CORRIM: Life-Cycle Environmental Performance of Renewable Building Materials

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Assessments of material flows and their environmental consequences are increasingly needed to address an expanding list of environmental performance issues. An analysis of the flow of mass, energy, and carbon from resources (such as a forest or mine pit) to products, and ultimately to disposal in a landfill or by recycling, is a complex undertaking. Any attempt to identify the environmental consequences of the life-cycle of houses constructed from alternative materials is burdened by enormous data requirements in order to characterize each stage of a product's life-cycle. The complexity of modern house construction exacerbates the analysis, because many products made from different materials are used. In addition, the time element associated with the growth of forests, the manufacturing of the wood products, and the duration of the useful life of a house and its many components adds another layer of complexity.

In 1996, the Consortium for Research on Renewable Industrial Materials (CORRIM) was formed by 15 research institutions as a nonprofit entity that would undertake research on the use of wood as a renewable material. In 1998, CORRIM published a 22-module research plan and protocol (CORRIM 1998) to develop a life-cycle assessment (LCA) for residential structures and other wood uses. The research plan required development of a complete life-cycle inventory (LCI) of all environmental inputs and outputs from forest regeneration through product manufacturing, building construction, use, maintenance, and disposal. Later, CORRIM published a summary and a Phase I Interim Report on the progress with a provisional LCI database to evaluate the environmental performance of building materials (Bowyer et. al 2001, 2002). The report also contained an LCA for residential structures focusing on energy use, air and water emissions, global warming potential (GWP), and solid waste production from resource extraction through construction. These five key performance indices were chosen to simplify the analysis. The process of developing an interim report allowed the research team to evaluate the LCI databases for use in each stage of processing "from cradle to grave" before finalizing them.

This article will summarize the findings of CORRIM's Phase I research, which covers wood resources and products from the Pacific Northwest supply region for a typical house in a cold climate (Minneapolis, Minnesota) and from the Southeast supply region for a typical house in a warm climate (Atlanta, Georgia). Since the 2002 interim report, the research effort has addressed many questions that arose during its review. This article includes more complete product coverage, and provides a summary of the most recent LCA results for residential construction, building use, maintenance, and disposal. There have been modifications to the house's bill of construction materials, improvements in both primary and secondary databases and models, and implementation of additional sensitivity analyses.

Since the 2002 interim report, we have analyzed in more detail the environmental and energy burdens associated with products and co-products and their dependency on forest and bioenergy management. We have isolated the energy use from various products, and analyzed their implications for purchased energy requirements. We have also summarized the cumulative environmental effects from resource extraction through to the completion of the shell onsite, its use, maintenance, and disposal. Also, subassemblies for the above-grade walls as well as floors and roofs were compared directly with alternative framing materials under similar structural capability and code R-values. Building components in floors, roofs, and walls were also changed to better reflect current construction practices; for example, the impacts associated with substituting I-joists in place of dimension lumber and oriented strandboard (OSB) instead of plywood were analyzed.

In this article, we summarize the most salient results of the CORRIM work. More details of the research results can be found in CORRIM's final report for the Phase I effort (Bowyer et. al 2004).

CORRIM Objectives

The following statements outline the objectives of this CORRIM project.

- 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 construction of residential housing, 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."
- 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.
- 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.
- Manage an organizational framework to obtain the best scientific information available as well as provide for effective and constructive peer review.

CORRIM Protocol

In all its research, CORRIM follows the 14000 series of standards of the International Organization for Standardization (ISO 1997, 1998, 2000a, 2000b), plus American Forest & Paper Association (AF&PA) guidelines for the forest industry (AF&PA 1996). The protocol includes an initiation phase that set project boundaries, followed by 1) an LCI phase that identifies and quantifies the energy, resource use, and environmental effects of a particular product, service, or activity; 2) an impact assessment phase that investigates the potential environmental consequences of energy and natural resource consumption and waste production; and 3) an improvement assessment phase where opportunities to reduce the environmental impacts and resource use are investigated.

Figure 1. — Minneapolis house.

Primary and secondary data sources were used by CORRIM. Primary data on all inputs and outputs associated with the production of lumber, plywood, OSB, glulam, laminated veneer lumber (LVL), and I-joists were collected using surveys of a range of mill types within the processing regions. The two primary U.S. wood-processing regions studied were the Pacific Northwest and Southeast. Recent studies of harvesting activities (secondary data) were used to gather forest regeneration, growth, and log production data. The most challenging aspect of our data collection was to maintain consistency across many products made from different processes and wood species. Product characteristics vary, as do the measurement practices used by different producers. In order to provide a validity check on the data quality, we conducted analyses of mass balance and energy use for each processing stage, and also compared data between mills and production regions. In selected cases, additional data were collected for the final report to improve the sample size and resolve mass balance discrepancies, such as the unit process for boilers that converts biomass to energy.

