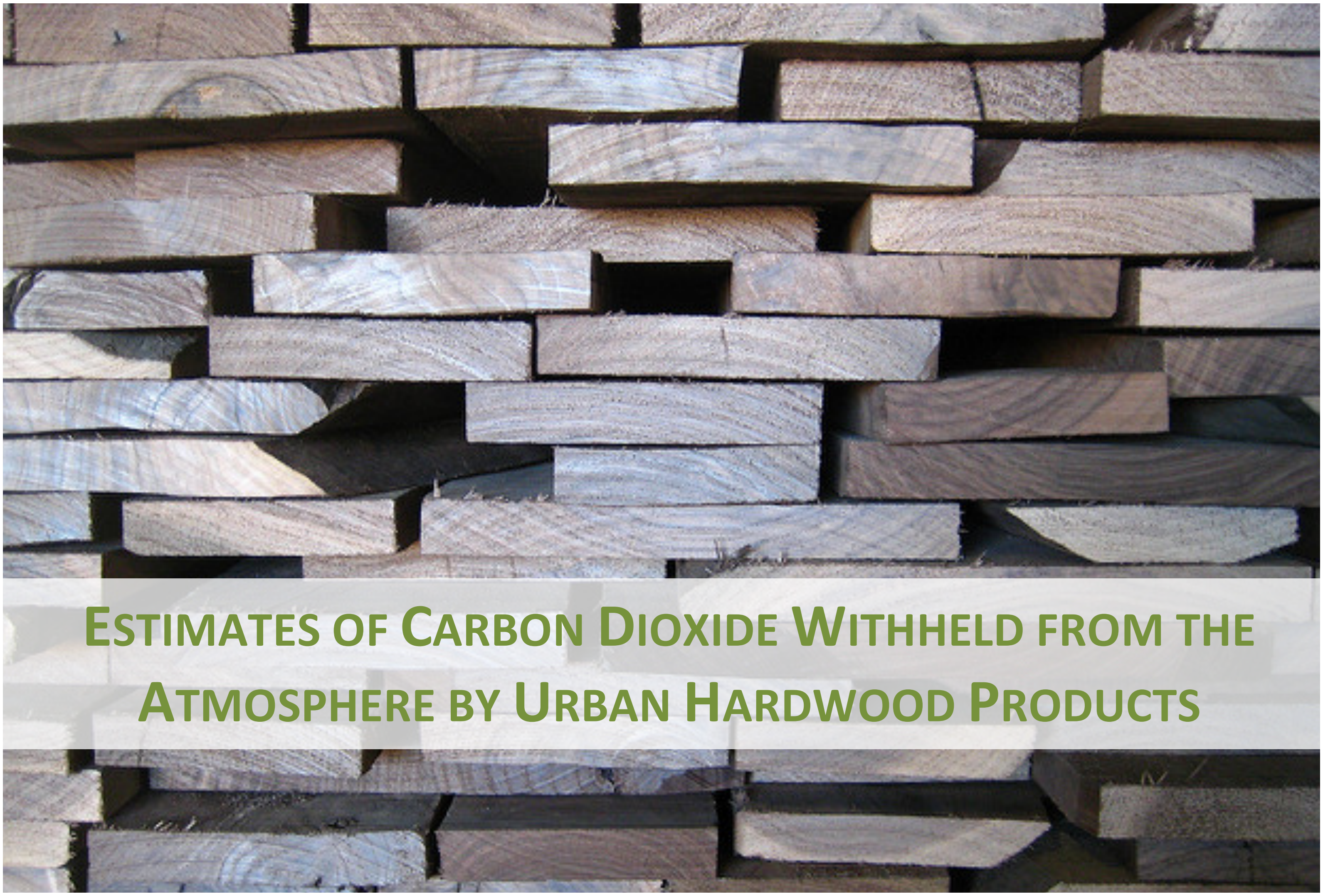

Estimates of Carbon Dioxide Withheld from the Atmosphere by Urban Hardwood Products

March 2018

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The work upon which this publication is based was funded in whole or in part through a grant awarded by the Wood Education and Resource Center, Northeastern Area State and Private Forestry, U.S. Forest Service.

Executive Summary

Funded in 2011 by the USDA Forest Service, Wood Education & Resource Center (WERC), Dovetail Partners conducted a study on the potential for carbon sequestration (storage) in three urban hardwood products: landscape mulch, biomass for fuel, and solid wood products. An Excel model was developed that focused specifically on tons of sequestered carbon dioxide equivalent (CO_2e) of solid hardwood products from urban forests in the United States. Estimates for a 30-year period were developed for several situations based on assumptions about variations in carbon and wood harvest. The minimum estimate from the 2011 study was approximately 124 million tons of CO_2e that could be sequestered (stored) nationally in urban hardwood products over a 30 year period.[1]

Beginning in 2016, a follow-up study was funded by WERC. The 2016 study reconstructed the national model developed in the previous investigation to convert tons of sequestered CO_2e into board feet. In addition, to making the results more user-friendly to urban wood industries, architects, and other interested parties, two products were selected, and sequestered CO_2e was estimated. The hardwood products were a white oak dining room table and chairs, and green ash flooring.

At the national or macro-level, results of the current study show that a minimum or baseline estimate of approximately 53 billion board feet of urban hardwood lumber could be produced to sequester an equivalent of over 124 million tons in CO_2e over a 30 year period. The 30-year total is equal to an average of 1.8 billion board feet per year. The maximum (upper limit) *realistic* estimates are 105 billion board feet (over 30 years) and 3.5 billion board feet (annually). Both the minimum and maximum estimates are under the lower limits from two independent studies by Bratkovich (2001) and MacFarlane (2009).

At the local or micro-level, results illustrate that a white oak dining room table with ten chairs (120 board feet) sequesters approximately 730 pounds of CO_2e. Also, 105 board feet of green ash flooring sequesters 535 pounds of CO_2e. These examples demonstrate the capacity for determining the carbon footprint of specific urban forest products. The white oak table and chairs, plus the flooring, results in a total CO_2e weight of 1,265 pounds. This combination equals the CO_2 emissions from one mower for fourteen years (or fourteen mowers for one year).

Similar to the table and flooring examples, urban forest product businesses can use the data in this study to calculate and advertise CO_2e amounts for their own specific products. Buyers will know that the urban wood product they are purchasing in some small way contributes to the reduction of a major greenhouse gas. In addition, they will also be made aware that they are purchasing products that utilize urban wood at its highest economic value.

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[1] Two reports based on this study are available from Dovetail Partners, Inc. The one dated July, 2011 entitled *Carbon and Carbon Dioxide Equivalent Sequestration in Urban Forest Products* by Sam Sherrill and Steve Bratkovich is more of a technical report for those interested in the details of the Excel model. Available at: http://www.dovetailinc.org/report_pdfs/2011/urbancarbonwercreport2011.pdf. The one dated July 19, 2011 entitled *Carbon Sequestration in Solid Wood Products from Urban Forests* by Steve Bratkovich, Sam Sherrill, Jeff Howe, Kathryn Fernholz, Sarah Stai, and Jim Bowyer is for an audience less interested in technical details and more in the broader implications of the findings. Available at: http://www.dovetailinc.org/report_pdfs/2011/dovetailurbansolidwoodcarbon0711-1.pdf.

Urban forest product businesses can also calculate the annual CO_2e weights of all of their products by species and board feet totals used in their yearly output. For example, assume the urban forest products business that produced the table, chairs, and flooring annually utilized ten thousand board feet of hardwoods (such as oak, ash, cherry, and walnut) to make products and held another five thousand board feet of these species as lumber in inventory. This small business could account for a total CO_2e weight of sixty-five thousand pounds or almost thirty-three tons of CO_2e. That is, in finished products and lumber inventory, this business can claim that in a given year it withheld thirty-three tons of CO_2 from the atmosphere. The typical car emits about 5.2 tons of CO_2 per year. Thus, this small business alone offsets the CO_2 emissions of about six cars per year. Numbers such as these will serve urban forest product businesses as important marketing information for buyers interested in purchasing environmentally responsible products.

