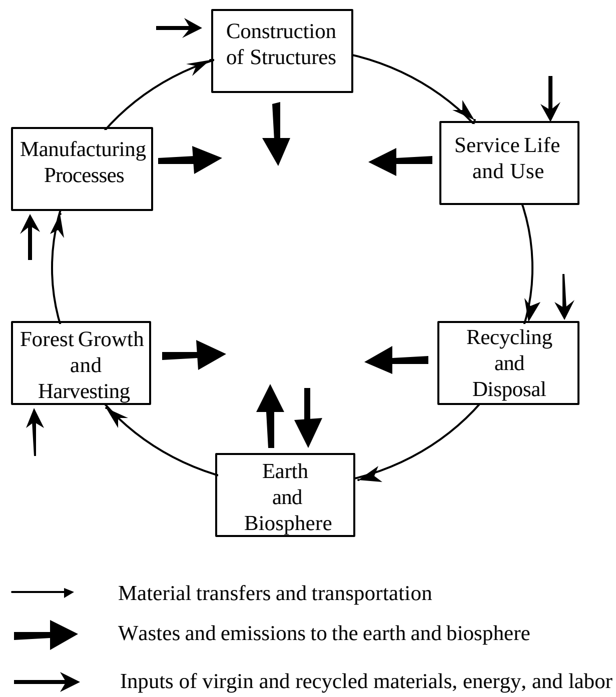
Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction



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

MAY 2, 2002

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

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PHASE I INTERIM RESEARCH REPORT

EXECUTIVE SUMMARY

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Prepared with financial support from the USFS (JV11111169-156) and contributions from a number of private companies based on a research plan developed for the Department of Energy (DOE Agreement No. DE-FC07-96ID13437) as a part of the American Forest and Paper Association's Agenda 2020 priorities. Any opinions, findings, conclusions, or recommendation expressed in this publication are those of the authors and do not necessarily reflect the view of the financially contributing entities

May 2, 2002

LIFE CYCLE ENVIRONMENTAL PERFORMANCE OF RENEWABLE BUILDING MATERIALS IN THE CONTEXT OF RESIDENTIAL CONSTRUCTION

PREFACE

This report provides interim research results from a study to develop a database and modeling capability to adequately describe the environmental performance of building materials and their uses, addressing key wood materials such as lumber, plywood, composite panels and other wood derived products. The report documents progress on the original research plan developed for the Department of Energy and the American Forest and Paper Association under Agenda 2020 priorities for pre-competitive research needs. The Consortium for Research on Renewable Industrial Materials (CORRIM) with the financial support of its 21 institutional and company members and the Department of Energy developed (1) a research plan, (2) a *Data, Standards and Procedures: Guideline for LCI and Economic Analysis*, and (3) an organizational approach to conducting the research plan in 1998. A Phase I research plan was designed to pilot-test the development of data and analysis procedures for each stage of processing, while providing data for the primary wood producing regions of the US. This Phase I report covers the first 5 modules of the 22 module research plan focusing on forest resources from the US Southeast and Pacific Northwest and residential construction in a warm climate (Atlanta) and a cold climate (Minneapolis). The USFS Forest Products Laboratory, 14 research institutions and 10 companies are providing financial support.

This report provides 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. The collected data and subsequent analysis follows consistent definitions and collection procedures that facilitate integration of results across the full life cycle for all stages of processing in order to address environmental performance questions. The findings are interim, reflecting a mid-point progress report that intentionally identifies data and procedural inadequacies that need to be corrected before completion of the final report. One of the more substantive impacts of this research effort has been the enhancement of institutional capabilities to support the development of environmental performance data and analysis.

The report is organized as follows: Major points are very briefly summarized in an executive summary preceding the table of contents. Section 1 provides the background, mission, organization of effort, and objectives. Section 2 provides the Life Cycle Inventory and Analysis (LCI/LCA) framework. The findings for each stage of processing are reported on in 7 modules (Appendices A-G). The appendices are essentially stand alone LCI reports for intermediate and final products. The last module, Appendix G, covers the construction aspects, integrating the information from the other modules for a residential structural building shell. Information on final building use, maintenance and ultimate disposal will be completed for the final report. The forest resource module demonstrates the impact of management alternatives on environmental performance. Additional scenarios and sensitivity analysis examining the impacts of changes in management and processing technologies will be included in the final report.

