's life-cycle inventory analysis will include manufacturing data from all national regions because its inputs are likely to be raw materials of standard industry grade and to be shipped and available in all regions. The assessment of these materials will be used as input values for the Integrated Modeling II module. The data for this module will also be compared to 1976 CORRIM report where possible to demonstrate any improvements in energy use and material balance (environmental impacts were not considered in the 1976 CORRIM study).

Research Statement:

Information is needed on the effects of using nonstructural, wood-based elements in residential and light commercial buildings. The purpose of this research is to develop knowledge on how manufacture of these nonstructural wood-based building components affects environmental emissions, energy consumption, and material flows. Data will be collected and analyzed on the product industry categories classified under Standard Industrial Classification Major Group 25 for furniture and fixtures and for Industry Number 2434, wood kitchen cabinets, under Major Group 24. Environmental, energy, material, and economic data related to the production of these products will be collected in a manner consistent with the CORRIM II protocol for measuring life-cycle consequences. The information generated will also provide a basis for cost/benefit comparisons with alternatives products. The type of input/output factors considered, but not limited to, are:

Inputs:

- Raw materials (type and amount)
- Ancillary materials (e.g. adhesives, nails/fasteners, and finishes)
- Water
- Energy (type and source)
- Air
- Capital
- Labor
- Transportation

Outputs:

- Emissions to air (CO, CO_2, CH_4, NOx, SO_2, particulate, VOC, formaldehyde), land, water
- Energy
- Solid waste
- Material (products, byproducts)
- Transportation

Procedures:

The study will use the outputs developed in the Processes II Nonstructural Wood/Non-Wood and Biomass Processing modules as raw material inputs to the manufacturing operations in this module. Relevant data will be developed from these inputs to a manufactured product ready for shipping. Several new analysis methods will be employed in collecting the CORRIM data. Where possible, instead of compiling only aggregate data for a product, an analysis by machine center or operation will be performed within a manufacturing process. For example in the manufacture of wood kitchen cabinets, data could be developed for the rough mill process which might then be reused for the same or similar rough mill processes for wood furniture. This should also prove helpful when analyzing new products or processes using known machine centers and when examining process or product modifications to determine any reductions in environmental, energy and resource impacts. A range or distribution of values for the inputs and outputs will also be used. This will produce a more realistic life-cycle inventory analysis. This module's output data will be presented in a form usable by the Integrated Modeling II module. The information produced from this analysis will also be used to compare these products with competitive substitute products such as metal or plastic furniture and fixtures.

Summary Statement in Agenda 2020 Format: Research is needed to develop on the environmental, energy, material, and resource impact of manufacturing nonstructural wood-based products such as fixed and free-standing cabinets, fixtures, and furniture used to furnish the interiors of residential and light commercial structures.
This requires a comprehensive life-cycle inventory analysis of the environmental, energy, and resource factors affecting the use of wood in nonstructural components. A comparison with similar non-wood-based components can than be performed with this information. The study should determine all the consequences, including all pertinent inputs and outputs, from the time the raw material enters the manufacturing process until the finished product is shipped. The products and related processes to be analyzed are those used to produce kitchen cabinets, fixtures, and furniture for furnishing the interior spaces of a residential or light commercial building. The analysis should include a comparison to the 1976 CORRIM data for similar processes where possible. The resultant data and analysis should facilitate identifying cost effective strategies for reducing the impacts of processing and product use on the environment.

19. Substitution IIb: Nonstructural (see #15 Substitution)

Cluster F - Infrastructure Uses (module 20 in conjunction with integrated modeling)

20. Structures III: Infrastructure Uses

Beyond light-frame and heavy timber building systems (see Structural Modules I and II), wood is used extensively as a basic infrastructure construction material. Included in the scope of applications of wood in the infrastructure are timber bridges and bridge components, utility lines, waterfront facilities (i.e., docks, piers, etc.), pile foundations, etc.

Objective and Output of Module:

- Provides environmental, energy, and resource impact data on the application of wood for infrastructures including timber bridges, waterfront facilities, pile foundations, and electrical and communication delivery systems
- Provides input data into the Integrated Modeling II module
- Provides benchmark data for these products which will enable future comparison of process improvements or to new processes
- Shows fossil versus biomass fuel dependency
- Provides a measure of resource use efficiency

Justification.

In addition to buildings, renewable wood and wood-based materials are used extensively as a structural component in infrastructure applications such as bridges, dock, piers, pile foundations, etc. These applications are similar to those in building systems; however, they typically involve larger timbers, more treated materials, and the direct application of material components into a complete structure (versus the use of subassemblies in building systems). Additionally, in infrastructure applications, there is less use of "nonstructural" components. The integration of structural components in infrastructure applications is critical to our ability to characterize the impact of the uses of these renewable materials.

