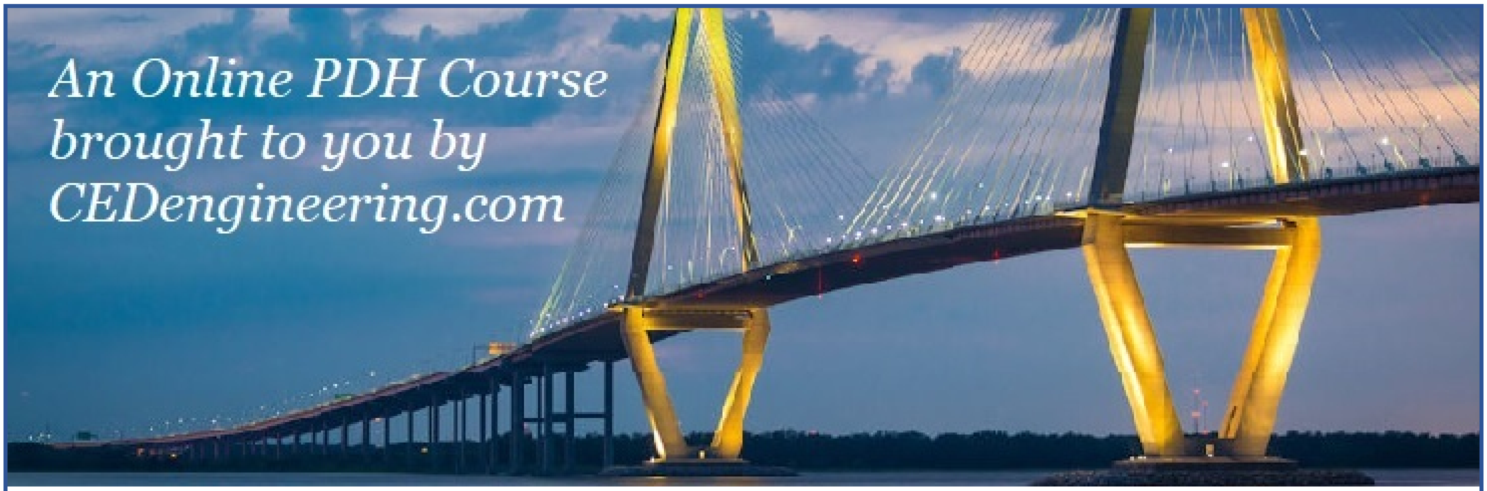

Wood as An Engineering Material: Wood as a Sustainable Building Material

Course No: S01-005
Credit: 1 PDH

Gilbert Gedeon, P.E.

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.com

Wood as a Sustainable Building Material

Robert H. Falk, Research General Engineer

Contents

Few building materials possess the environmental benefits of wood. It is not only our most widely used building material but also one with characteristics that make it suitable for a wide range of applications. As described in the many chapters of this handbook, efficient, durable, and useful wood products produced from trees can range from a minimally processed log at a log-home building site to a highly processed and highly engineered wood composite manufactured in a large production facility.

As with any resource, we want to ensure that our raw materials are produced and used in a sustainable fashion. One of the greatest attributes of wood is that it is a renewable resource. If sustainable forest management and harvesting practices are followed, our wood resource will be available indefinitely.

Wood as a Green Building Material

Over the past decade, the concept of green building[1] has become more mainstream and the public is becoming aware of the potential environmental benefits of this alternative to conventional construction. Much of the focus of green building is on reducing a building's energy consumption (such as better insulation, more efficient appliances and heating, ventilation, and air-conditioning (HVAC) systems) and reducing negative human health impacts (such as controlled ventilation and humidity to reduce mold growth). However, choosing building materials that exhibit positive environmental attributes is also a major area of focus. Wood has many positive characteristics, including low embodied energy, low carbon impact, and sustainability. These characteristics are important because in the United States, a little more than half the wood harvested in the forest ends up as building material used in construction.

Embodied Energy

Embodied energy refers to the quantity of energy required to harvest, mine, manufacture, and transport to the point of use a material or product. Wood, a material that requires a minimal amount of energy-based processing, has a low level

---

[1] Green building is defined as the practice of increasing the efficiency with which buildings use resources while reducing building impacts on human health and the environment—through better siting, design, material selection, construction, operation, maintenance, and removal—over the complete building life cycle.