Architects, commercial developers, and housing developers will be able to calculate the same offsets in much larger amounts. This is a way for them to possibly earn LEED credits and to bring innovative and sustainable materials to the marketplace.

The conservative results of this study assume a sequestration capacity (growth in size) of the urban forest of zero percent, one percent annual tree removal rate, 10 percent (minimum) and 20 percent (maximum) utilization rates of downed trees, and use of commercial standards to define longevity of products. Changing only the longevity assumption (longer life but *staggered by decade)* of urban hardwood products provides an estimate above the 3-4 billion board feet annual range of the two independent studies. Changing other assumptions such as sequestration capacity, removal rate, or utilization rate, provide total and annual board feet values above *realistic* estimates.

The minimum and maximum sequestration estimates of 53 and 105 billion (30-year total) and 1.8 and 3.5 billion board feet (annually) are based on the following important limitations or caveats. Sequestered CO_2e is set at 4.7 pounds per board foot (weighted average of 34 hardwood species), longevity is based on commercially manufactured products, approximately one-third of urban tree biomass is converted to solid-wood products, National Hardwood Lumber Association grading rules are used, and scraps and cut-offs (disposed of as either waste/short-life products or used for future long-life products) are ignored. Individual businesses making specific products from only certain species can tailor the sequestration estimates to their particular situation.

Introduction

There are approximately four billion trees in urban areas (large cities, small towns, villages, etc.) of the United States. This number includes trees growing along streets, in downtown areas, parking lots in shopping malls, yards and parks, and other populated places. The number grows to 74 billion trees if metropolitan areas (as defined by the U.S. Office of Management and Budget) are included (Sherrill, 2002).

As urban land in the U.S. expands, urban forests, as measured by geographic size, expand as well. Urban land in the lower 48 states increased from 2.5% of total land area in 1990 to 3.1% in 2000, an increase in area the size of Vermont and New Hampshire combined (about 19,000 square miles). Researchers from the U.S. Forest Service forecast that urban land in the coterminous U.S. will expand to over 8% of the U.S. land base by 2050. This is an area larger than Montana which at about 147,000 square miles is the nation's fourth largest state (Bratkovich, et al., 2008).

As of 2012, more than 80% of Americans lived in urban areas. According to Bratkovich, et al. (November 12, 2014), for some states this percentage is even higher. For example, just a few years ago, 95% of the respective populations of New Jersey and California were living in urban areas. According to The World Health Organization (WHO), as of 2014, 54% of the world's population lives in urban areas. The United Nations (UN) estimates that 70% of the world's population will live in cities by 2050.

Despite these trends, trees in urban and municipal areas, as measured by community canopy cover, are not expanding at the rate of population growth. Still, urban trees must be removed for many reasons. Sometimes trees are taken down due to storms, development, natural mortality, or pest problems, to name a few. The vast majority of these trees are not made into products like flooring or furniture. Most urban trees end up as firewood, mulch, or are even landfilled. However, on a national basis, the potential for solid wood products made from the urban forest to store carbon for many years is astounding. In our companion study, a conservative estimate of carbon storage from tree removals in urban areas is over 124 million tons of CO_2e in a 30 year period (Sherrill and Bratkovich, July, 2011). This is an impressive possibility for solid wood urban forest products at the national or macro-level. To make carbon storage numbers more meaningful though, a conversion from tons to board feet is needed. Through this conversion, the carbon storage potential of specific common consumer items can be calculated (for example, tables, chairs, etc.). This information can also be used as a selling point from a business perspective and to inform consumer choices.

Background

Solid wood products, fuel, and mulch are the three most common ways downed urban trees are utilized. This report focuses on estimating the amounts of carbon dioxide that could be withheld from the atmosphere based on the amounts of carbon sequestered in solid hardwood products made from urban trees. These products include lumber held in inventory for later use.

Urban hardwood products, such as furniture, flooring, and lumber held in inventory, will sequester carbon that would otherwise be released immediately when the wood is burned as fuel or in a very short time when used as mulch. Unlike fuel and mulch, urban hardwood products are long-term carbon sinks. As such, they can contribute to the mediation of rising levels of atmospheric CO_2, a major greenhouse gas that drives climate change and global warming.

In this report, CO_2e represents the *equivalent* amounts of CO_2 (carbon dioxide) that otherwise would be formed when carbon is released into the atmosphere by burning urban wood or using it as mulch.[2] When one pound of carbon bonds with oxygen, 3.67 pounds of CO_2 are formed; thus, sequestering one pound of carbon in an urban forest product will prevent the formation of the equivalent of 3.67 pounds of CO_2, represented by CO_2e. Estimates of the amounts of CO_2e measured in pounds per board foot are provided for commonly named North American hardwood species found in urban areas (Table 1). For example, one board foot of green ash made into a long-lived product will sequester 1.4 pounds of carbon and thereby prevent the formation of 5.1 pounds CO_2e.

Board foot estimates by species serve two important purposes: first, urban forest product businesses can calculate CO2e for each of their products by the board feet of each species they use. This information can be featured in product marketing. For the large and growing number of consumers interested in environmentally friendly products, knowing the amount of CO_2e will be an important product attribute.

> *For example, a small business that annually utilizes ten thousand board feet of eastern urban hardwoods (such as oak, ash, cherry, and walnut) to make products and holds another five thousand board feet of these species as lumber in inventory can claim a total CO_2e weight of sixty-five thousand pounds or almost thirty-three tons of CO_2e. That is, in finished products and lumber inventory this business can claim that in a given year they withheld thirty-three tons of CO_2 from the atmosphere. The typical car emits about 5.2 tons of CO_2 per year. Thus, a business this size offsets the emissions of about six cars in the given year. Even with no change in its lumber inventory from the previous year, this business can still claim that in the subsequent year another ten thousand board feet of new products would offset the emissions of over three cars.*

[2] CO_2 represents existing carbon dioxide already in the atmosphere. Both are measured in pounds and short tons.

Table 1
Amounts of CO_2e Measured in Pounds per Board Foot
For Common Urban Hardwood Trees*

Species by Common Name	*CO_2e Measured in Pounds per Board Foot*
Alder	3.6087
Ash, White	5.2969
Ash, Black	4.3831
Ash, Green	5.0956
Aspen, Quaking	3.3609
Balsam*	3.4074
Basswood	3.3609
Beech	5.8081
Birch, Paper	4.8943
Birch, Yellow	5.6841
Cherry, Black	4.5380
Chestnut*	3.8720
Cottonwood, Black	3.0976
Cypress, Southern*	4.1818
Elm, Rock	5.6841
Elm, American	4.5225
Gum, Black*	4.5225
Hackberry	4.7703
Hickory	6.5825
Hickory, Pecan	6.0714
Locust, Black*	6.3501
Magnolia, Southern	4.5225
Maple, Sugar	5.6841
Maple Red*	4.9562
Maple, Silver	3.4848
Oak, Red	5.6841
Oak, White	6.0714
Sweet gum	4.3831
Tupelo, Black	4.5225
Tupelo, Water	4.5225
Poplar, Yellow (tulip)	3.6397
Sycamore	4.3831
Walnut, Black	4.9097
Mean	4.7139
Standard Deviation	0.9362

Sources: Karl E. Wenger (ed.), *Forestry Handbook*, 2nd edition, 1984,
John Wiley & Sons, Inc., Table 4, pg. 23.
*http://www.globalwood.org/tech/tech_wood_weights.htm
*See Appendix A for calculations by species.