Inputs:

- Treated and untreated solid wood products
  - lumber
  - glued laminated lumber
  - wood trusses
  - poles and piles
- Treated and untreated composite wood products
  - LVL
  - Parallam
  - wood/synthetic composites
- Other essential materials
  - connectors (nails, spikes, bolts, glues)
- Type of structure
  - bridge (traditional, stress-laminated, etc.)
  - waterfront (docks, piers, piles)
  - utilities (transmission/power poles)
- Type of construction
  - site-constructed
  - prefabricated (modular construction, etc.)
- Transportation
- Labor
- Capital

Outputs:

Based on available data, several typical (representative) designs will be analyzed in detail. The analysis will yield the following data:

- Quantity of the individual components
- Quality of the structure
- Emissions to air (CO, CO_2, CH_4, NOx, SO_2, particulate, VOC, formaldehyde), land, water

- Energy
- Solid waste
- Material (products, byproducts)

Procedures:

The first step in the analysis will be an evaluation of available components and the relative quality and performance of these components as appropriate for the various applications. The second step will be the evaluation of structural systems (bridge, pier, dock, utility, etc.) comprised of the aforementioned components, again including an assessment of the relative quality and performance. An important aspect of this is the inclusion of life-safety, life-line (i.e., loss of essential infrastructure, especially during natural hazard events) and performance criteria in the life-cycle evaluation procedure. The results will be reported for each component and structure type discussed above. Regional categories may be introduced if such factors are deemed significant. A standard situation will be analyzed, that is, the assumption will be made that all the materials and technologies are properly used and applied.

Summary Statement in Agenda 2020 Format: Research is needed to synthesize data on the environmental, energy, and resource impact of constructing infrastructure such as timber bridges and bridge components, waterfront facilities such as docks and piers, pile foundations, and poles for electricity and communication delivery systems.
A comprehensive life-cycle inventory analysis is needed of the environmental, energy, and resource impacts of wood use for infrastructure applications such as bridges, docks, piers, piling, and poles. These applications often use large timbers or laminated beams that may or may not be treated. The study should address the impact of constructing these structures of wood and wood-based materials, along with comparison to non-wood alternative materials.

Cluster G - Comprehensive Integration (all modules) for comprehensive analysis of carbon storage and energy with consistent global linkages (#21 Integrated Modeling II, #22 Reporting/Technology Transfer)

21. Integrated Modeling IIb (see #4 Data Management and Integrated Modeling)

22. Final Reporting (and Outreach)

There are many reports that will be developed as a consequence of this research. Each research module will have a mid-term report as needed for other research modules as well as a final report. In addition, module results will be integrated into a final multi-volume report (an outline of the contents for this final integrated report is provided in Appendix D). A sequence of review conferences will be held to involve practitioners in the review and provide guidance on the assembly of final reports.

APPENDIX C

ORGANIZATION OF CORRIM'S SCIENTIFIC EXPERTISE

BOARD OF DIRECTORS: CORRIM member research institutions each provide a representative to the voting Board of CORRIM. Supporting companies provided additional non-voting representatives to facilitate information flow and review by experienced practitioners.

<u>The Board of Directors is composed of:</u>

Research Institutions (and voting members):

Bruce Lippke, President, University of Washington (UW)
Jim Bowyer, Vice President, University of Minnesota (U. Minn.)
Tom McLain, Secretary, Oregon State University (OSU)
Donald Bender, Washington State University (WSU)
Jim Dangerfield, FORINTEK, Canada
Geza Ifju, Virginia Polytechnic Institute and State University (VPI)
Bo Kasal, North Carolina State University (NCSU)
W. Ramsay Smith, Louisiana State University (LSU)
Leonard Johnson, University of Idaho (U. Idaho)
Dennis Le Master, Purdue University
Sue LeVan, U.S. Forest Service-Forest Products Laboratory (USFS-FPL)
Doug Gardner, Michigan Tech University (MTU)
Darrel Nicholas, Mississippi State University (MSU)
Paul Winistorfer, University of Tennessee (U. Tenn.)
Mike O'Halloran, APA

Company representatives.

Del Raymond, Weyerhaeuser Co.
Bill Nicholson, Potlatch
John Gorman, Simpson Investment Co.
Gary Watson, Boise Cascade Corp.
David Crooker, Plum Creek Timber Co.
Bob Glowinski (ex officio), AF&PA

TECHNICAL STEERING COMMITTEE MEMBERS: The Board formed a technical Steering Committee made up of the Board and selected independent expertise representing government, environmental interests, and other materials experts to provide guidance for the technical panels of experts who are assigned the tasks of developing and reviewing the research modules.

<u>The Steering Committee includes (in addition to Board members):</u> Jim Bowyer, Chair

Panel Chairs:

David Briggs, Data, Standards and Procedures, UW
Jim Wilson, Stages of Processing, OSU
Con Schallau (acting): Strategy Assessment, consultant

Steering Committee Members at Large:

Steve Kelley, National Renewable Energy Laboratory (NREL)
Valri Robinson, DOE, Office of Industrial Technologies
Scott Chubbs, American Iron and Steel
Connie Best, The Pacific Forest Trust
Joe Demkin, American Institute of Architects
Reid Miner, National Center for Air and Stream Improvement (NCASI)
Roger Blair, EPA

Technical Panels: The Board identified three primary panels and a number of supporting Technical Advisory Committees (TAC's) to assist the panels. The three primary panels are (1) Data, Standards and Procedures, (2) Stages of Processing, and (3) Strategy Assessment. The Stages of Processing Panel was subdivided into four TAC's: (1) Resources, (2) Processing, (3) Structures, and (4) Use and Disposal.