Table 1–1. Wood products industry fuel sources[a]

Fuel source	Proportion used (%)
Net electricity	19
Natural gas	16
Fuel oil	3
Other (primarily biomass)	61

[a]EPA (2007).

of embodied energy relative to many other materials used in construction (such as steel, concrete, aluminum, or plastic). The sun provides the energy to grow the trees from which we produce wood products; fossil fuels are the primary energy source in steel and concrete manufacture. Also, over half the energy consumed in manufacturing wood products in the United States is from biomass (or bioenergy) and is typically produced from tree bark, sawdust, and by-products of pulping in papermaking processes. The U.S. wood products industry is the nation's leading producer and consumer of bioenergy, accounting for about 60% of its energy needs (Table 1–1) (Murray and others 2006, EPA 2007). Solid-sawn wood products have the lowest level of embodied energy; wood products requiring more processing steps (for example, plywood, engineered wood products, flake-based products) require more energy to produce but still require significantly less energy than their non-wood counterparts.

In some plantation forest operations, added energy costs may be associated with the use of fertilizer, pesticides, and greenhouses to grow tree seedlings. During the harvesting operation, energy is used to power harvesting equipment and for transporting logs to the mill. Lumber milling processes that consume energy include log and lumber transport, sawing, planing, and wood drying. Kiln drying is the most energy-consumptive process of lumber manufacture; however, bioenergy from a mill's waste wood is often used to heat the kilns. Unlike burning fossil fuels, using bioenergy for fuel is considered to be carbon neutral. Also, advances in kiln technologies over the past few decades have significantly reduced the amount of energy required in wood drying. Overall, the production of dry lumber requires about twice the energy of producing green (undried) lumber.

The Consortium for Research on Renewable Industrial Materials (CORRIM) found that different methods of forest management affect the level of carbon sequestration in trees (Perez-Garcia and others 2005). They found that shorter rotation harvests can sequester more total carbon than longer rotation harvests.

CORRIM also calculated differences in energy consumed and environmental impacts associated with resource extraction, materials production, transportation, and disposal of homes built using different materials and processes. Their calculations show that the energy consumed in the manufacture of building materials (mining iron and coal for steel or harvesting wood for lumber) and the construction of a steel-framed house in Minneapolis is 17% greater than for a wood-framed house (Lippke and others 2004). The difference is even more dramatic if one considers the use of bioenergy in the manufacture of wood products. By this comparison, the steel-framed house uses 281% more non-bioenergy than the wood-framed house (Perez-Garcia and others 2005). Global warming potential, air emission index, and water emission index are all higher for steel construction than for wood construction (Table 1–2).

These analyses indicate that the amount of energy necessary to produce wood products is much less than comparable products made from other materials. If wood is substituted for these other materials (assuming similar durability allows equal substitution), energy is saved and emissions avoided each time wood is used, giving it a distinct environmental advantage over these other materials (Bowyer and others 2008).

Carbon Impact

The role of carbon in global climate change and its projected negative impact on ecosystem sustainability and the general health of our planet have never been more elevated in the public's consciousness.

Forests play a major role in the Earth's carbon cycle. The biomass contained in our forests and other green vegetation affects the carbon cycle by removing carbon from the atmosphere through the photosynthesis process. This process converts carbon dioxide and water into sugars for tree growth and releases oxygen into the atmosphere:

$$\text{energy (sunlight)} + 6H_2O + 6CO_2 \rightarrow C_6H_{12}O_6 + 6O_2$$

A substantial amount of carbon can be sequestered in forest trees, forest litter, and forest soils. Approximately 26 billion metric tonnes of carbon is sequestered within standing trees, forest litter, and other woody debris in domestic forests, and another 28.7 billion tonnes in forest soils (Birdsey and Lewis 2002). According to Negra and others (2008), between 1995 and 2005 the rate of carbon sequestration in U.S. forests was about 150 million tonnes annually (not including soils), a quantity of carbon equivalent to about 10% of total carbon emissions nationally.

Unfortunately, deforestation in tropical areas of the world is responsible for the release of stored carbon, and these forests are net contributors of carbon to the atmosphere. Tropical deforestation is responsible for an estimated 20% of total human-caused carbon dioxide emissions each year (Schimel and others 2001).