EXECUTIVE SUMMARY

The Consortium for Research on Renewable Industrial Materials (CORRIM) was organized as a non-profit company supported by 15 research institutions 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. We use the same CORRIM acronym as the 1976 study, which was managed by a committee of scientists.

An expanding list of environmental-performance issues has gained considerable attention over the last two decades, yet there had been no update of the 1976 CORRIM study, or extensions to include environmental issues not addressed in the original study until this effort was undertaken. 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, or for companies to develop strategic investment plans that could improve environmental performance.

This study's objectives 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.

Data was collected through surveys of a range of mill types within processing regions characterizing all inputs and outputs associated with the production of lumber, plywood, and oriented strandboard. For forest regeneration, growth and log production, growth and yield models representative of conditions in the Pacific Northwest and Southeast growing regions and recent studies of harvesting activities reported in the literature were found to satisfy most data requirements with minimal new data collection. The most difficult aspect of data collection has been to maintain consistency across many products made from different processes, and wood species. Product characteristics vary substantially, as do the measurement practices used by different producers. Analysis of the mass balance in and out of a processing stage provided a validity check on the data quality. Different measurement conventions and imprecise measurement of characteristics such as moisture content sometimes corrupted data collection. In selected cases, as that for softwood green lumber, additional data will be collected prior to the final report to improve the sample size and resolve mass balance discrepancies.

Based on analysis of the designs of the representative residential structures for a cold climate (Minneapolis) and a warm climate (Atlanta), fifteen different wood and non-wood materials were found to be used. Additional materials were used in the generation of energy used in production processes.

In the United States, a little over half of the wood produced in the forest is used directly in construction. The environmental burdens from the production processes used to produce building materials were allocated according to the mass of materials used in building construction. Other burdens were allocated to co-products such as paper. Similarly, the burdens accumulated from transportation, processing energy, and construction energy were allocated to the building according to the mass of materials used in building construction. The environmental impacts from energy uses are derived from national/regional grids of_purchased electrical energy and fossil fuels. Thus the environmental burdens derived from energy consumption are allocated according to the specific type of energy consumed (7 types) and its place of origin (raw material and manufacturing producing regions and construction regions).

In this study, sixteen different kinds of air emissions are reported for each stage of production (extraction, manufacturing, transportation, and construction). Twenty-five different sources of water emissions are identified with manufacturing. Six categories of solid waste are tracked. Vital measures of the forestland environment are also tracked to characterize impacts on water, habitat, carbon and biodiversity, several of which require landscape-wide measures to be useful. This complex array of environmental outputs for the construction of a residential building are reduced to environmental performance indices to simplify the analysis and communication of findings. However, the science behind best weighting schemes to represent aggregate environmental risk indices for water, air, solid waste, global warming potential, and forest health are still evolving, and for the most part beyond the analysis provided by CORRIM. The environmental impacts of forest management are being analyzed at the landscape level and will be available for the final report.

Indices for water and air emissions, solid waste, and global warming potential were derived by the ATHENA™ Institute, a Canadian research institute and cooperator on the project. The ATHENA™ model provides Life Cycle Inventory (LCI) measures based on the bill of materials developed for the US house designs and the LCI data that was developed for each US product, thereby extending the ATHENA™ database to cover US producing regions. These index measures currently do not account for the impacts from use, maintenance and disposal of a building, nor do they integrate the carbon stored in the forest as developed in the Forest Resource module; these are impacts that develop over a long period of time in contrast to the narrow time frame associated with impacts from extraction to construction.

With one exception, all of these index measures indicate significantly lower environmental risk for the wood design in Atlanta and Minneapolis compared to non-wood construction (see table below). The one exception is in Minneapolis where the steel design produces 9 % less solid waste than the wood design. From experience with sensitivity analysis ATHENA considers relative differences of less than 15% as not significantly different.