<u>The Data Standards and Procedures Panel is composed of:</u> (* identifies active reviewers)

David Briggs*, Chair, University of Washington

<u>Members and Candidates:</u>

John Zerbe*, vice chair, USFS-FPL (consultant)
Jim Bowyer*, U. Minn.
Leonard Johnson*, U. Idaho
Pat Layton*, AF&PA
Bruce Lippke*, UW
Jamie Meil*, JKM Associates for FORINTEK, Canada
John Perez-Garcia*, UW
Jim Wilson*, OSU
Reid Miner*, NCASI

<u>The Stage of Processing Panel and its Technical Committees are composed of:</u>

Panel Chair: Jim Wilson*, OSU
Resources Committee Chair: Leonard Johnson*, U. Idaho
Processing Committee Chair: Jim Wilson* (acting), OSU
Structures Committee Chair: Ken Fridley*, WSU
Use and Disposal Committee Chair: Paul Winistorfer*, U. Tenn.

Panel and Committee chairs have identified candidates for each committee as listed below. When the final work plan for each research module is being developed the availability of the candidates to support the research effort will be determined. The asterisk indicates those that contributed directly to the preparation or review of the research plan.

Resource Committee Members and Candidates: (* identifies active reviewers)

J. Sullivan, VPI
Charles Blinn, U. Minn.
Niels de Hoop, LSU
John Perez-Garcia*, UW
Chad Oliver*, UW
Bruce Lippke*, UW
Richard Pierson, Weyerhaeuser
Fred Cubbage, NCSU
Rex McCullough, Weyerhaeuser
Jay O'Laughlin, U. Idaho
Mike Vasevich, NCFES
Scott Wallenger, WVACO
Brian Greber, Weyerhaeuser
Dick Porterfield, Champion
Scott Berg, AF&PA
Mitch Dubensky, AF&PA
Blairr Orr, MTU

Processing Committee Members and Candidates: (* identifies active reviewers)

Processes (primary), Nonstructural Substitution, Nonstructural. Biomass, Treated:

Fran Wagner, U. Idaho
Fred Kamke, VPI
New Guy, LSU
Ali Moslemi, U. Idaho
John Erickson*, MTU. Consultant
Rod DeGroot, USFS-FPL
Charles Brunner*, OSU
Jim Funck*, OSU
Mike Milota, OSU
Phil Steele, MSU
Terry Sellers, MSU
Darrel Nicholas, MSU
Phil Mitchell, NCSU
Craig Forbes, NCSU
Mike Wolcott*, WSU
Hank Montrey, Weyerhaeuser
Del Raymond*, Weyerhaeuser
Bill Nicholson*, Potlatch
Russ Moody*, USFS

(* identifies active reviewers)

Biomass:

- J. Zerbe*, USFS-FPL, consultant
- W. Ramsay Smith*, LSU
- W. Glasser, VPI

Treated:

- J. Morrell*, OSU
- Peter Laks, MTU
- Maureen Puettman, U. Minn.

Operations Research:

- Rado Gazo*, Purdue
- David Briggs*, UW

Coatings and Finishing:

- Dan Cassens, Purdue

Substitution:

- Quinlin Wu, LSU
- Ivan Eastin*, UW
- Eric Hansen, OSU
- Bob Bush, VPI
- Richard Vlosky, LSU
- Bob Tichy, WSU
- Bob Falk, USFS-FPL
- Steve Shook, UW
- Doug Gardner, MTU

<u>Structures Committee Members and Candidates</u>:

Structures:

- David Grunsrud, U. Minn.
- Tim Larson, U. Minn.
- Dan Dolan, VPI
- Rakesh Gupta, OSU
- Bo Kasal*, NCSU
- Tom Gorman, U. Idaho
- David McKeever, USFS-FPL
- Hank Montrey, Weyerhaeuser

Bridges:

- Mike Ritter, USFS-FPL
- Bob Smith, VPI
- Dick Bennett, U. Tenn.