The data collected were used to construct LCIs using the SimaPro software[1] for each wood product. These U.S. wood product LCIs were incorporated into the ATHENA™ Environmental Impact Estimator model (EIE).[2] The EIE also contains more than 50 different assemblies that incorporate combinations of concrete, steel, and wood products LCIs for materials used in construction. We then proceeded to analyze the architectural designs for the representative residential structures and corresponding bills of construction materials. The EIE model provides LCI measures associated with the house construction, which are based on the bill of materials developed for each structure. One point to note is that many similar materials are used in the construction of each house design. In other words, a wood-framed house has many non-wood materials used in its construction that are impacting the environmental profile.

To study the use of alternative building materials, typical residential designs were used for each climate type: 1) a wood-frame design and a steel-frame design for the cold Minneapolis climate (Fig.1); and 2) a wood-frame design and a concrete design for the hot and humid Atlanta climate (Fig. 2).

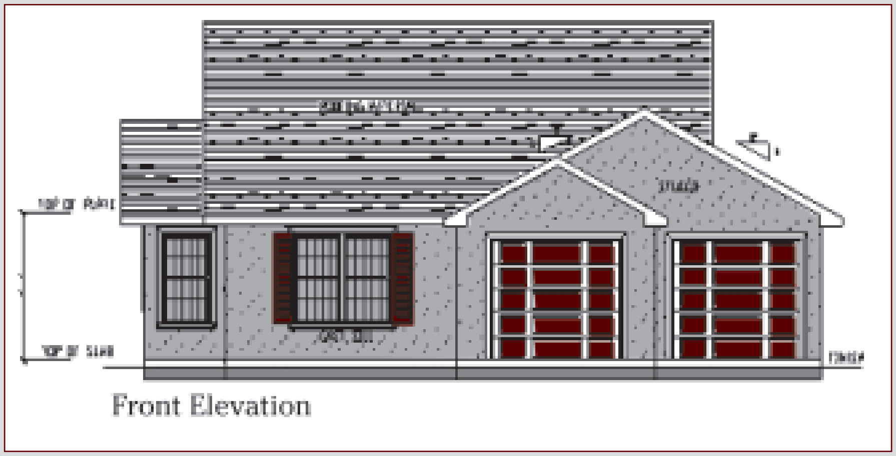

Figure 2. — Atlanta house.

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[1] SimaPro is a professional software data analysis package designed for life cycle analysis, licensed from Pre' Consultants, Amersfoort, Netherlands.

[2] The ATHENA Sustainable Materials Institute, Ottawa, Canada, is a cooperator with CORRIM on this research and provided its commercially available software for simulating building construction to generate LCI and environmental impact measures.

The configuration of the structures was based on the most recent surveys conducted by the U.S. Census Bureau and the National Association of Home Builders.

The average size of a new house in the United States is about 2,225 ft.^{2} The designs reflected the local building codes with matched thermal properties, including building envelope designs. The Minneapolis structure was designed as a two-story building with a basement, representing typical construction in the area. The total floor area of the structure was 2,062 ft.^{2} The base case design consisted of solid wood framing members except for the floor joists, which were composite I-joists. Other wood structural components consisted of OSB sheathing for roof, walls, and floor, and pre-engineered roof trusses for the roof system. Alternative wood materials studied were: 1) solid wood joists in place of I-joists; and 2) plywood in place of OSB. As a non-wood alternative, steel floor joists and wall studs were substituted for wood I-joists and 2 by 6 wall studs, with an extra layer of exterior insulation to meet code requirements.

The wood and concrete Atlanta structures were a grade-on-slab single-story design with an area of 2,153 ft.^{2} The concrete design consisted of a concrete slab floor, a concrete block wall system with furred out wood stud walls, and a wood truss roof with OSB sheathing.

Mass, Energy, and Primary Emissions

Flows of materials used in residential houses and associated environmental burdens were tracked using the completed LCIs for forest resources, wood products, and associated transportation data. These data were introduced into the ATHENA™ EIE model, which integrates the various combinations of products into functionally equivalent assemblies and completed structures, and reports five environmental performance indices to summarize the many output measures for the LCI on the building shell.

Flows of mass, energy, and emissions are reported for extraction and manufacture activities, transport to site, and construction activities. So, for example, the activities associated with construction (i.e., activities in which building materials and energy are consumed and solid wastes and emissions are produced) include those activities involved in producing building materials as well as those associated with the construction activities themselves. Energy for heating and cooling, maintenance, and disposal are tracked separately and are assessed after the analysis for the building shell. In the following paragraphs, we first consider the flow of materials through construction, and then present how much energy is consumed, the amount of emissions produced including the GWP, and the quantity of waste generated associated with the LCI of the constructed house.