Carbon in wood remains stored until the wood deteriorates or is burned. A tree that remains in the forest and dies releases a portion of its carbon back into the atmosphere as the woody material decomposes. On the other hand, if the tree

Table 1–2. Environmental performance indices for above-grade wall designs in residential construction[a]

	Wood frame	Steel frame	Difference	Change[b] (%)
Minneapolis design				
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	–0.9
Atlanta design				
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

[a] Lippke and others (2004).

[b] % change = [(Steel frame – Wood frame)/(Wood frame)] × 100.

is used to produce a wood or paper product, these products store carbon while in use. For example, solid wood lumber, a common wood product used in building construction (the building industry is the largest user of sawn wood in the United States), sequesters carbon for the life of the building. At the end of a building's life, wood can be recovered for re-use in another structure, chipped for use as fuel or mulch, or sent to a landfill (usual fate). If burned or mulched, stored carbon is released when the wood decomposes, essentially the reverse process of photosynthesis:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Carbon contained in wood products currently in-use and as wood debris in landfills is estimated at 2.5 billion tonnes and accumulates at a rate of about 28 million tonnes per year (Skog 2008). Much of the carbon contained within wood products resides in the nation's housing stock, estimated at 116 million units in 2000. Skog (2008) estimated that in 2001, about 680 million tonnes of carbon was stored in the nation's housing stock, nearly a third of the total carbon (2.5 billion tonnes) cited above.

As indicated in Table 1–3, carbon emitted to produce a tonne of concrete is about eight times that emitted to produce a tonne of framing lumber. A similar comparison for steel indicates that its production emits about 21 times as much carbon as an equal weight of framing lumber. Wood products also mitigate carbon emissions to the degree that they substitute for steel or concrete, which emit more greenhouse gases in their production.

Also, because wood products have this low level of embodied energy compared with other building products and because wood is one-half carbon by weight, wood products can actually be carbon negative (Bowyer and others 2008).

Comparisons of the environmental impact of various wood products have also been made using life cycle analysis software (Calkins 2009). The more processing involved in the manufacture of wood products (such as flaking, veneer cutting, added heat for pressing, gluing, kiln drying), the more impact on energy use, solid waste production, pollution production, and global warming potential (carbon).

Sustainability

Unlike metals and fossil-fuel-based products (such as plastics), our forest resource is renewable and with proper management a flow of wood products can be maintained indefinitely. The importance of forest-based products to our economy and standard of living is hard to overemphasize—half of all major industrial raw materials we use in the United States come from forests. However, the sustainability of this resource requires forestry and harvesting practices that ensure the long-term health and diversity of our forests. Unfortunately, sustainable practices have not always been applied in the past, nor are they universally applied around the world today. Architects, product designers, material specifiers, and homeowners are increasingly asking for building products that are certified to be from a sustainable source. For the forest products sector, the result of this demand has been the formation of forest certification programs. These programs not only ensure that the forest resource is harvested in a sustainable fashion but also that issues of biodiversity, habitat protection, and indigenous peoples' rights are included in land management plans.

Forest Certification Programs

More than 50 different forest certification systems in the world today represent nearly 700 million acres of forestland and 15,000 companies involved in producing and

Table 1–3. Net carbon emissions in producing a tonne of various materials

Material	Net carbon emissions (kg C/t)[a,b]	Near-term net carbon emissions including carbon storage within material (kg C/t)[c,d]
Framing lumber	33	–457
Medium-density fiberboard (virgin fiber)	60	–382
Brick	88	88
Glass	154	154
Recycled steel (100% from scrap)	220	220
Concrete	265	265
Concrete[e]	291	291
Recycled aluminum (100% recycled content)	309	309
Steel (virgin)	694	694
Plastic	2,502	2,502
Aluminum (virgin)	4,532	4,532

[a] Values are based on life-cycle assessment and include gathering and processing of raw materials, primary and secondary processing, and transportation.
[b] Source: EPA (2006).
[c] From Bowyer and others (2008); a carbon content of 49% is assumed for wood.
[d] The carbon stored within wood will eventually be emitted back to the atmosphere at the end of the useful life of the wood product.
[e] Derived based on EPA value for concrete and consideration of additional steps involved in making blocks.

marketing certified products. These programs represent about 8% of the global forest area and 13% of managed forests. From 2007 to 2008, the world's certified forest area grew by nearly 9%. North America has certified more than one-third of its forests and Europe more than 50% of its forests; however, Africa and Asia have certified less than 0.1%.