Structural Substitution:

- Ivan Eastin*, UW
- Eric Hansen, OSU
- Doug Gardner, MTU

Jamie Meil*, FORINTEK (* identifies active reviewers)
David Cohen, Univ. of British Columbia
Bob Tichy, WSU
Bob Falk, USFS-FPL
Steve Shook, UW
Bogue Sandburg, MTU
Bill Bullit, MTU
Rakesh Gupta, OSU
Duane Lyon, MSU
Bo Kasal*, NCSU

<u>Use (Occupancy) and Disposal Committee Members</u>:

Joe Loferski, VPI
Jim Bowyer*, U. Minn.
Peter Ince*, USFS-FPL
E. Chong, LSU
Tom Gorman, U. Idaho
Richard Buggain, U. Tenn.
Claire Montgomery, OSU
Clark Row, consultant in Baltimore
Said Abubakr, USFS-FPL
Gary McGinnis*, MTU
Mike Hunt, Purdue
Mike Barnes, MSU
Susan Diehl, MSU
Peter Laks, MTU — Life Expectancy
Jeff Morrell*, OSU — Treated disposal

<u>Strategy Assessment Panel Members and Candidates</u>: for Integration of Processing Research Modules, and Data Management

John Perez-Garcia*, UW
Bruce Lippke*, UW
David Briggs*, UW
Bob Abst, NCSU
Charles McKetta, U. Idaho
Joe Massey, U. Minn.
Jim Bowyer*, U. Minn.
Jay O'Laughlin, U. Idaho
Wayne Trusty*, FORINTEK
Susan Stafford, OSU
Al Goetzl, consultant
Peter Ince*, USFS-FPL

INDEPENDENT REVIEWERS: The Steering Committee identified additional outside reviewers who could provide a completely independent perspective on the objectivity and adequacy of the research. The candidate list of independent reviewers is:

Richard Denison, Environmental Defense Fund
Henry F. Taylor, Massachusetts Institute of Technology
Kevin Brady*, Demeter Group
Tom Osboda, Minnesota Office of Environmental Assistance
Edgar Miller, National Recycling Center
Sergio Galeano, Georgia-Pacific Corporation
Roger Sedjo*, Resources for the Future

Those who met the review timeline for the research plan are indicated by an asterisk.

APPENDIX D

OUTLINE OF FINAL REPORTS FROM THE COMPLETED RESEARCH PLAN:
Environmental Performance of Renewable Wood Materials in Construction Applications

SUMMARY VOLUME

Executive Summary
Introduction
Historical Perspective
Life-Cycle Analysis Across Stages of Processing, Use and Disposal
Progress in Energy Efficiency and Environmental Performance Since CORRIM I
Key Environmental-performance Issues and Promising Alternatives
- Forest Resource Management
- Primary Structural Products and Processing
- Nonstructural Products for Buildings
- Biomass Processing
- Infrastructure Uses
- Structures
- Use and Disposal

Critical System Tradeoffs in Environmental and Economic Performance
Regional Supply Substitution and Non-Wood Substitution in a Global Context
  International Substitution and Trade
  Non-wood Substitution
Key Environmental-performance Issues Across Stages of Processing, Use and Disposal
- Forest Ecosystems
- Wood Use Efficiency
- Energy Efficiency
- Carbon Sequestration
- Waste and Toxic Reduction

Incentives, Regulatory Systems, and Disincentive
Mixed Strategies Across Owner Groups and Processing Sectors
Serving Multiple Objectives: Sustaining Timber, Rural Economics, and Ecosystems While Serving Growing Product and Environmental Demands

VOLUME I - Environmental Performance: Forest Resources

Executive Summary
Inventory Measures
Consumption Trends
Timber Supply Trends
Non-market Use Trends
- Biodiversity

- Carbon
- Riparian protection
- Recreation

Timber Supply Models and Management Alternatives
- Biomass Production
- Intensive Commercial Management

Harvest Systems
Labor, Capital, and Energy Requirements
Environmental Measures
Regional Environmental Impact Models (by region)
- Riparian
- Uplands

Timber Production/Environmental/Economic Tradeoffs
Sustaining Timber, Rural Economics and Ecosystems
Alternative Wood Supplies and Substitution
Key Environmental-Performance Issues and Promising Alternatives - Case Studies
- Carbon Sequestration
- Biodiversity

Incentive Systems, Regulatory Systems and Disincentives
Resource Use Efficiency
Land Use Competition/Allocation
Mixed Management Strategies Across Owner Groups

VOLUME II - Environmental Performance: Forest Products and Processing

Executive Summary
Trends in Product Use and Development
Primary Structural Products for Light Construction Components
Material Properties and Component Standards
Machine Center Processing
Nonstructural products for Structures
Flow of Materials to Structures
Labor, Capital, and Energy Requirements
Wood Use Efficiency
Environmental-Performance Measures
Environmental-Performance Impact Models
Alternative Manufacturing Processes
Process Energy and Chemicals
Alternative Wood Products
Other Substitute Products
Key Environmental-Performance Issues and Promising Alternatives - Case Studies
Recycle, Energy Reclamation, and/or Disposal Impacts
Advanced Product and Process Technologies
Environmental/Economic Tradeoffs
Incentive Systems, Regulatory Systems, and Disincentives

VOLUME III - Environmental Performance: Structures

Executive Summary
Baseline Structural Wood Systems
Labor, Capital, and Energy Requirements
Structural Performance Standards
Environmental-Performance Measures
Environmental-Performance Impact Models
Alternative Wood, Non-Wood, and Hybrid Structures
Engineered Systems
Manufactured Housing and Light Construction
Recycle, Energy Reclamation, and/or Disposal Impacts
Key Environmental-Performance Issues and Promising Alternatives - Case Studies
Environmental/Economic Tradeoffs
Incentive Systems, Regulatory Standards, and Disincentives