Second, in the Sherrill and Bratkovich report (July, 2011), an Excel model is used to generate nationwide estimates of CO_2e in tons over a three decade period. The model is constructed on conservative assumptions about the capacity of the nation's urban forests to sequester carbon, the potential carbon sequestered in urban forest products, and on conservative estimates of product longevity measured in years. Based on low values for these assumptions, CO_2e equals 124 million tons. This amount is used in both reports as a baseline estimate.

Though an impressively large number, nationwide tonnage estimates are not very useful to individual urban forest product businesses, local parks departments, or to community urban forestry organizations. Pounds of CO_2e by board foot are directly useful both for marketing and policy purposes.

For this study, the Excel model has been modified to calculate the CO_2e per board foot by species. The model still generates nationwide estimates of CO_2e. Now, it also generates, in board feet, the amount of urban wood products required by each specific CO_2e estimate. For example, 53 billion board feet used to make these products will sequester enough carbon to prevent the formation of at least 124 million tons of CO_2e over thirty years. This averages out to about 1.8 billion board feet per year. At a utilization rate of three to four billion board feet per year, the totals for thirty years are 90 to 120 billion board feet, respectively. These two ranges, annual and total, are designated in this report as the most realistic amounts of urban hardwoods that at present can be utilized in the production of solid hardwood products.

Different sets of assumptions about the capacity of urban forests to sequester carbon, the potential carbon captured in urban forest products, and estimates of product longevity were used in the Excel model to calculate annual and total board foot estimates required to prevent the formation of specific amounts of CO_2e. Only two of the selected sets yielded totals within the annual three to four billion board foot and total 90 to120 billion board foot ranges.

These two sets of assumptions are both based on no increase in urban forest sequestration capacity and on the conservative estimates of product longevity. Two minimal percentages for annual potential product carbon sequestration yielded annual and total amounts that fell within the lower limits from two independent studies by Bratkovich (2001) and MacFarlane (2009). The first is the baseline estimate: 124 million tons of CO_2e requires a total of about 53 billion board feet that annually averages 1.8 billion board feet. The second assumed a relatively small increase in potential product sequestration. The result is a total of 105 billion board feet that averages about 3.5 billion board feet each year. Given the available data, we believe the two estimates are conservative as well.

More accurate data might yield higher annual and total board foot results. For example, based on anecdotal information, we suspect that urban hardwood products are longer-lived than the commercial wood product estimates used here. Also, the three to four billion board feet per year estimates by Bratkovich (2001) and McFarlane (2009) refer only to dimensional lumber that meets National Hardwood Lumber Association (NHLA) standards. This excludes a substantial amount of urban wood used to make products that do not meet these strict standards.

A major goal for future research is a census of urban forest product businesses across the nation. This will provide more accurate primary data on, for example, industry growth, product longevity, and the approximate proportion of urban trees used to make products that do not meet NHLA standards.

Companion Study

This report is the logical follow-up to the two published in 2011.[1] To get a complete overview of carbon sequestration in urban forest hardwood products all three can be read as one report in three parts.

The 2011 reports examine the potential carbon sequestration and CO_2 formation for three urban wood products: landscape mulch, biomass fuel, and solid wood products such as furniture and flooring. [3]

The major finding in that report is that urban trees used to make solid hardwood products are long-term repositories of carbon, referred to as a carbon sink. The same trees used as fuel or ground into mulch are not. Estimates are provided of the net cumulative amounts of CO_2 withheld from the atmosphere, represented by CO_2e, for urban hardwood products.

In forestry research on climate change, the letter "e" in CO_2e refers to the equivalent amounts of CO_2 that would have been formed in the atmosphere but is not when carbon from trees remains sequestered in wood products instead. [4]

The potential of wood products to sequester carbon and thereby reduce CO_2 formation is not a new idea.[5] Research on this topic has focused on commercially harvested trees used to make products such as framing lumber and other wood products used in construction and commercially manufactured furniture.

What *is* new in both this and the 2011 reports is that for the first time the focus of CO_2e estimates is on hardwood products made specifically from *urban* trees. These two reports support the growing body of evidence that the nation's emerging urban forest products industry can provide meaningful benefits from both economic and environmental perspectives.

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[3] In addition to being made into these three products, downed urban trees can be and often are landfilled, buried on-site, or left above-ground to decompose where they fell. Leaving them above ground in specific places, such as commercial and residential lots, does not seem likely. Viewed as unsightly waste, the vast majority would be disposed of elsewhere by landowners. Urban trees left to decay above ground will release carbon which forms CO_2. This will happen at a slower pace than when used as fuel or mulch but faster than when the same wood is used to make solid wood products. Burying the trees on-site, a disposal method often used in land-clearing by developers, could also create a very long-term carbon sink (see Zeng, Ning. January 3, 2008. *Carbon Sequestration via wood burial*. Springer Open, https://cbmjournal.springeropen.com/articles/10.1186/1750-0680-3-1). Under the right conditions this is also true of trees disposed of in urban landfills. While these CO_2 related disposal methods warrant mention in this report they are outside the scope of our studies.

[4] By contrast, in climatology and other climate-related fields, both the word and letter refer to greenhouse gas equivalents to CO_2. For example, one ton of methane (CH_4), a very potent greenhouse gas, is equivalent to about 25 tons of CO_2. Greenhouse gas measures are most often expressed in terms of CO_2 equivalent amounts.

[5] Among many reports and publications, see Tonn, Bruce, and Gregg Marland. (2007). *Carbon Sequestration in Wood Products: A Method for Attribution to Multiple Parties*. Environmental Science and Policy 10 (2007). rethink Wood (sponsor). April, 2015. *Evaluating the Carbon Footprint of Wood Buildings*. http://www.awc.org/pdf/education/gb/ReThinkMag-GB500A-EvaluatingCarbonFootprint-1511.pdf. Bowyer, Jim. 2012. *Carbon Implications of Construction Materials Selection*. http://www.woodworks.org/wp-content/uploads/Bowyer-Carbon.pdf. Dovetail Partners, Inc., Minneapolis, MN.

The Excel model created for the 2011 project generates net cumulative CO_2e estimates for urban forest hardwood products over a thirty-year period. The estimates are based on assumptions about the growth in the capacity of the nation's urban forests to sequester carbon[6] and on the potential carbon captured in urban forest products. The baseline estimates in both reports are conservative.

For several specific comparisons, the baseline estimate in the 2011 project rests on two assumptions: first, a zero percent growth rate in the total size of the nation's urban forests that serves as a measure of their carbon sequestration capacity; and, second, an annual one percent removal rate of trees from the urban forests, ten percent of which could be then used to make urban hardwood products. In other words, one-tenth of the one percent of annual tree removals from urban forests could become carbon sequestering products.

Based on the above assumptions, we estimated CO_2e at 124 million tons in the 2011 project over three decades. Slightly more generous assumptions about urban forest growth and utilization percentages yielded much higher CO_2e estimates (see Sherrill and Bratkovich, July, 2011, report for detailed results).

With the perspective of hindsight, two limitations of the 2011 project are apparent. The first is that CO_2e estimates in millions and billions of tons are too large and far removed from local urban tree policies and urban forest product businesses. Consequently, these estimates are of limited use to local policy-makers and the marketing efforts of individual urban forest product businesses. That 124 million tons of CO_2e can be withheld from the atmosphere over three decades is an impressive and important number. But from a local perspective, the question is, so what? The second limitation is that CO_2e estimates are not provided by a measure useful to individual businesses. Board feet (not tons) are the common industry metric when manufacturing, buying, or selling logs and intermediate products such as lumber.

The 2011 reports represent a nationwide perspective. However, much of the current report focuses on carbon sequestration estimates at the local level. This current report should be of much greater value to local urban forest and waste management personnel, individual wood product businesses (manufacturers and sellers), and buyers of these products.