Mass Flow

Quantities of basic resources required to produce the materials used in each building design are presented in Table 1. The Minneapolis designs contained about the same total mass of all materials: 88.6 metric tons for the steel-frame design and 86.1 metric tons for the wood-frame design. Both houses had slightly less than three quarters of the total mass in concrete materials, with an additional 11 percent in concrete materials when limestone was included. Wood fiber and steel made up 20.5 percent in the steel-frame house and 18.6 percent in the wood-frame house with more wood being used in the wood house than steel in the steel house.

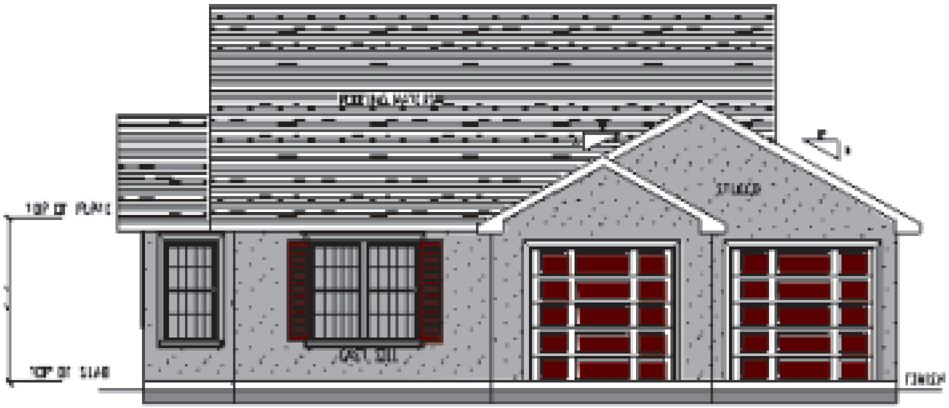
In Atlanta, concrete materials including limestone accounted for 91.7 and 87.9 percent for the concrete and wood house, respectively. The total mass was higher than the Minneapolis houses, reaching 105.5 metric tons and 97.1 metric tons for the concrete and wood designs, respectively. The wood-frame house in Atlanta used only 2.3 percent more wood than the concrete house, accounting for only 10 percent of the total mass of materials.

Energy Used From Extraction Through Construction

Energy use through completed construction is shown in Table 2. The table includes the purchased electrical energy and the primary fuels needed to produce the reported electricity use, as well as all other uses such as manufacturing process heat and transportation. Since hydro energy is not considered a primary fuel, i.e., it does not lead to any depletion of resources, it was excluded from the summation of total primary fuels.

Table 1. — Quantities of raw materials required to manufacture the materials used in structures (excluding water, natural gas, oil, coal, but not metallurgical coal).

	Minneapolis house		Atlanta house	
Raw material	Steel frame	Wood frame	Concrete frame	Wood frame
Limestone (kg)	10,333	9,775	11,590	9,518
Clay and shale (kg)	2,496	2,496	2,916	2,269
Iron ore (kg)	6,614	1,019	667	507
Sand (kg)	1,256	1,403	776	748
Ash (kg)	48	48	59	45
Other (kg)	4,571	4,666	3,956	4,505
Gypsum (kg)	1,712	1,712	5,721	5,621
Semi-cementitious material (kg)	728	728	1,057	1,057
Coarse aggregate (kg)	24,687	24,687	35,997	35,871
Fine aggregate (kg)	24,437	24,437	32,848	26,427
Obsolete scrap steel (kg)	1,361	971	874	291
Wood fiber (kg)	6,595	12,993	8,191	9,811
Phenol-form. resins (kg)	126	144	65	103
Metallurgical coal (kg)	2,864	407	254	189
Prompt scrap steel (kg)	764	602	545	178
Total material (kg)	**88,592**	**86,088**	**105,516**	**97,140**
Wood fiber (%)	7.4	15.1	7.8	10.1
Steel (%)	13.1	3.5	2.2	1.2
Concrete materials (%)	72.2	73.8	80.7	78.1
Subtotal (%)	92.7	92.4	90.7	89.4
Limestone (%)	11.7	11.4	11.0	9.8



Front Elevation

Table 3. — Environmental performance indices for residential construction.