Environmental Performance Indices for Residential Construction

Minneapolis design	Wood	Steel	Difference	Other Design vs. Wood (% Change)
Embodied Energy (G_j)	186	308	122	66%
Global Warming Potential (CO_2 kg)	39810	59290	19480	49%
Air Emission Index (index scale)	2778	4711	1933	70%
Water Emission Index (index scale)	185	1179	994	537%
Solid Waste (total kg)	12110	11020	-1090	-9%

Atlanta design	Wood	Concrete	Difference	Other design vs. wood (% change)
Embodied Energy (Gj)	115	162	47	41%
Global Warming Potential (CO_2 kg)	20020	33130	13110	65%
Air Emission Index (index scale)	1035	1862	827	80%
Water Emission Index (index scale)	86	99	13	15%
Solid Waste (total kg)	4270	7970	3700	87%

The primary difference between the Minneapolis wood and steel house is the use of materials for floors and walls. Both designs share the same basement and roof elements. For the Atlanta structure, the only major difference between the wood and concrete design is in the exterior wall structure as both designs use concrete floors and wood roofs. Making cross design comparisons at the wall and floor section shows much more dramatic percentage differences than for the buildings as a whole (last two columns of the table below) since some parts of the structure share common materials, and the construction process itself is energy intensive and not that much different across the designs. In effect a substantial environmental performance difference for nearly substitutable products may not seem so great for a completed structure with many common components.

An examination of a change in forest management suggests small but significant changes in index measures. A small increase in PNW management intensity resulting in an estimated 5% increase in forest productivity increases the availability of wood such that the number of wood homes built in Minneapolis increases and the number of those built of steel decreases. It is assumed, for simplicity, that the increased forest productivity forces product substitution within the region rather than imports and exports from other regions or international sources. Consequently there is a 6% reduction in embodied energy and air emissions, a 25% reduction in water emissions and a 1% increase in solid waste. The same forest productivity increase in the Southeast results in a 17.5% increase in the construction of wood homes vs. concrete in Atlanta and a reduction in all output measures ranging from 3% for water emissions to 13% for solid wastes.

To support this environmental assessment for a residential structure and be able to analyze the impact for each process, LCIs, were developed for each wood product (logs, lumber, plywood, and oriented strandboard) used in home construction.

The Forest Resource module (Appendix A) provides the environmental, energy and resource impact data on the growth, management, and harvesting of logs and reforestation of harvested timber for the Pacific Northwest (PNW) and Southeast regions of the US for a representative acreage within each region. The study calculates volume harvested for three general combinations of management intensity and site productivity for each region. The combinations were reduced to a single estimate of yield using weighting factors for the acreage under each management regime. The weighting scheme creates a base case for each region. Alternative weights resulting from increasing the acres under a different level of management intensity are used to produce alternative cases, with a different calculated volume. For example, the increase in merchantable volume under a prescribed alternative case was 21% in the Southeast (including the volume from a partial second rotation when rotation ages were reduced) and a nearly 16% increase in volume in the PNW.

The portion of lumber and pulpwood produced in the Southeast changed slightly under the alternative scenario; lumber share declined 2.1 percentage points as pulpwood share increased 2.1 percentage points. The alternative scenario also leads to a 3.2 year reduction in the average rotation age in the Southeast, which is responsible for the percentage shifts in lumber and pulpwood produced. Lumber output increased 15%, 0nly 68% of the merchantable volume increase. Lumber share remained at 100% in the base and alternative PNW scenarios.

System costs increased by around one percentage point above the percent change in the amount of merchantable volume removed in the Southeast, while increasing about the same percent as merchantable volume removed in the PNW. A similar result is observed for fuel and lubricant consumption during harvesting operations: an 11% increase in the Southeast and 16% increase in the PNW roughly corresponding to the changes in merchantable volumes harvested, although there appears to be a slight increase in the consumption factors in the Southeast due to the change in rotation age and products harvested. The increase in harvested volume resulted from using 4 times more nitrogen and phosphate in the Southeast and 2 times mores nitrogen and phosphate in the PNW as fertilizer inputs in conjunction with the other management changes.