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[6] Over time carbon sequestration capacity can vary as a function of urban forest size as measured by the number of trees for a given area based on net tree replacement, by changes in the mix of species that sequester differing amounts of carbon, or by the weighted average age of the trees that comprise the forest, or some combination of any two or more of these. For a discussion of factors that affect the spatial variability of urban forests, see Dwyer, John F. *et al.* 2000. *Connecting People with Ecosystems in the 21st Century: An Assessment of Our Nation's Urban Forests*. USDA Forest Service. General Technical Report, PNW-GTR-490, chapter 3. In addition, urban forests can grow by annexing rural forestland at the periphery of expanding urban areas. Nowak, David J. and Walton, Jeffrey T. (2005) estimate that by 2050 urban forests will have taken over about 45 thousand square miles of rural forests, an area they point out that is about the size of the State of Pennsylvania. How capacity varies is a very important issue, especially for estimates that stretch decades into the future where the number of trees, urban forest acreage, species mix, and average age can vary significantly. The Forest Service has begun working with urban governments to apply FIA (Forest Inventory Analysis) tree census methods to urban forests using their i-Tree software. While twenty-five cities are currently participating, over 100 are expected to eventually join the effort to eventually conduct an urban forest census. See, USDA Forest Service. November, 2016. *Urban FIA: Urban Forest Inventory & Analysis*. https://www.fs.fed.us/research/docs/urban/urban-fia-briefing-paper-2016.

Thinking Globally, Acting Locally

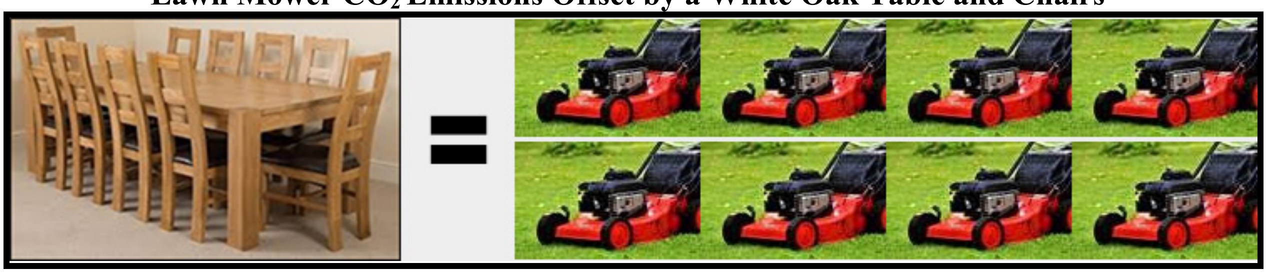
At the national level, the 2011 Excel model has been modified to provide estimates of the board foot content of urban forest hardwood products required to sequester the CO_2e tonnage estimates.

The concept of a board foot is very familiar to those who work with wood in all its unfinished forms since it is almost always priced by this measure.[7] Even for those not familiar with this measure, knowing that one board foot is 144 cubic inches (or twelve inches by twelve inches by one inch) is easy to grasp.

As shown in Table 1, CO_2e can be measured in pounds per board foot for common tree species.[8] The CO_2e weights are equivalent to the weights by species of CO_2 that would have formed in the atmosphere if the carbon in the wood had been released (for example, when burned as fuel or used as mulch) instead of being sequestered in wood products. The CO_2e weights information allows urban forest product businesses to easily compute CO_2e for each of their products.[9] For example, the table and ten chairs shown in Figure 1 contain about 120 board feet of white oak. As given in Table 1, the CO_2e per board foot for white oak weighs slightly more than six pounds. Therefore, 120 board feet have a corresponding CO_2e weight of about 730 pounds; that is, the table and chairs will withhold 730 pounds of potential CO_2 from the atmosphere as long as they exist.

Figure 1

Lawn Mower CO_2 Emissions Offset by a White Oak Table and Chairs



According to the Environmental Protection Agency, 88 pounds of CO_2 are emitted annually by a typical four-stroke gas-powered lawn mower (see Appendix D for more on mower emissions estimates). The oak table and chairs will offset potential CO_2 emissions from one mower over eight years (730 pounds CO_2e ÷ 88 pounds CO_2e per year = 8.3 years).

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[7] Some wood products are priced only by their length in lineal feet where width and thickness are presumed: a common example is wood flooring which is typically sold in a standardized finished thickness of ¾ inch and width of 2 ¼ inches. Buying thicker flooring will cost more per lineal foot which implicitly means all wood is sold by the board foot.

[8] In linking CO_2e weight to board feet, it is helpful to remember that gases have mass and therefore weight. The air we breathe is a combination of about 78 percent nitrogen, 21 percent oxygen, 0.93 percent argon, and 0.04 percent carbon dioxide. At sea level a static column of air one inch square that reaches the top of the earth's atmosphere weighs about 14.7 pounds (known commonly as atmospheric pressure).

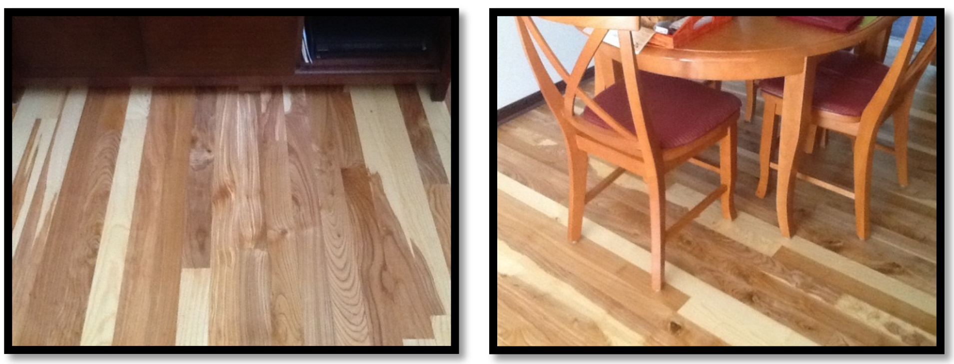
[9] Many lists of weights by species that differ from those in Table 1 can be quickly found on the Internet. We chose these particular weights from the widely accepted *Forestry Handbook*, 2nd edition, supplemented by a few additional species from http://www.globalwood.org.

Or, as illustrated in Figure 1, the table and chairs offset as much CO_2 as would be emitted by eight mowers in one year (or one mower for eight years).

Another example is flooring shown in Figure 2. One of the authors (Bratkovich) recently installed a green ash floor with boards which are three-quarters of an inch thick by three inches wide.[10]

About 140 square feet (a 10 by 14 foot area) of wood flooring would adequately accommodate the white oak table and chairs. Covering an area this size requires 105 board feet (140 x ¾). From Table 1, green ash has a CO_2e weight of 5.0956 pounds per board foot. Therefore, the 10 by 14 square foot green ash floor has a CO_2e weight of 535 pounds (140 x 3/4 x 5.0956).

Figure 2
Green Ash Flooring in St. Paul, Minnesota



Combined with the white oak table and chairs, the total CO_2e weight is 1,265 pounds. This combination equals the CO_2 emissions of fourteen mowers for one year (or one mower for fourteen years).

Similar to the table and flooring examples, urban forest product businesses can use the data in Table 1 to calculate and advertise CO_2e amounts for their own specific products. Buyers will know that the urban wood product they are purchasing in some small way contributes to the reduction of a major greenhouse gas. In addition, they will also be made aware that they are purchasing products that utilize urban wood at its highest economic value.

Urban forest product businesses can easily calculate the annual CO_2e weights of all of their products since the pricing of each one is in part based on estimates by species of the board feet used in their yearly output. For example, assume the urban forest products business that produced the table, chairs, and flooring annually utilized ten thousand board feet of hardwoods (such as oak, ash, cherry, and walnut) to make products and held another five thousand board feet of these species as lumber in inventory.

[10] The ash trees used to make the floor were removed before they were infested with emerald ash borer (EAB) (e.g., pre-emptive removal). The goal was to reduce canopy cover of green ash and reduce the future EAB impact. The trees were removed from a golf course and could have been burned as fuel or ground for mulch.