Minneapolis house	Wood frame	Steel frame	Difference	Steel vs. wood (% change)
Embodied energy (GJ)	651	764	113	17%
Global warming potential (CO_2 kg)	37,047	46,826	9,779	26%
Air emission index (index scale)	8,566	9,729	1,163	14%
Water emission index (index scale)	17	70	53	312%
Solid waste (total kg)	13,766	13,641	-125	-0.9%

Atlanta house	Wood frame	Concrete frame	Difference	Concrete vs. wood (% change)
Embodied energy (GJ)	398	461	63	16%
Global warming potential (CO_2 kg)	21,367	28,004	6,637	31%
Air emission index (index scale)	4,893	6,007	1,114	23%
Water emission index (index scale)	7	7	0	0%
Solid waste (total kg)	7,442	11,269	3,827	51%

The Minneapolis house used more energy than the Atlanta house, over 60 percent more, and the steel-framed house utilized 17 percent more total primary fuels than the wood-framed house. In Atlanta, the concrete-framed house utilized about 15 percent more energy than the wood-framed house.

Primary Emissions

Numerous air, water, and solid waste emissions are tracked in the EIE model. Sixteen different air emissions are identified, and 23 different sources of water emissions are associated with the manufacturing of products. Six categories of solid waste are tracked for all production stages. Many more are listed in the LCIs of each stage of processing. Summarizing the individual emissions for our analysis was complex due to the many different values. Air and water emissions were evaluated using an environmental index that lists the worst offender and the volume of air/water required to reduce the impact to a safe level. Solid waste production was summarized by the weight of all waste materials produced. Also, carbon dioxide, methane, and nitrous oxide emissions were used to construct a GWP index based on specific carbon weights and their atmospheric lifetimes. The five environmental indices that were created using primary emission data are discussed below.

Discussion of the LCA findings

Completing the LCI for alternative house designs permitted us to compare environmental indices and conduct further analyses by taking the wood-frame house as a base case and then substituting alternative steel and concrete materials and comparing the results. We also compared the energy implications "from cradle to grave" of a house, the impacts of within-wood substitution, and identified some opportunities for improvements. The following discussions analyze the LCI results with these thoughts in mind.

There are many common materials between the two designs, and the majority of the energy associ-

Table 4. — Environmental performance indices for above-grade wall designs.

Minneapolis house	Wood frame	Steel frame	Difference	Steel vs. wood (% change)
Embodied energy (GJ)	250	296	46	18%
Global warming potential (CO_2 kg)	13,009	17,262	4,253	33%
Air emission index (index scale)	3,820	4,222	402	11%
Water emission index (index scale)	3	29	26	867%
Solid waste (total kg)	3,496	3,181	-315	-9%

Atlanta house	Wood frame	Concrete frame	Difference	Concrete vs. wood (% change)
Embodied energy (GJ)	168	231	63	38%
Global warming potential (CO_2 kg)	8,345	14,982	6,637	80%
Air emission index (index scale)	2,313	3,373	1,060	46%
Water emission index (index scale)	2	2	0	0%
Solid waste (total kg)	2,325	6,152	3,827	164%

ated with home construction, which excludes occupancy heating and cooling, was used in the extraction of raw materials and manufacture of the building materials. Almost all of the substitution in the Minneapolis designs takes place in the structural components (steel wall studs and floor joists) and the insulation, and almost all of the substitution in the Atlanta designs occurs in the structural components (concrete block and rebar with a stucco finish vs. wood studs and sheathing with vinyl cladding).

Table 3 presents the environmental performance indices for embodied energy, water and air emissions, solid waste production, and GWP from resource extraction to a completed residential building shell. Table 3 shows that with two exceptions, all of the construction index measures had considerably lower environmental risk for the wood-frame designs in Atlanta and Minneapolis compared to the non-wood-frame designs. The steel and wood designs produced similar amounts of solid waste in Minneapolis, and the concrete and wood designs produced similar water pollution impacts in Atlanta.

One may note considerable differences in the environmental results presented here and those presented in previous reports (Bowyer et al. 2001, 2002). Those differences reflect improvements in the database and models during the intervening time between reports, including a more complete bill of materials and revisions in both primary and secondary data.

The environmental indices for subassemblies such as "above-grade wall" showed larger percentage differences than for the buildings as a whole because the materials being compared (wood vs. steel and wood vs. concrete) made up a larger share of the subassemblies (Table 4). The Minneapolis wood wall subassembly used less energy and produced less GWP than the steel wall subassembly that incorporated an outside layer of insulation to provide equivalent thermal properties. The Atlanta concrete wall subassembly was much worse in comparison to the wood subassembly because the concrete wall had to contain a wood frame in addition to the concrete in order to house insulation and its gypsum covering.