Approximately 80% to 90% of the world's certified forests are located in the northern hemisphere, where two thirds of the world's roundwood is produced (UNECE 2008). In North America, five major certification systems are used:

- Forest Stewardship Council (FSC)
- Sustainable Forestry Initiative (SFI)
- American Tree Farm System (ATFS)
- Canadian Standards Association (CSA)
- Programme for the Endorsement of Forest Certification (PEFC) schemes

In terms of forest acreage under certification, the Forest Stewardship Council and the Sustainable Forestry Initiative dominate in the United States. These two systems evolved from different perspectives of sustainability. The FSC's guidelines are geared more to preserve natural systems while allowing for careful harvest, whereas the SFI's guidelines are aimed at encouraging fiber productivity while allowing for conservation of resources (Howe and others 2004). The growing trends in green building are helping drive certification in the construction market in the United States.

Forest Stewardship Council (FSC)

FSC is an independent, non-governmental organization established to promote responsible management of the world's forests and is probably the most well-known forest certification program worldwide. More than 280 million acres of forest worldwide are certified to FSC standards and are distributed over 79 countries. The FSC program includes two types of certifications. The Forest Management Certification applies FSC standards of responsible forestry to management of the forest land. A Chain-of-Custody (COC) certification ensures that forest products that carry the FSC label can be tracked back to the certified forest from which they came. More than 9,000 COC certifications are in use by FSC members. The FSC has certified 18 certification bodies around the world. Four are located in the United States, including the non-profit Rainforest Alliance's SmartWood program and the for-profit Scientific Certification Systems. Both organizations provide up-to-date lists of FSC-certified wood suppliers across the country.

Sustainable Forestry Initiative (SFI)

The SFI program was established in 1994 and currently certifies over 152 million acres in the United States and Canada. This program has a strong wood industry focus and has been adopted by most of the major industrial forest landowners in the United States. It is based on the premise that responsible forest practices and sound business decisions can co-exist. The SFI program includes third-party certification, which verifies the requirements of the SFI 2010–2014 Standard. Independent certification bodies evaluate planning, procedures, and processes in the forest and in wood processing operations. Annual surveillance audits are mandatory on all certified operations, and a full recertification audit is required for forest operations every 3 years.

American Tree Farm System (ATFS)

The American Tree Farm System, a program of the American Forest Foundation's Center for Family Forests, is the oldest of forest certification programs and was established in 1941. The ATFS focuses its program on private family forest landowners in the United States. Currently, ATFS has certified 24 million acres of privately owned forestland and more than 90,000 family forest owners. The ATFS forest certification standard requires forest owners to develop a management plan based on strict environmental standards and pass an inspection by an ATFS inspecting forester. Third-party certification audits, conducted by firms accredited by the ANSI–ASQ National Accreditation Board (ANAB) or the Standards Council of Canada (SCC), are required for all certifications of the ATFS.

Canadian Standards Association (CSA)

The Canadian Standards Association is a non-profit organization and has developed over 2,000 different standards for a variety of industries. The CSA first published Canada's National Standard for Sustainable Forest Management (SFM) CAN/CSA-Z809 in 1996. The SFM program has four components: the SFM Standard itself, a Chain-of-Custody program, product marking, and the CSA International Forest Products Group, which promotes the program. The CSA Standard has been adopted by the major industrial forestland managers in Canada. As of June 2007, about 60% (198 million acres) of Canadian forests were certified under the CAN/CSA-Z809 SFM Standard.

Programme for the Endorsement of Forest Certification (PEFC) Schemes

The multitude of certification programs with competing standards and claims has made it difficult for land managers, members of the wood industry, and consumers to determine which certification program fits their needs (Fernholz and others 2004). The Programme for the Endorsement of Forest Certification schemes was developed to address this issue and serves as an umbrella endorsement system that provides international recognition for national forest certification programs. Founded in 1999, the PEFC represents most of the world's certified forest programs and the production of millions of tons of certified timber. The FSC, SFI, and ATFS programs have received official PEFC endorsement.