Thus, this small business can claim a total CO_2e weight of sixty-five thousand pounds or almost thirty-three tons of CO_2e. That is, in finished products and lumber inventory this business can claim that in a given year it withheld thirty-three tons of potential CO_2 from the atmosphere. The typical car emits about 5.2 tons of CO_2 per year.[11] Thus, this small business alone offsets the CO_2 emissions of about five cars in the given year. Even with no change in its lumber inventory from the previous year, this business can still claim that in the subsequent year another ten thousand board feet of new products would offset the emissions of over three cars. Numbers such as these will serve urban forest product businesses as important marketing information for buyers interested in purchasing environmentally responsible products.

Architects, commercial developers, and housing developers will be able to calculate the same offsets in much larger amounts. This is a way for them to possibly earn LEED credits[12] and to bring innovative and sustainable materials to the marketplace.

Urban Forest Product Residues and CO_2 Emissions

The three basic stages of the production of urban forest products are: felling and bucking trees, sawing and drying the lumber and slabs, and making retail products for sale. Residues are by-products of all stages.

Felling and Bucking

As discussed in the Sherrill and Bratkovich report (July, 2011, pgs. 11 – 12), urban forests are not deliberately logged like commercial timberlands. Hence, there are no additional CO_2 emissions from felling and bucking urban trees attributable to the use of the wood to make products. Similarly, residue amounts (principally saw dust, bark, and limbs) generated are no greater because the wood is being used to make products instead of being treated as green waste, fed into a grinder, or left for property owners to use as fuel. In short, the marginal amount of carbon released by the residue specifically attributable to the production of urban forest products is zero.

Sawing and Drying

In the nineteenth century, large steam powered sawmills used cutoffs and sawdust to make hog fuel that served as fuel for the mills' steam boilers. The boilers powered the steam engines that ran the saws and kilns. The excess over the amounts used as fuel was burned in what was then called teepees or conical burners, releasing enormous amounts of carbon into the atmosphere.

[11] Environmental Protection Agency. *Greenhouse Gas Emissions from a Typical Passenger Vehicle*. https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle

[12] LEED (version four) credits may be available under *Building product disclosure and optimization - sourcing of raw materials; option 2, leadership extraction practice: Materials reuse*. See https://www.usgbc.org/node/2616388?return=/credits.

Today, markets have arisen for residues such as cutoffs and sawdust to make products such as fuel pellets, pulp, panels, and animal bedding. By one estimate, about 15 percent of mill revenues come from the sale of residues.[13]

Currently, we know sawing urban trees into logs and then lumber produces sawdust, bark, and cutoffs. We have only anecdotal information on how these residues are disposed of by urban forest product businesses. While some sawdust is used as bedding, most (including the bedding) have about the same short carbon sequestration life as mulch. Like their large counterparts, small urban saw mills may be able to sell the residues for the same kinds of products. Future research should address the CO_2 residue emissions which should be subtracted from product CO_2e estimates.

Drying wood in kilns that use electricity generated by fossil-fueled power plants indirectly creates additional CO_2. Estimates of these emissions are built into the 2011 Excel model.[14]

Production of Urban Wood Products

Urban forest product businesses use more wood than what ultimately ends up in their final products. To follow on the white oak table example, about 140 board feet would be needed to make the finished table. Probably about 20 board feet ended up on the shop floor as scraps and cutoffs. Sawdust is also a by-product from sawing and planing.

These residues are disposed of in various ways. When used as fuel or mulch, released carbon becomes CO_2 that should also be subtracted from CO_2e values for the final products.

Based on anecdotal conversations with urban forest products businesses of various sizes, at present the emerging urban forest products industry does not seem to be facing a major production residue disposal problem. In the twenty-year experience of one author and woodworker (Sherrill), more than 90 percent of all scraps and cutoffs were held in inventory for future use and thereby continued to sequester carbon. Some scraps were sold to other woodworkers. Less than five percent was used as fuel. A small percentage was given to livestock owners while the rest was spread out with leaf debris on the property (for example, as mulch).

Urban wood products typically use more of each tree than their commercial counterparts making standardized products (as an example, see Figure 3 below).

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13 Lutz, Jack. July 13, 2017. *Sawmills: Chopping Down Waste*. Waste Management World. https://waste-management-world.com/a/sawmills-chopping-down-waste

14 For small businesses another option is solar powered kilns that have no carbon footprint. One of the more popular plans for building a small solar kiln is in Popular Woodworking Magazine: Munkittrick, Dave. September 29, 2009. *Dry Your Own Wood Fast and Hassle-Free*. https://www.popularwoodworking.com/projects/solar-kiln. Also see Bond, Brian. 2014. *Design and Operation of a Solar-Heated Dry Kiln*. Publication 420-030. Virginia Cooperative Extension, Virginia Tech and Virginia State University. Available at: https://pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/420/420-030/420-030_pdf.pdf

In the commercial lumber industry, approximately half of a merchantable log becomes dimensional, grade-stamped lumber.[15] The other half is eliminated because of the strict grading standards set by the National Hardwood Lumber Association and utilized in various other products and/or resold into other markets for further uses (see pgs. 6 through 11 in the Sherrill and Bratkovich, July, 2011 report for a broader discussion).

Figure 3
Wood Sculpting Using Discarded Tree Trunks

Photo Caption: Sculptor Emilie Brzensinski, age 85, utilizes discarded tree trunks as material for her wood sculptures shaping them with chain saws. Her favorite, entitled *Apollo and Daphne*, is made of two trunks over nine feet tall and three feet wide whose form retells the Greek story of tree nymphs. *Power Sculpture: Sculptor Emilie Brzezinski seeks out fallen tree trunks and turns them into art*. AARP Magazine, June/July Magazine. Pg. 60.

Anecdotal experiences reported by current urban forest product business owners suggest that two-thirds to three-fourths of the entire tree is used or is potentially usable. Urban forest sawmill operators, urban forest product businesses, and wood artisans are not bound by the NHLA grading standards and are thereby free to make creative uses of wood that would otherwise be rejected.[16] This suggests that even as the urban forest products industry grows, waste will be proportionally less of an issue than it is for the commercial wood products industry.

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[15] For further discussion, see *North American Forest Products Industry Wood Utilization*. 2012. Dovetail Partners. Available at: http://www.dovetailinc.org/report_pdfs/2012/dovetailwoodutilization1012.pdf

[16] For one-hundred imaginative examples of how urban wood can be used to make furniture and other wood products see https://www.youtube.com/watch?v=RbA1beXE7r0. Almost none of the pieces featured in this video are made from wood that as lumber would meet even the minimum NHLA grading standards. Note, too, how many pieces are pallets.

In this report, we do not modify CO^2e estimates attributable to the residue-generated CO_2 from the production of urban forest products. Nevertheless, given the history of both the commercial sawmill and wood products industries, the emissions impact of urban wood product residues cannot be completely dismissed and should be addressed in future research.

Results: Wood Content (in board feet) of Urban Forest Products and Related CO_2e Estimates

The key to understanding the results given below is to keep the following six points in mind:

1. in this report forty-eight percent of urban hardwood trees are comprised, by weight, of carbon;
2. the carbon remains captured or sequestered in trees as long as they live;
3. the carbon in downed trees can be transferred to urban hardwood products where it remains sequestered as long as the products exist;
4. by contrast, when used as fuel or mulch, that same carbon is instead released into the atmosphere where it bonds with two oxygen molecules to form CO_2;
5. when 1 pound of this carbon bonds with oxygen, 3.67 pounds of CO_2 are formed; thus,
6. sequestering 1 pound of carbon in an urban forest product will prevent the formation of the equivalent of 3.67 pounds of CO_2, represented by CO_2e.