VOLUME IV - Environmental Performance: Infrastructure Uses

Executive Summary
Baseline Bridge Systems
Baseline Dock Structures
Baseline Pallet Systems
Treated Components
Labor, Capital, and Energy Requirements
Environmental-Performance Measures
Environmental-Performance Impact Models
Alternative Wood, Non-Wood, and Hybrid Structures
Recycle, Energy Reclamation, and/or Disposal Impacts
Key Environmental-Performance Issues and Promising Alternatives - Case Studies
Environmental/Economic Tradeoffs
Incentive Systems, Regulatory Standards, and Disincentives

VOLUME V - Environmental Performance: Durability, Occupancy/Use, and Disposal

Executive Summary
Product Durability
Life Stages and Renovation
Alternative Wood, Non-Wood and Hybrid Structures
Environmental-Performance Measures
Environmental-Performance Impact Models - Use and Disposal
Durability, Renovation Flexibility, and Environmental Performance - Case Studies
Environmental/Economic Tradeoffs

VOLUME VI - Environmental Performance Across Stage of Processing Clusters: From Resources to Structures

Executive Summary
Life-Cycle Inventory and Analysis Across Stages of Processing

Management and Stage of Processing Alternatives and Environmental Tradeoffs
Progress in Energy Efficiency and Environmental Performance Since CORRIM I
Substitution Dynamics
Economic Dynamics
Key Environmental-Performance Issues and Promising Alternatives - Case Study Impacts
- Forest Ecosystems
- Wood Use Efficiency
- Energy Efficiency
- Carbon Sequestration
- Waste and Toxic Reduction

Environmental/Economic Tradeoffs

VOLUME VII - Environmental-performance Biomass Processing

Executive Summary
Biomass Residual Uses
Biomass Processing for Fuels and Feedstocks
Dedicated Forests for Biomass Fuels and Feedstocks
Non-Biomass Source Comparisons - Case Studies
Land Use Substitution
Environmental/Economic Tradeoffs

VOLUME VIII - Environmental Performance of Renewable Wood Buildings in a Regional, National, and Global Context

Executive Summary
Management and Stage of Processing Alternatives and Environmental Tradeoffs
Regional Supply Substitution and Non-Wood Substitution
Key Environmental-Performance Issues and Promising Alternatives - Case Study Impacts
- Forest Ecosystems
- Wood Use Efficiency
- Energy Efficiency
- Carbon Sequestration
- Waste and Toxic Reduction

Environmental/Economic Tradeoffs

VOLUME IX - Technology Transfer

Research
Education
Public Environmental-Performance Awareness
Industry Environmental-Performance Awareness
Certification User Environmental-Performance Awareness

APPENDIX E

COMMENTS OF INDEPENDENT REVIEWERS

PREFACE:

The research plan was subjected to review at several different levels. First, each Panel and its Technical Advisory Committee's reviewed their contributions. Second, the Steering Committee Reviewed the integrated report with both written comments and an open discussion at a Steering Committee meeting. Most of the comments received during this phase of the reviews were incorporated in the report. Third, the draft report was submitted to several outside reviewers. Where review comments include either different perspectives or a level of detail that will need consideration as the research plan is implemented, it seemed appropriate to list these comments as an attachment, hence this Appendix. The list of comments includes those issues raised by reviewers that have not been developed in the research plan. Since many review comments were incorporated in the document, reviews were not included in their entirety.

OVERVIEW COMMENTS FROM SPECIFIC REVIEWERS:

Roger Sedjo, Resources for the Future: My overall assessment of this project is very positive. The project, while very ambitious, appears doable. It offers a comprehensive method for assessing the full life-cycle environmental implications of using wood as a material. I know of no other available research that would allow such a comprehensive assessment of the environmental implications of wood as a material. Without the research outputs of this study, a comprehensive and complete assessment could not be done.

Cynthia Page for Kevin Brady, Demeter Group: Overall, the structure of the Research plan is fairly clear. The modular approach simplifies the very large research project into digestible portions. It is obvious that a great deal of attention has gone into the careful development of these modules. The ultimate success of the research will depend in part on successfully integrating these modules.

SPECIFIC COMMENTS AND RESPONSES:

Roger Sedjo, Resources for the Future

1. There is considerable discussion of "efficiency of material use." On one level, we could argue that the market probably is using the most efficient techniques, given the prices it faces. In this case, the argument for efficiency is one of environmental costs not being correctly priced. Although you may not want to articulate it using this economic jargon, some argument like this should probably be made.

Response: There is no conceptual disagreement and this will need further development in the research dealing with efficiency of use. The baseline for management and technology alternatives should reflect current market pricing. Alternatives will reflect different costs, environmental performance and materials use.

2. A role for revised standards, as stated in the proposal, seems to be appropriate. Regarding innovative manufacturing techniques and product innovations and technologies, aren't they somewhat beyond the realm of this type of proposal? How far will these activities go?