Along with harvested volumes, the Forest Resource module also produces harvesting cost data and air emission estimates related to stand growth and harvesting, and regeneration. Resources used to produce the harvested volume, such as fuel, fertilizer and herbicides, are quantified and their impacts reported in the Environmental Impact Report (Appendix G) during the extraction phase of the single family shell construction.

The Forest Resource Module also produces estimates of tree biomass by component. These estimates are used to approximate the standing and removed carbon pool over time. Other environmental performance measures including indices of stand structure, diversity, and habitat and fragmentation will be developed in subsequent phases of the project using a landscape approach to forest management will be developed in subsequent phases of the project.

Harvested volumes from the two forest resource regions are considered in the context of lumber manufacturing in the Pacific Northwest and Southeast regions. Here the research developed independent LCIs for the two regions. The two regional lumber manufacturing modules were developed to provide the environmental, energy and resource impact data associated with the manufacturing of softwood lumber. In the Northwest (Appendix B) a survey produced the data for sawing, drying and planing processes. A unit process approach produced detailed descriptions of activities and the resources used to produce specific outputs. For example, the sawing process involves log movement within the mill, sorting and storage, delivery to debarkers, and bucking to length. The logs are then debarked and sawn into rough lumber producing rough lumber, resulting in the co-products pulp chips, bark and sawdust. The rough lumber is transported within the mill to stacks for kiln dryers or planer facilities. Maintenance work on equipment and vehicles are also recorded, as were emissions to air, water and land. The results of the survey work produced detailed information that was then analyzed with the SimaPro life cycle program. The SimaPro analysis considered four processes, including energy generation in addition to the three processes mentioned above. The result of the analysis produces unit factor estimates for one Mbf of planed dry lumber. These unit factor estimates include raw material use, airborne, waterborne, and solid emissions, and energy use. A similar module was used for Southeastern lumber production (Appendix C).

Harvested volumes from the two forest resource regions were also considered in the context of softwood plywood manufacturing in the Pacific Northwest and Southeast regions (Appendix D). Surveys were implemented in a manner similar to those used in conjunction with the the lumber manufacturing modules. The plywood process was defined in terms of six processes: bucking and debarking, block conditioning, peeling and clipping, drying, lay-up and pressing, and trimming and sawing. The results of the survey work produced detailed information that was then analyzed with the SimaPro life cycle program to produce unit factor estimates for one Msf of 3/8-in basis of plywood.

An LCI for Oriented Strand Board (OSB) production was produced in a similar manner (Appendix E); however for this interim report, the integrated residential construction analysis used plywood as the default for all panels because the material balances were not completed at the time that the integration analysis was performed. The survey also collected information on log transport, production of phenol-formaldehyde and MDI resins and wax.

Data is now available to provide a comparison of energy and resource impacts relative to the 1976 CORRIM study. Data is also available to provide a measure of resource use efficiency. With the LCI data produced by the lumber, plywood and OSB modules, LCIs can be produced for derived products such as glulams, trusses, and laminated veneer lumber, all of which will be incorporated into the final report. Management and process improvements can also be identified and analyzed with key scenarios planned for the final report. An analysis of costs and carbon accounting have been initiated in Phase I and can now be completed in conjunction with a more thorough integration with resource harvesting, production, and the ultimate use, maintenance, and disposal phases of each product.

With these additions and corrections, the final report will provide:

- Measures of carbon emissions, and carbon storage on the forest floor and in wood products for each stage of processing and region, 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.

- 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 as well as other measures of the health and sustainability of forest ecosystems, (3) solid waste reduction, and (4) reduction in the production and emission 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.

- Cost effective approaches to meet changing environmental goals, and develop investment strategies that are more responsive to those needs.

- Opportunities to adopt strategies that improve environmental performance where costs are not a limiting factor and support for the development of policy alternatives that could offset cost impacts when necessary.