The energy difference became even more significant when we compared just those materials that substituted for wood in the steel and concrete designs. For the Minneapolis house designs (Fig. 3), the total embodied energy in the steel-frame house was 759 GJ compared to 646 GJ for the wood-frame house. Since embodied energy includes the internally produced bioenergy from wood processing, the non-bioenergy that must be purchased will decrease for the wood house. The non-bioenergy for steel, insulation, and wood used in the steel frame was 164 GJ (22% of the total) and the non-bioenergy for these same materials in the wood frame was only 43 GJ (7% of the total). ***While the total energy in the completed steel-frame house was only 17 percent greater than the completed wood-frame house, for the products being compared, the steel-frame design used 281 percent more non-bioenergy than the wood-frame design.*** The 121 GJ net difference from substitution results from a 127 GJ increase in energy for steel and insulation with only a 6 GJ decrease from the reduced use of wood in the steel frame, i.e., 21 times more energy used than saved by this substitution of materials.

For the Atlanta house designs, the total embodied energy for the concrete-frame design was 461 GJ compared to 398 GJ for the wood-frame design. The non-bioenergy for concrete block, mortar, rebar, and wood used in the concrete frame was 84 GJ (18% of the total) and only 24 GJ for the wood frame (6% of the total). ***While the total energy in the concrete-frame house was only 16 percent greater than the wood-frame house, for the products being compared, the concrete frame used 250 percent more non-bioenergy than the wood frame.*** The 60 GJ net difference from substitution results from a 63 GJ increase in energy for concrete block, mortar, and rebar with only a 3 GJ decrease from the reduced use of wood in the concrete frame, i.e., 21 times more energy used than saved by this substitution of materials.

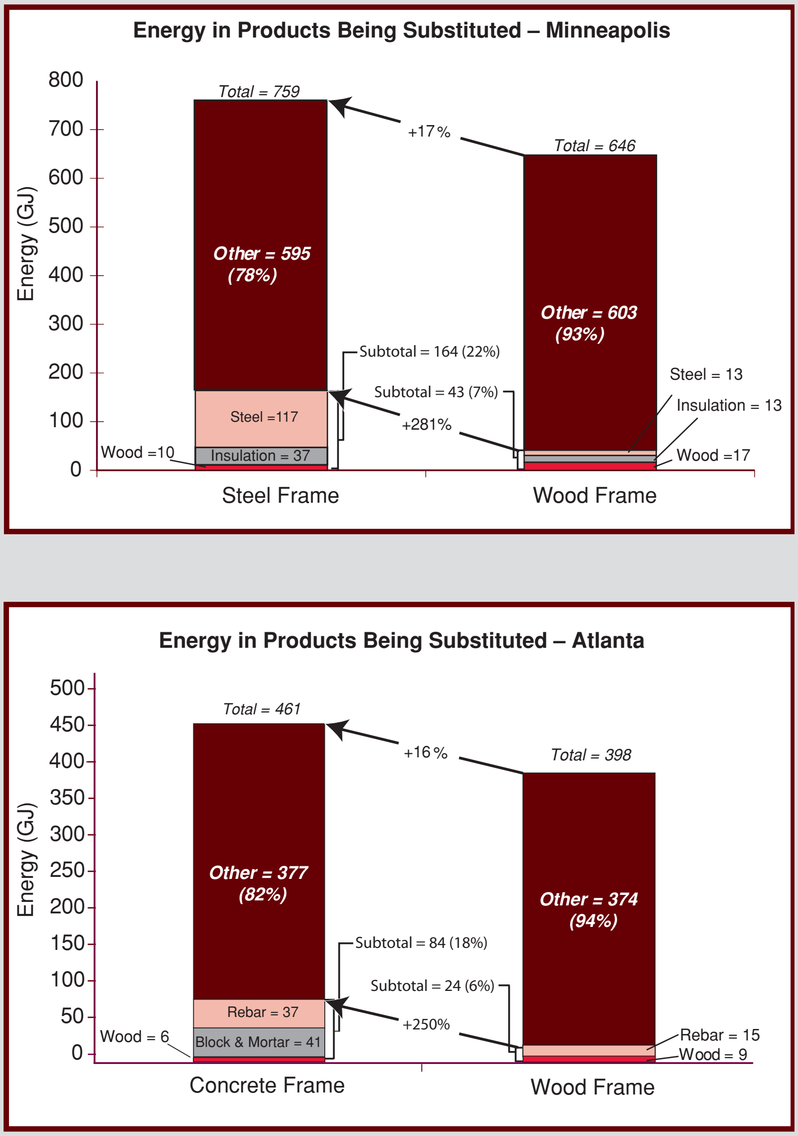


Figure 3. — Energy in products being substituted for each type of construction.

The explanation of the differences between the completed house comparisons and the substitute materials comparisons is that there are a number of products other than wood that are common to all the designs, such as concrete foundations, glass, gypsum, and asphalt roofing, and these are energy intensive and contribute the largest percentage to total embodied energy. Comparing just the substitute materials in the frames underscores the environmental advantage of wood.