Response: No original research on innovation is contemplated. However, promising technologies exist that can be evaluated. Also, the increasing use of current best practices will have a significant impact on environmental performance and will be evaluated. Finally, the database will make it relatively easy for future research projects to consider the impact of new technologies in a consistent framework.

3. Some of the areas identified have been fairly well researched, e.g., above ground forests and carbon sequestration. Nevertheless, there is surely a role for the study to bring these considerations into a broad multi-dimensioned analysis of the environmental implications of using this material.

Response: The final integrated modeling providing the broadest range of product use and regional coverage is intended to provide a comprehensive evaluation of the role of wood on carbon sequestration and other environmental measures.

4. The question of the advantages of longer rotations has been fairly well researched. However, one remaining question is whether, with the absence of old-growth to fill the niche for quality wood, the prices of longer rotation wood might rise to financially justify the longer rotations. However, this appears unlikely given many years of Canadian old growth at our border.

Response: The research will reveal the cited advantages for given price assumptions. The projection of prices will not be a focus of the project and if the results are especially sensitive to price assumptions, the results will be characterized by a sensitivity analysis.

5. Impact-Analysis Tradeoff Matrix: This is a good idea and a useful table. However, why is the long rotation more energy efficient? Fewer harvests? This <u>might</u> <u>not</u> be true of smaller stems.

Response: The examples may be incorrect and must be validated by the research. Since long rotations produce substantially more wood per acre per year than short rotations albeit at an economic loss, the assumption used in the example based on other studies was that the system energy efficiency per unit of end use would be greater.

Cynthia Page for Kevin Brady, Demeter Group:

The comments focus on ensuring the Final Report's consistency with the ISO 14040 standard on LCA. This review covers the following areas: general methodology, goal and scope; data issues; and some general comments on assumptions, limitations and the overall report are given.

1. **General Methodology:** The general methodology, as described in Appendix A, appears to follow recognized LCA approaches. The Goal and scope definition stage, and the Inventory analysis stage (Appendix A) methodology seem to be comprehensive and detailed and will probably provide adequate guidance to the individual Module studies. It is acknowledged that the

Impact Assessment and Interpretation procedures have not been fully developed at this point. Overall, the methodology does not appear to be specifically tailored to the CORRIM study, and does not refer to specific issues that may arise during the study.

To maintain consistency with ISO 14040 terminology, it may be useful to use "Interpretation" instead of "Improvement Assessment" in future reports.

Response: The Appendix A protocol was developed as a guideline to existing LCA practices and literature and was not designed to anticipate every specific procedure that CORRIM may need in its research as they can be addressed and resolved when they occur. The protocol does develop methods to handle the long lifetimes of forests and buildings as essential to the CORRIM area of research and this approach is not generally available in the literature.

2. Goal: The goal of the overall research project, as described in the Final Report, appears to be to update and broaden the 1976 CORRIM study. More specifically, the goal appears to be to develop a scientific information research base to address environmental performance of key building products. The reasons for carrying out the research are clear, especially in terms of Agenda 2020.

To an external reviewer, the direct applications of this research project and its audience are ambiguous. The main audience of this research appears to be CORRIM; however, it is also suggested that life-cycle data will be used for comparisons between management strategies, materials, processes and overall building systems. If the results of these comparisons are to be used internally by CORRIM's member research organizations and member companies, then this should be clearly stated. If the data and results are to be conveyed to other audiences, e.g., other external research institutions or the public, then this intent should be clearly stated in the Final Report document. This statement of intent is especially important if comparisons are made, as it will guide the level of transparency and additional data requirements for each Research Module.

The task of managing life-cycle analyses for numerous alternatives has been conceptually simplified by adopting a modularized approach. The relationships between the Modules are clear, each Module is distinct, and the objectives and purpose or justification of each Module appear well developed.

Response: The audience of the research is intended to be CORRIM members, other researchers, and policy analysts.

3. Scope: The scope of the overall project and of the individual Research Modules are not explicit at this point. Within the final report, some overall assumptions, allocation issues, data requirements, geographic boundary considerations are presented. It is understood that these primary protocols and specific CORRIM II procedures will apply to each Research Module. Within each Research Module, however, the scope is currently not well defined.

Response: The protocols developed for the research plan will be applied specifically to each research module as a proposal is developed for each module, and the boundaries may depend upon the specific goals of the funding organization.

3.1. Functional Units: The use and importance of the functional unit has been well described in Appendix A. In the Final Report and in Appendix B, it appears that functional units have not been fully explored or at least explicitly stated for the specific research projects. Because of the modular structure of the research, where information gathered in one module feeds into another, developing appropriate functional units and system definitions (see below) will be important.

As an example, the output of the Module 1 (Forest Resource 1) serves as input to the processing modules. The report states that some of the output variables may be expressed: (i) on a per acre basis, (ii) as a regional impact, (iii) as stand alone measures, and/or (iv) will be inputted into processing modules. From the text, it appears that Module 1 focuses on timber production and the output variables link back to the amount of timber and logs produced. It also appears that the data will subsequently be "raw materials" data (i.e., types and amounts) in product manufacturing and construction. The compatibility between the outputs (units) of Module 1 and the inputs into another Module could be clarified. It should be noted that there often exist numerous possible functions for a given system. The selection of the system function must be related to the study goals and scope, and the functional unit must be defined and measurable.