Additional Information

Helpful online tools provide more information and data on forest certification, including the Forest Certification Resource Center (www.metafore.org), which identifies forests, manufacturers, distributors, importers, and retailers certified under FSC, SFI, and CSA programs. The database is searchable by product, location, and certification system. Another helpful resource is the Forest Products Annual Market Review (www.unece.org), which provides general and statistical information on forest products markets in the United Nations Economic Commission for Europe (UNECE) and covers the regions of Europe, North America, and the Commonwealth of Independent States.

Literature Cited

Birdsey, R.; Lewis, G. 2002. Carbon in U.S. forests and wood products, 1987–1997: state by state estimates. Gen. Tech. Rep. GTR–NE–310. Washington, DC: U.S. Department of Agriculture, Forest Service.

Bowyer, J.; Bratkovich, S.; Lindberg, A.; Fernholz, K. 2008. Wood products and carbon protocols: carbon storage and low energy intensity should be considered. Minneapolis, MN: Dovetail Partners, Inc. www.dovetailinc.org. (28 April 2008). 13 p.

Calkins, M. 2009. Materials for sustainable sites: a complete guide to the evaluation, selection, and use of sustainable construction materials. Hoboken, NJ: John Wiley & Sons. 457 p.

EPA. 2006. Solid waste management and greenhouse gases—a life cycle assessment of emissions and sinks. 3rd Ed. Washington, DC: U.S. Environmental Protection Agency.

EPA. 2007. Energy trends in selected manufacturing sectors: opportunities and challenges for environmentally preferable energy outcomes. Washington, DC: U.S. Environmental Protection Agency, Office of Policy, Economics and Innovation. (March 2007).

Fernholz, K.; Howe, J.; Guillery, P.; Bowyer, J. 2004. Beginner's guide to third-party forest certification: shining a light on the programme for the endorsement of forest certification schemes (PEFC). Minneapolis, MN: Dovetail Partners, Inc. www.dovetailinc.org.

Fernholz, K.; Howe, J.; Guillery, P.; Bowyer, J. 2005. Beginner's guide to third-party forest certification: shining a light on the Canadian Standards Association (CSA). Minneapolis, MN: Dovetail Partners, Inc. www.dovetailinc.org. (18 January 2005). 10 p.

Howe, J.; Fernholz, K.; Guillery, P.; Bowyer, J. 2004. A land manager's guide to FSC & SFI—to certify or not to certify: is that a question? Minneapolis, MN: Dovetail Partners, Inc. www.dovetailinc.org. (15 September 2004). 13 p.

Lippke, B.; Wilson, J.; Perez-Garcia, J.; Bowyer, J.; Meil, J. 2004. CORRIM: life-cycle environmental performance of renewable building materials. Forest Products Journal. 54(6): 13. (June 2004).

Murray, B.; Nicholson, R.; Ross, M.; Holloway, T.; Patil, S. 2006. Biomass energy consumption in the forest products industry. Washington, DC: U.S. Department of Energy; Research Triangle Park, NC: RTI International. 81 p.

Negra, C.; Sweedo, C.; Cavender-Bares, K.; O'Malley, R. 2008. Indicators of carbon storage in U.S. ecosystems: baseline for terrestrial carbon accounting. Journal of Environmental Quality. 37: 1376–1382.

Perez-Garcia, J.; Lippke, B.; Briggs, D.; Wilson, J.; Bowyer, J.; Meil, J. 2005. The environmental performance of renewable building materials in the context of residential construction. Wood and Fiber Science. (37)12: 3–17.

Schimel, D.S.; House, J.I.; Hibbard, K.A.; Bousquet, P.; Ciais, P.; Peylin, P.; Braswell, B.H.; Apps, M.J.; Baker, D.; Bondeau, A.; Canadell, J.; Churkina, G.; Cramer, W.; Denning, A.S.; Field, C.B.; Friedlingstein, P.; Goodale, C.; Heimann, M.; Houghton, R.A.; Melillo, J.M.; Moore, B., III; Murdiyarso, D.; Noble, I.; Pacala, S.W.; Prentice, I.C.; Raupach, M.R.; Rayner, P.J.; Scholes, R.J.; Steffen, W.L.; Wirth, C. 2001. Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. Nature. 414: 169–172.

Skog, K. 2008. Sequestration of carbon in harvested wood products for the United States. Forest Products Journal. 58(6): 56–72.

UNECE / FAO. 2008. Forest products annual market review 2007–2008. Geneva, Switzerland: United Nations Economic Commission for Europe / Food and Agriculture Organization. www.unece.org/trade/timber.