We also analyzed recent changes in within-wood substitutes to see how important these changes are. A few years ago, plywood was often used for sheathing, so we did an analysis that substituted plywood for OSB, and the results generally showed a 3 percent lower environmental burden for a completed house. The exception to this lower burden for plywood was the finding that OSB is superior regarding water-related impacts, probably because some of the OSB mills were in compliance with new stricter standards regarding water emissions. The substitution of solid-sawn wood joists for engineered I-joists resulted in very little difference in the environmental performance indices because the greater material efficiency of the I-joists was offset by the increased use of resins and energy. The use of green Douglas-fir lum-

Table 5. — Energy used in representative building life-cycle stages.

	Minneapolis house		Atlanta house	
	Steel frame	Wood frame	Concrete frame	Wood frame
Energy in the structure (GJ)	646	759	395	456
Energy from maintenance (GJ)	73	73	110	110
Energy for demolition (GJ)	7	7	7	9
Energy subtotal	**727**	**840**	**512**	**573**
Energy use for heat & cool (GJ) (75 yr.)	7800	7800	4575	4575
House cost	$168,000	$168,000	$135,000	$135,000
Construction cost	$92,000	$92,000	$74,000	$74,000
Cost/yr. heat & cool	$692	$692	$491	$491
Present value cost (75 years @ 5%)	$13,490	$13,490	$9565	$9565
% of construction	**14.7%**	**14.7%**	**12.9%**	**12.9%**

ber for studs, which is still prevalent in the west, reduced energy by 4 percent and GWP by 2 percent compared to using kiln-dried studs in construction.

If low-grade co-products are used as bioenergy, the energy requirement is lowered, especially for drying. We define co-products as the products made from a log that are not used in a house but are sold on the market (hog fuel is not included because it is used within the plant). A sensitivity analysis revealed that using all co-product material for bioenergy (except chips for paper production) generally resulted in surplus energy for the production of wood, offsetting some of the energy purchased for steel, concrete, insulation, and other materials (Bowyer et. al 2004).

These analyses also raise issues regarding material-use efficiency. OSB is produced from wood of several species that are generally considered to be of lower value. In that sense, OSB reduces the pressure on the acres that have been producing higher quality wood and are in greater demand. This results in a substantial productivity increase in terms of total production per acre of forest land. In addition, the I-joists use OSB and require less wood per house. I-joists use only 62 to 65 percent of the wood required by solid-sawn joists. Since I-joists were only used in the floor in the designs studied, returning to the use of solid-sawn joists would increase the use of wood fiber by 10 percent (1.3 metric tons) for the total house, and this material would generally be from higher valued species, i.e., those in greater demand. These material use efficiency gains can be quite significant when wood use is traced back to the producing land base.

Table 5 summarizes the energy used for each life-cycle stage of the residential building, including the use phase of the building, maintenance, and disposal. The energy used in heating and cooling dominated the energy used for each life-cycle stage. However, from an economic standpoint, heating and cooling energy is spread over the 75-year life-cycle of a house and results in a relatively small share of the total construction investment. We arbitrarily selected a 75-year life-cycle as some others have used, but show in Module L in Bowyer et al. (2004) that the expected service life probably exceeds 85 years.

The carbon emissions associated with energy use represented one of the more important environmental burdens. Carbon in forest products acts as an offset to the emissions associated with energy use. Table 6 reports accumulated carbon emissions (and avoided emissions) associated with the life-cycle of a house. Emissions from product manufacturing, construction, and demolition were added to the emissions from maintenance, heating, and cooling. To a large degree, these emissions are offset by the avoided emissions from the carbon stored in forests and products; the emissions from bioenergy were subtracted from stored carbon to avoid double counting since the GWP for construction excludes such emissions. The carbon stored in the forest was determined by the number of hectares required to support the construction of one useful life-cycle for

Table 6. — Carbon emissions in representative building life-cycle stages.

	Minneapolis house		Atlanta house	
	Wood frame	Steel frame	Wood frame	Concrete frame
	(metric tons)			
Emissions in mfg., construction & demo.	37.1	46.8	21.4	28.0
Emissions from biofuel	3.6	2.6	3.4	2.7
Emissions from maintenance	3.4	3.4	4.1	4.1
Emissions from heating & cooling	390	390	232	232
Subtotal of sources	434	443	261	267
Forest sequestration	(467)	(246)	(103)	(85)
Wood product storage	(22.4)	(11.8)	(17.1)	(14.1)
Subtotal of sinks and stores	(489)	(258)	(121)	(100)
Net emissions	**(55)**	**185**	**140**	**167**

the house. Only the carbon allocated to the materials in the house was shown as a positive pool, thereby excluding the carbon-supporting co-products coming from the same number of hectares.