Response: Since markets develop a very complex distribution from forests to final end uses, the outputs of the Forest Resource module are only partially consumed by each of several downstream processing modules. The compatibility of units could have been specified more precisely but was not judged to be a problem by the Technical Panels who will use the information. The more difficult boundary problem resides with the consistent flow of raw materials to ultimate use. The integrated modeling modules must characterize a consistent flow for materials hence this is a major task within the integrated modeling modules.

3.2. Product System and Boundaries: Within each Module's Research Statement and Procedures (Appendix B), general research descriptions are given. At this stage, neither the product system nor the boundaries have been explicitly stated. It appears that the product systems to be studied are currently being chosen or being defined. It is acknowledged that clearly defining the boundaries of the systems, at this point, is not feasible. It should be noted that system boundaries, defining the unit processes, must be included in the LCA according to ISO 14040. It is anticipated that these boundaries will be included in future reports for each Module and that the boundaries will be consistent with the goals.

To illustrate the importance of clear product system definitions and boundaries, consider the descriptions of the Reuse, Recycle and Disposal Module (12) and the Life Expectancy and Durability Module (11). These modules appear to overlap, where Module 12 includes the costs associated with repair of the structure during its life, while Module 11 gives maintenance costs as outputs. Clear boundaries and process definitions will alleviate confusion.

When defining product system to be studied, it may be advisable to keep a system's potential environmental performance separate from its definition. For example, an option under Module 1's Research Statement is a "high timber output at low cost, while maintaining low environmental impacts."

Some questions arise when considering the choice of scenarios to be studied. Using Module 1 again as an example, under the Objectives it is stated that general scenarios will be considered. However, under Procedures, the options chosen represent the most likely scenarios to meet environmental objectives. It appears that the overall study is not focusing on typical practices, but rather on practices perceived as more environmentally positive. It may be useful to clarify the rationale behind the choices in this section, especially in light of the potential application of this study (i.e., presented to the public) and the importance of Module 1 relative to the larger study.

Response: The Life Expectancy and Durability Module was designed as a submodule to the ultimate use and disposal module and hence must provide the output information on Life Expectancy and Durability needed for the analysis of use and disposal. The lack of definitive boundaries could become a serious problem if the two proposals are not developed together.

On the selection of scenarios, the focus of the study will be to compare a baseline study (i.e., typical practice) to a range of alternatives for each stage of processing. Those alternatives that produce more environmentally positive tradeoffs will be selected for analysis across all stages of processing. The rationale for that selection will be typical benefit cost analysis.

3.3. Temporal Boundaries: It appears that the importance of temporal boundaries has been considered. Important issues regarding time dimensions and forecasting data are clearly raised in the Final Report (Research Methods) and in Appendix A. It is expected that how the temporal boundaries will be handled will be clearly outlined in future reports, specifically with regard to data quality.

3.4. Data and Data Quality: The data categories, as presented in the Final Report, are an adequate starting point for considering inputs and outputs. Methodology concerning data issues is well described in Appendix A. The text makes clear that propriety information will be handled with appropriate confidentiality and security, however, further details regarding the effect on the study's transparency and related data issues have not been given.

Data quality is important for any LCA study. At this point, temporal and geographic data considerations have clearly been initiated. It is acknowledged that much of CORRIM's data may come from original research, and the analysis of machine centers within a process will be used. It is understood that primary data will be used for wood products processing, however, secondary data will be used for the analysis of alternative materials. The consideration of data quality issues such as representativeness of the data, and additional aggregation issues will be of primary importance to this study. Thus far, the representativeness of data has not been specifically addressed, especially in light of the comparison of systems that will occur (i.e., original research data derived for this project, versus secondary data). Finally, a strategy to deal with compilation issues (i.e., one module feeding into others) and the accompanying data quality issues should be explicit.

Response: The importance of characterizing the relative quality of various data sources will be developed in greater detail in the data and modeling module specifications. CORRIM intends to capture the statistical distribution of each data item (mean, mode, range, standard deviation etc.) as critical measures of data quality. Many LCA studies rely on point estimates (weighted averages) and therefore fail to provide any information on confidence intervals on final results; and as a result, in many cases the purported differences may not be significant.

In particular, issues raised where primary and secondary data sources are integrated or compared, an assessment of the degree to which differences may be related to data quality may be needed. The selection of secondary data sources will largely depend upon knowledge of the quality of the data. Sources of secondary data, like the ATHENA™ Institute, are developing data to the same international standard which should minimize data quality problems.

3.5. Comparisons Between Systems: From the Final Report, it appears clear that a comparative analysis will be conducted. It will be essential to ensure that the systems being compared are equivalent in light of: the functional unit, methodology, performance, system boundaries, and allocation procedures. In addition, the data quality between systems must be compared, as discussed above.