The Excel model created for the 2011 report has been modified to generate estimates of the wood content, measured in board feet, of urban forest products (including lumber inventories) required to prevent the formation of specific amounts of CO_2, measured in tons, as represented by CO_2e. As noted in the Background section, for the three decade period used in the original model, about 53 billion board feet used to make urban hardwood products will sequester enough carbon to prevent the formation of 124 million tons of CO_2e. This is the baseline amount to which other estimates are compared.

Four significant points need to be made about the current model:

1. Carbon Sequestration by Region and Product In-Use Estimates

First, estimates by Smith et al. (2005) are used by the proportions of carbon sequestered in hardwood products in-use for six regions of the country for thirty years (see Appendix B). Multiplying these proportions for each year times the potential carbon sequestered for that year yields the gross annual carbon sequestration in urban forest products by region. (Because of the frequent references throughout this report to the Smith report, from now on it will be referred to simply as “Smith estimates” or the “Smith in-use estimates”).

For example, in the North East (first column in Appendix B) 61 percent (0.614) of the products put in use the first year lasted through the end of that year. However, by the end of the second year, the percentage for the first-year products had dropped to 57 percent (0.572). However, 61 percent of new products put in use the second year are added to the amount still in use from the first year. This procedure of adding new product sequestration for each year to the reduced amounts from previous years is done for thirty years.

The results for the six regions are summed to arrive at an estimate of CO_2e for the U.S. The same calculations are performed on all in-use percentages entered in the model.

From testimonials by the urban forest product business owners and the *Youtube* video referenced above, many urban forest products will likely remain in use longer, perhaps far longer, than those based on the Smith in-use estimates. Many of these products take on the status of art work and heirlooms to be passed down for generations. Other products such as pallets made from urban wood have much shorter useful lives (typically three to five years). The blend of products by longevity is important to CO_2e estimates. We need to know more about this to make more accurate estimates.[17]

Unfortunately, no specific product distribution percentages can be inferred from these testimonials that urban forest products are longer-lived than their commercial counterparts. Also, a search uncovered no data sources from which such percentages could be directly or even indirectly derived.

Even so, we did test two alternatives to the Smith in-use estimates starting with a ninety percent/eighty percent/seventy percentage combination: ninety percent for the first decade, eighty percent for the second and seventy percent for the third and final decade. The drop of ten percentage points each decade reflects an assumption that some products are less durable (shipping pallets, for example) and that even long-lived custom and heirloom pieces are lost.

We also tried proportions that dropped one percentage point each year for the thirty year period starting at one-hundred percent in year one. While the results were lower than the ninety/eighty/seventy percent combination they still were much larger than those from the Smith in-use estimates.

2. Measurements of Pounds per Board Foot of CO_2e

The second point is the addition of CO_2e measured in pounds per board foot. This allows estimates to be made of board feet in urban products needed to sequester enough carbon for various nationwide CO_2e estimates. The amount used is 4.7139 pounds of CO_2e per board foot. This is based on the equally weighted mean of the thirty-four species from Table 1. However, different urban forest product businesses in different regions of the U.S. almost certainly do not use all of these species in equal proportions. For example, the urban hardwood mix in the north central and north eastern regions (where the prevailing species are oak, ash, walnut, maple, and poplar) will differ significantly from other regions such as the far west (which includes urban softwoods which are not covered in either of our two projects).

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[17] The proportional distribution of hardwood lumber among six domestic end-uses calculated by Smith (Table D2, page 209) is built into the in-use estimates cited above (see Appendix B). As given in Appendix C, among the six end-use categories, furniture and shipping storage units (pallets, containers, and dunnage) are about equal and together consume about three-fourths of all commercial hardwood production. Based on the slim anecdotal evidence, we believe that at present for urban wood the furniture percentage is higher, perhaps much higher, than the shipping percentage.

We have no data on the percentages by species removed from urban forests to use even as proxy weights much less data on actual use by species. Absent any source of information on weighting, our default assumption is to weigh each species equally. One of the priority subjects for future urban forest product research should focus on this weighting issue.

3. Carbon Content of Trees

Third, in the original model, we used fifty percent as the carbon content of trees. In the modified version used in this report, this is reduced to forty-eight percent based on estimates for hardwoods by Lamiom and Savidge, (2003).[18]

4. Total Above-Ground Biomass Estimates

Finally, in the modified model we used 0.74 as the proportion of the total above-ground mass of urban trees available for making products.[19] On average just over one-third (0.74 x 0.48 = 0.36) of the total biomass of urban trees will become carbon sequestering products. Even ignoring residue emissions, this is a conservative estimate since, as noted above, urban forest businesses, wood workers, and wood artisans use at least as much as fifty percent (versus thirty-six percent) of the total tree including its below-ground mass. Nevertheless, as stated at the beginning of this report, our goal in these reports is to err on the side of underestimation.

Board Feet of Wood in Urban Forest Products and Related CO_2e

Using two different methods seven years apart, both Bratkovich (2001) and MacFarlane (2009) estimated the annual amount of potentially usable wood from downed urban trees at between three and four billion board feet. The respective totals over thirty years are 90 billion and 120 billion board feet. In this report, these annual and total amounts, respectively, are treated as the most realistic range of urban wood that can be used to make hardwood products. The annual three to four billion foot range reflects the limiting amounts available from urban hardwood trees that come down owing to natural causes (for example, old-age, fatal infestations, and storms) and human actions (which includes, land clearing for residential and commercial developments) and not from deliberate logging of urban forests for lumber.

[18] Lamiom, S.H. and Savidge, R. A. *A Reassessment of Carbon Content in Wood: Variation Within and Between 41 North American Species*. Biomass and Bioenergy, No. 25. Oct. 2003, p. 183.

[19] Above ground mass was inferred from two sources: Nowak and Crane, 2002. *Carbon Storage and Sequestration by Urban Trees in the* USA. Environmental Pollution 116, (202) 381-389. Heath, Linda S., et al. 2009. *Investigation into calculating tree biomass and carbon in the FIADB using a biomass expansion factor approach*. In: McWilliams, Will; Moisen, Gretchen; Czaplewski, Ray, comps. Forest Inventory and Analysis (FIA) Symposium 2008; October 21-23, 2008; Park City, UT. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Tables 2 through 5 below give the results of calculations based on variations in the following:

1. the sequestration capacity of the nation's urban forest starting at a capacity of 774.1 billion tons[20] (column A);
2. the wood utilization rate which is the percentage of urban wood utilized as a percentage of removals from the urban forest owing to natural and human causes (column B); and,
3. Smith's in-use estimates (column C) versus estimates based on the ninety/eighty/seventy percentages (column E in Tables 2 and 4) and the one percentage point drop per year alternative (column E in Tables 3 and 5).

The related board foot estimates for each of the variations in sequestration capacity, utilization rates, and in in-use percentages are given in columns D and F. In all four tables, the baseline estimates (in bold) are in the first row of estimates in columns C (124.2 million tons of CO_2e) and D (a total of 52.7 billion board feet and average annual amount of 1.8 billion board feet).

As shown in Tables 2 and 3, changes in the carbon sequestration capacity of the nation's urban forest range from 0.0 percent to 3.0% per year for thirty years (column A). Wood utilization (column B) is fixed at 0.1 percent.

In Table 2, based on the Smith in-use estimates (column C), a zero percent change in carbon sequestration capacity (starting at 774.1 billion tons of carbon), and a 0.1 percent utilization rate, CO_2e equals 124.2 million tons of CO_2 that would have formed over thirty years but did not. For the thirty year period, this amount of CO_2e requires carbon sequestration in a total of 52.7 billion board feet of urban hardwood products, averaging about 1.8 billion board feet per year. These two amounts are well below the Bratkovich-MacFarlane lower total limits of 90 billion board feet and the average annual amount of three billion board feet.