While the total sources of emissions were dominated by the impact of energy used in heating and cooling, the forest and wood product sinks for carbon tend to be larger for the Minneapolis wood-frame house. The net CO_2 avoided was 55 metric tons for the Minneapolis wood-frame house, compared to a net source of emissions of 185 metric tons for the steel-frame house. Net emissions of CO_2 were 140 metric tons for the Atlanta wood-frame, and 167 for the concrete design, i.e., only the Minneapolis wood-frame showed more carbon stored than emissions. The shorter rotation in the Southeast supply region sequesters less carbon in the forest, which is the main reason why there was less carbon sequestered for the Atlanta house compared to the Minneapolis house.

Integration over all of the activities performed on today's stocks of forest lands and housing, coupled with today's processing, construction, and demolition and disposal methods, provides a realistic "bottom line" inventory report on the current status of resource and energy consumption and releases to the environment. However, efforts to identify cost-effective improvements may need to take into consideration the time value of money, which differs across several of these life-cycle stages.

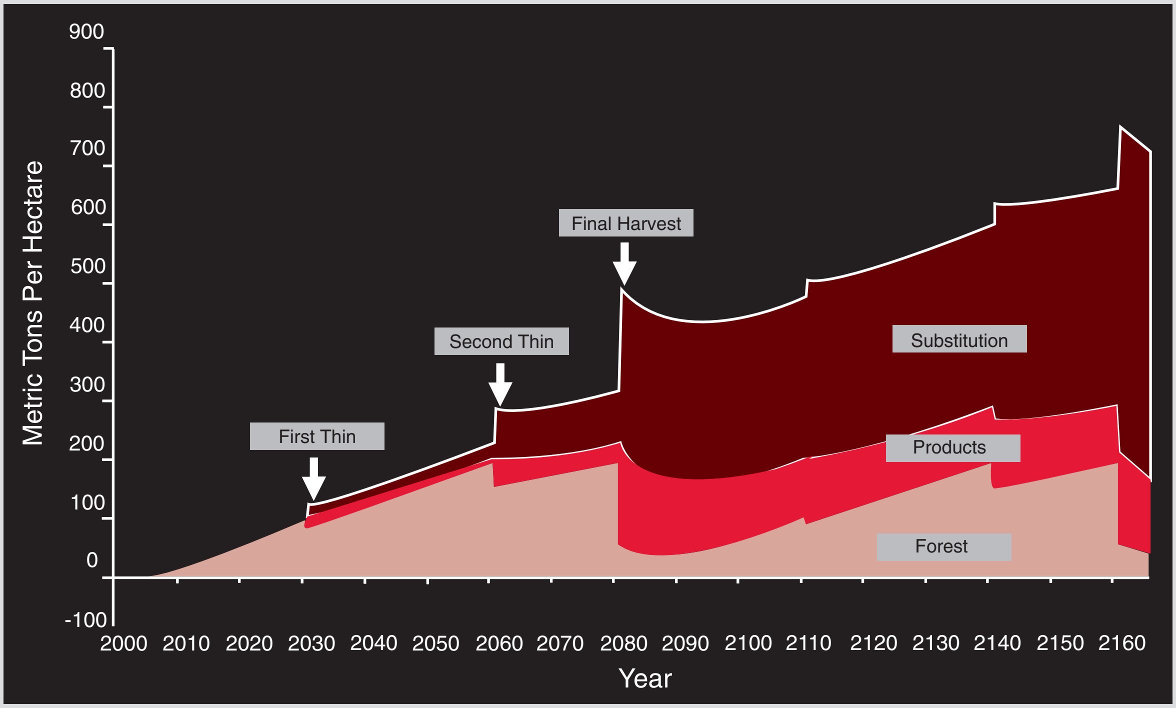


Figure 4. — Carbon in the forest and product pools with concrete substitution for the 80-year rotation.