3.6. Economic Considerations: The intent of developing Economic Performance Measures appears compatible with the overall structure of the study. It is not clear, however, whether or how dollar values will be attributed to environmental benefits/impacts that may in turn be used in a cost/benefit analysis. Also, it is not clear how net present value will be calculated, for example what discount rate will be used, how will the cash flows be timed, how will the benefit stream be measured?

Response: The research plan does not call for developing a common utility value or weighting system for environmental benefits but rather to develop the benefit to cost trade-offs for each environmental amenity. For each environmental area there may even be more than one measure that will be considered. The measurement of costs and amenities is a relatively more hard science than estimating public preferences. The results will serve as a sound data base for future work on such utility values. The typical long term discount rate used for cost analysis of timber values has been 5% (real) as consistent with the relative risk of timber management, but the sensitivity of cost benefit analysis to a discount rate assumption may also be important.

4. Other Comments: In a LCA study, it is necessary to clearly describe assumptions and limitations of the study. As discussed above, the methods for choosing some of the study scenarios are not clear (see Product Systems and Boundaries). Similar clarifications may be required when describing the case study combinations of structures. These considerations tie in with the requirements for comparisons between systems described above.

It is understood that the environmental and economic performance tradeoffs will be examined in a matrix. It is not clear how the relative importance of economic indicators will be handled (i.e., all of equal importance, etc.) and if any weighting of attributes of environmental performance or and economic performance will be undertaken.

The terminology used to refer to impacts could be clarified to reflect the limitations of LCA studied. For example, it has been stated in the Report and Appendices that "all" impacts will be considered. Perhaps impacts could be referred to as "potential" impacts or "anticipated impacts", to reflect the actual capabilities of the LCA Impact Assessment.

Response: These are all important points that need consideration in the development of proposals for each module.

ADDITIONAL COMMENTS OF OTHER REVIEWERS AND RESPONSES:

(since these comments were excerpts from lengthier comments and may have been taken out of context, they are listed without attribution)

1. The study should include paper products.

Response: The research plan is a response to a request for proposal that focuses on solid wood products, and in particular those that are used as building materials. The study area is vast even within this boundary. Limiting the study focus to wood products does not ignore all environmental performance impacts relating to paper, as the boundary conditions require a consistent allocation of impacts to all uses of the volume flow. What the study will not provide are any comparisons among alternative paper technologies or paper products. CORRIM Inc. is interested in a comparable study covering paper products and would expand the science teams to include the necessary expertise if and when the opportunity exists.

2. The study does not focus directly enough on a comparison of wood vs. non-wood materials since all of the effort, data and analysis is designed around wood products. Is there comparable data available elsewhere for these materials?

Response: The primary goal of the research is to understand the environmental performance of wood resources hence the focus on wood. Emphasizing comparative studies could create the false impression that CORRIM's purpose is to advocate wood or that it has developed equally accurate non-wood databases. Other industries are providing comparable research for non-wood materials and should be considered the source for their data. Some hybrid products will be a part of the wood analysis. The ATHENA™ Institute is cooperating with other material sectors and it is anticipated that the CORRIM data can be directly compared to other building systems using ATHENA's data for other materials in a building system. The CORRIM objective is to provide the best possible data and most objective information on the environmental performance of wood products which can be compared to non-wood data when they are developed under similar protocols.

3. A much more plausible general methodology, one which could adequately address the stated objectives, would be the approach of regional market modeling and technology forecasting, such as employed in the Forest Service Timber Assessment modeling framework. LCA could then be used to identify appropriate coefficients for energy and environmental attributes of production processes. Then those coefficients could be added to economic models to analyze all of the stated objectives.

Response: Since most of the analysis involves measuring environmental performance for a specific end use (consistent use across alternative management and technologies), market models were not considered appropriate, as the level of use is constant. While there may be a change in cost or other environmental performance tradeoffs that contribute to some substitution, the market model would then have to characterize all substitutes, which none do. Where changes in use level are evaluated, such as substitution, best estimates of market substitution will be used for allocation of products and this will include using outputs from market models. The methodology in the research plan was overwhelmingly supported by the CORRIM panels as it includes benefit/cost analysis for Life Cycle Inventories, addressing both economic criteria and environmental performance tracking. Hence results can be compared to other studies being developed under consistent international standards.

4. It would seem more appropriate to focus on methods to evaluate how "policy, product, technology, or process changes" could really contribute to improved human welfare(e.g. the welfare of the producers and consumers). This is the approach used in economic modeling for example, but not in LCA (which does not in fact focus on analysis of human welfare from an economic perspective or market-based perspective).

Response: While the ultimate perspective may be human welfare, the research plan develops a hard science approach to developing measures of environmental amenities and the costs to produce them. The weighting of relative welfare values that might be applied to these amenities is a soft science at best and more appropriately considered a part of the political perspective. Translating amenity measures to welfare values will largely disguise the environmental performance impacts with soft data. The basic data on environmental performance needs to be developed first in any case.