By comparison to the Smith estimates, for the ninety/eighty/seventy percentages per decade alternative (column E), CO_2e equals 334.2 million tons that requires a total of 141.8 billion board feet for thirty years for an annual average of 4.7 billion board feet. For all column E estimates, the Bratkovich-MacFarlane benchmarks are exceeded (their upper limit of 120 billion board feet over 30 years as well as the average of four billion board feet per year).

A three percent increase per year in capacity would require about 6.5 (Table 2, column F) billion board feet per year, far above the maximum of four billion board feet. The shortcoming of these estimates is that the nation's urban forests are very unlikely to grow in size and sequestration capacity at three percent per year. Even two and one percent seem unlikely. Compounding urban forest growth at just one percent per year for thirty years means that its size will increase by about one-third from the current 141 million acres to about 190 million acres.[21] At two percent, in thirty years the urban forest will reach 255 million acres. At three percent annual growth, the urban forest would reach 342 million acres.

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[20] Nowak, David and Crane, Daniel E. 2002. *Carbon Storage and Sequestration by Urban Trees in the USA*. Environmental Pollution 116, 3, (March, 2002), 381-389.

[21] Leahy, Ian. March 2, 2017. *In Search of 141 Million Acres of Urban Forest*. Loose Leaf (the official blog of American forests). http://www.americanforests.org/blog/search-141-million-acres-urban-forest/.

None of these estimates seem realistic since the nation's urban forests are currently losing about four million trees per year (about 0.27 percent per year) which most likely means carbon sequestration capacity is not increasing and could actually be decreasing.[22]

The results in Tables 4 and 5 are based on a zero growth rate in the carbon sequestration capacity of the urban forest and increases in the urban wood utilization rate (column B in both tables) in increments of 0.05% starting at 0.10%. Increases in this rate indirectly reflect a growing urban forest products industry that from year to year over thirty years is utilizing progressively more urban hardwood trees to make carbon sequestering products.

For the Smith in-use estimates the results (column C) fall within the Bratkovich-MacFarlane annual and total limits up to 0.25% where the annual and total of CO_2e amounts exceed those limits. As shown in column F, using the ninety/eighty/seventy percentages per decade alternative, the results beginning at 0.15% are substantially above the limits as well.

In Table 5, the results for the one percentage point drop per year (column F) also greatly exceed the limits as do the Smith in-use estimates for 0.25 percent and 0.30 percent. Based on the one point percentage drop, even at the starting utilization rate of 0.10 percent the board feet needed to reach 355 million tons (column E) exceeds the maximum of four billion board feet.

So, what do the results given in Tables 2 and 3 suggest? Given growth in carbon sequestration capacity from zero percent to three percent (with a fixed utilization rate of 0.1 percent and using the conservative Smith in-use percentages) a slow growing urban products industry will not fully utilize what is available within the three to four billion board foot annual limits. But if future research reveals that buyers of urban products are actually holding their products longer, maybe much longer than the Smith estimates, then CO_2e estimates will have to be revised upward. Even a slow growing industry would be closer to a maximum of four billion board feet per year as in-use rates rise. However, as noted above, growth in carbon sequestration capacity, to the extent it is linked directly with the size of the urban forest, is unlikely especially since it is losing about four million trees per year.

The results in Tables 4 and 5 suggest increased utilization rates (from 0.10 percent to 0.30 percent in column B) even for the conservative Smith in-use percentages push urban forest product businesses closer to the maximum of four billion board feet per year. At the utilization rate of 0.25 percent the annual utilization exceeds the maximum of four billion board feet (column D). Overall, growing utilization indirectly reflects a mix of the entry of new businesses into the industry as well as growth in the size and output of existing businesses.

As shown in columns E and F in Tables 4 and 5, both alternative in-use estimates are well past the maximum of four billion board feet per year even at the utilization rate of 0.1 percent. Rates from 0.15 percent to 0.30 percent raise total and annual board foot estimates and the related amounts of CO_2e even higher as well.

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[22] Nowak, David J. and Eric J. Greenfield. 2012. Tree and impervious cover change in U.S. cities. Urban Forestry and Urban Greening, vol. 11, issue 1, pgs. 21 – 30. http://www.sciencedirect.com/science/article/pii/S1618866711000999.

In Table 5, urban forest sequestration capacity (size) is fixed at 0.0 percent per year (column A) while potential sequestration (annual removal multiplied by utilization rate) in urban forest products is increased from 0.1 percent to 0.2 and 0.3 percent (column B). For the Smith in-use estimates at 0.1 through 0.2 percent, both the annual board feet of urban wood required to sequester CO_2e annually and in total are within the three to four billion board foot range and the maximum total of 120 billion tons for thirty years (column D). However, at 0.3 percent both the average annual amount of 5.3 billion board feet and the total of 158.1 billion board feet are outside their respective ranges of four and 120 billion board feet.

Of all the alternatives we tried, we consider the results of a zero percent per year urban forest sequestration rate together with product sequestration growth at 0.1 and 0.2 percent to be the most realistic.

These two estimates come with five caveats.

1. Average sequestration by board foot

First, the board foot estimates linked to specific CO_2e estimates in tons are based on an equally weighted average of sequestration by board foot for the 34 species listed in Table 1 (4.7142 pounds per board foot). This assumes each one of the species is used in the same proportion as all the rest in the production of urban forest products. This is a very unlikely coincidence even if all these species are equally distributed throughout the nation's urban forests. A more exact average can only be directly calculated with data from urban forest businesses themselves.

2. Conservative estimates of in-use lives for urban forest products

Second, based largely on anecdotal reports, urban forest products, especially furniture, flooring, and art objects, most likely have longer in-use lives than the corresponding commercially manufactured products used in the Smith estimates. Urban wood products often take on the status of heirlooms that will be passed down through generations. To the extent that this is true, the Smith estimates understate CO_2e sequestration of urban forest products, perhaps by a substantial number of years.

3. Conservative estimate of wood utilization proportion for urban wood products

Third, the Excel model rests on the assumption that half of an urban tree ultimately ends up as a product. This is based on estimates for commercially produced products. This, too, is a likely underestimate since anecdotal evidence suggests that much more of an urban tree is utilized to make products because usable urban wood does not have to meet the strict NHLA standards for fungible lumber often sold in large quantities.

4. Exclusion of non-NHLA wood

Fourth, following from the third caveat, both the Bratkovich (2001) and MacFarlane (2009) estimates are based on lumber meeting NHLA standards. Excluded is urban wood that does not meet this standard but which is used to make products. The three to four billion board foot estimates would be greater if non-NHLA wood is included. How much could be added can only be calculated with data from urban forest product businesses.

5. No consideration of scraps and cutoffs

Finally, we have offered no information on what becomes of scraps and cutoffs from the production of urban forest products. Some could be held indefinitely in inventory for future use while the rest is disposed of as fuel, mulch, and bedding. The latter three uses could in a short time release carbon and contribute to the formation of atmospheric CO_2. Estimates of CO_2e would require the subtraction of the released CO_2 to arrive at more accurate sequestration estimates.[23]

The first four caveats together suggest that sequestration in urban forest products is greater, perhaps much greater, than in their commercial counterparts. From this, we conclude that the estimates given in this report are minimums. We maintain that they are at least what we have presented but are probably more. Absent data from the businesses themselves, we cannot offer precise estimates of how much more.

In a larger sense, the major problem of conducting urban forest products research is the lack of data on the production of urban forest products. Our estimates are derived from the commercial timber and wood manufacturing industries and are not specific to the emerging urban forest products industry. This is a major shortcoming that should be addressed by future research.

[23] The exact impacts would depend upon the specific use as well as any offsetting or substitution impacts (for example, wood fuel as a replacement for fossil fuel use).