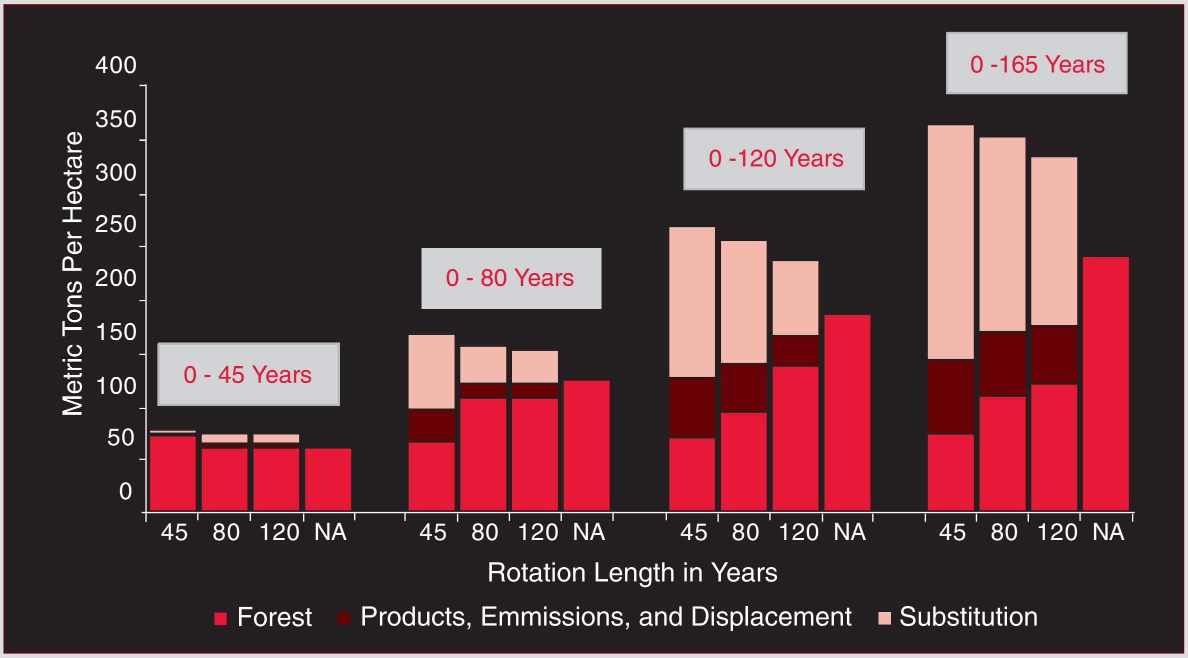


Figure 5. — Average annual carbon in forest, product, and concrete substitution pools for different rotations and specified intervals.

Management Impacts on Carbon

An alternate perspective more related to forest management would track the carbon pools over time, in the forest, in both short- and long-lived products, in bioenergy displacement of fossil fuel energy, and through product substitution (Fig. 4). Unlike the life-cycle analysis, which assumed a cross-sectional snapshot of all activities as a steady state, a time series analysis showed that while the carbon in the forest approached stability, the carbon in products continued to grow, with the substitution for fossil fuel intensive products being an important factor.

Analyzing these carbon pools for the Pacific Northwest as they are impacted by the length of the management rotation showed smaller carbon pools and greater emissions from longer rotations (Fig. 5). Short rotations gained the benefits of increasing product pools and substitution sooner, with these product-dependent pools more than offsetting the decline in the forest pool for short rotations. We also examined the impact of increasing management intensity, and for substitution with concrete noted that more intensive management on the 45-year rotation adds another 20+ percent to the product and substitution pools. The intensively managed rotation provided 193 metric tons of carbon per hectare in all pools over an 80-year interval compared to 153 tons for the 80-year rotation, with this difference rising to 409 tons versus 353 tons over a 165-year time interval. The result that more carbon was stored under short intensively managed rotations suggests that substantially more carbon could be stored in the Northwest supply region with a small incentive for intensive management. However, this contribution is not recognized by the Kyoto Protocol, which only recognizes forest carbon. Leaving out the carbon stored in wood products and the impact of non-wood substitution would appear to have counterproductive implications for current carbon policy.

Conclusions

The CORRIM report is intended to be used as a reference source for those interested in the LCI data for various building materials. The reader is provided with an explanation of the data, the methods used in LCI and LCA, and examples of the use of such data. The report also demonstrates a number of sensitivities through the analysis of alternative scenarios. Many additional reports can be based on the data and methods presented in the CORRIM report.

Many opportunities for environmental improvement have been noted, including those related to management, process, and material substitution. There may be internal tradeoffs between environmental burdens, with some rising while others fall. There may also be cost tradeoffs that need to take into consideration the time value of money. Those opportunities that would appear to have substantial improvement potential include:

- Redesign of houses to use less fossil-fuel intensive products;
- Redesign of houses to reduce energy use (both active and passive);
- Redesign of the codes that result in excessive use of wood, steel, and concrete;
- Greater use of low-valued wood fiber for bioenergy;
- Greater use of engineered products that utilize less desirable species;
- Improved process efficiencies, such as in the boiler or dryer (including air-drying);
- Environmental pollution control improvements that consider LCI/LCA impacts;
- More intensive forest management;
- Recycling of demolition wastes;
- Increased product durability through improved products, construction designs, and maintenance of houses.

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