Table 2
Smith Wood Products In-Use Estimates Versus 90/80/70 In-Use Estimates for Select Changes in the Carbon Sequestration Capacity of the Urban Forest

A	B	C	D	E	F
Change in Carbon Sequestration Capacity of Urban Forest (Starting at 774.1 billion tons)	Urban Wood Utilization Rate (10% use of 1% Annual Removal)	Net Cumulative CO_2e Based on Carbon Sequestration in Urban Hardwood Products: Using Smith In-Use Estimates and (Carbon Sequestration Capacity After Thirty Years)	Total Amount of Urban Wood Products Measured in Board Feet for Specific CO_2e Estimates and (Average Annual Amounts)	Net Cumulative CO_2e Based on Carbon Sequestration in Urban Hardwood Products: Using 90%/80%/70% Assumption and (Carbon Sequestration Capacity After Thirty Years)	Total Amount of Urban Wood Products Measured in Board Feet for Specific CO_2e Estimates and (Average Annual Amounts)
0.0%	**0.1%**	**124.2 million tons (774.1 billion tons)**	**52.7 billion board feet (1.8 billion board feet)**	**334.2 million tons (774.1 billion tons)**	**141.8 billion board feet (4.7 billion board feet)**
0.5%	0.1%	131.6 million tons (894.6 billion tons)	55.8 billion board feet (1.9 billion board feet)	351.6 million tons (894.6 billion tons)	149.2 billion board feet (5.0 billion board feet)
1.0%	0.1%	139.5 million tons (1,033.1 billion tons)	59.2 billion board feet (2.0 billion board feet)	370.2 million tons (1,033.1 billion tons)	157.1 billion board feet (5.2 billion board feet)
1.5%	0.1%	148.1 million tons (1,192.2 billion tons)	62.8 billion board feet (2.1 billion board feet)	390.2 million tons (1,192.2 billion tons)	165.6 billion board feet (5.5 billion board feet)
2.0%	0.1%	157.4 million tons (1,374.8 billion tons)	66.8 billion board feet (2.2 billion board feet)	411.8 million tons (1,374.8 billion tons)	174.7 billion board feet (5.8 billion board feet)
3.0%	0.1%	178.4 million tons (1,824.3 billion tons)	75.7 billion board feet (2.5 billion board feet)	460.0 million tons (1,824.3 billion tons)	195.2 billion board feet (6.5 billion board feet)

Table 3
Smith Wood Products In-Use Estimates Versus One Percentage Point Drop per Year in In-Use Estimates for Select Changes in the Carbon Sequestration Capacity of the Urban Forest

A	B	C	D	E	F
Change in Carbon Sequestration Capacity of Urban Forest (Starting at 774.1 billion tons)	Urban Wood Utilization Rate (10% use of 1% Annual Removal)	Net Cumulative CO_2e Based on Carbon Sequestration in Urban Hardwood Products: Using Smith In-Use Estimates and (Carbon Sequestration Capacity After Thirty Years)	Total Amount of Urban Wood Products Measured in Board Feet for Specific CO_2e Estimates and (Average Annual Amounts)	Net Cumulative CO_2e Based on Carbon Sequestration in Urban Hardwood Products: Using One Percentage Point Drop/Year Assumption and (Carbon Sequestration Capacity After Thirty Years)	Total Amount of Urban Wood Products Measured in Board Feet for Specific CO_2e Estimates and (Average Annual Amounts)
0.0%	**0.1%**	**124.2 million tons (774.1 billion tons)**	**52.7 billion board feet (1.8 million board feet)**	**355.1 million tons (774.1 billion tons)**	**150.6 billion board feet (5.0 billion board feet)**
0.5%	0.1%	131.6 million tons (894.6 billion tons)	55.8 billion board feet (1.9 billion board feet)	373.5 million tons (894.6 billion tons)	158.5 billion board feet (5.3 billion board feet)
1.0%	0.1%	139.5 million tons (1,033.1 billion tons)	59.2 billion board feet (2.0 billion board feet)	393.4 million tons (1,033.1 billion tons)	166.9 billion board feet (5.6 billion board feet)
1.5%	0.1%	148.1 million tons (1,192.2 billion tons)	62.8 billion board feet (2.1 billion board feet)	414.7 million tons (1,192.2 billion tons)	175.9 billion board feet (5.9 billion board feet)
2.0%	0.1%	157.4 million tons (1,374.8 billion tons)	66.8 billion board feet (2.2 billion board feet)	437.7 million tons (1,374.8 billion tons)	185.7 billion board feet (6.2 billion board feet)
3.0%	0.1%	178.4 million tons (1,824.3 billion tons)	75.7 billion board feet (2.5 billion board feet)	489.1 million tons (1,824.3 billion tons)	207.5 billion board feet (6.9 billion board feet)

Table 4
Smith Wood Products In-Use Estimates Versus 90/80/70 In-Use Estimates
For Select Changes in the Urban Wood Utilization Rates

A	B	C	D	E	F
Change in Carbon Sequestration Capacity of Urban Forest (Starting at 774.1 billion tons)	Urban Wood Utilization Rate (10% use of 1% Annual Removal)	Net Cumulative CO_2e Based on Carbon Sequestration in Urban Hardwood Products: Using Smith In-Use Estimates and (Carbon Sequestration Capacity After 30 Years)	Total Amount of Urban Wood Products Measured in Board Feet for Specific CO_2e Estimates and (Average Annual Amounts)	Net Cumulative CO_2e Based on Carbon Sequestration in Urban Hardwood Products: Using 90%/80%/70% Assumption and (Carbon Sequestration Capacity After Thirty Years)	Total Amount of Urban Wood Products Measured in Board Feet for Specific CO_2e Estimates and (Average Annual Amounts)
0.0%	**0.10%**	**124.2 million tons (774.1 billion tons)**	**52.7 billion board feet (1.8 billion board feet)**	**334.2 million tons (774.1 billion tons)**	**141.8 billion board feet (4.7 billion board feet)**
0.0%	0.15%	186.4 million tons (774.1 billion tons)	79.1 billion board feet (2.6 billion board feet)	501.4 million tons (774.1 billion tons)	212.7 billion board feet (7.1 billion board feet)
0.0%	0.20%	248.5 million tons (774.1 billion tons)	105.4 billion board feet (3.5 billion board feet)	668.5 million tons (774.1 billion tons)	283.6 billion board feet (9.5 billion board feet)
0.0%	0.25%	310.6 million tons (774.1 billion tons)	131.8 billion board feet (4.4 billion board feet)	835.6 million tons (774.1 billion tons)	354.5 billion board feet (11.8 billion board feet)
0.0%	0.30%	372.7 million tons (774.1 billion tons)	158.1 billion board feet (5.3 billion board feet)	1,002.7 million tons (774.1 billion tons)	425.4 billion board feet (14.2 billion board feet)

Table 5
Smith Wood Products In-Use Estimates Versus One Percentage Point Drop per Year in In-Use Estimates For Select Changes in the Urban Wood Utilization Rates

A	B	C	D	E	F
Change in Carbon Sequestration Capacity of Urban Forest (Starting at 774.1 billion tons)	Urban Wood Utilization Rate (10% use of 1% Annual Removal)	Net Cumulative CO_2e Based on Carbon Sequestration in Urban Hardwood Products: Using Smith In-Use Estimates and (Carbon Sequestration Capacity After Thirty Years)	Total Amount of Urban Wood Products Measured in Board Feet for Specific CO_2e Estimates and (Average Annual Amounts)	Net Cumulative CO_2e Based on Carbon Sequestration in Urban Hardwood Products: Using One Percentage Point Drop/Year Assumption and (Carbon Sequestration Capacity After Thirty Years)	Total Amount of Urban Wood Products Measured in Board Feet for Specific CO_2e Estimates and (Average Annual Amounts)
0.0%	**0.10%**	**124.2 million tons (774.1 billion tons)**	**52.7 billion board feet (1.8 billion board feet)**	**355.1 million tons (774.1 billion tons)**	**150.6 billion board feet (5.0 billion board feet)**
0.0%	0.15%	186.4 million tons (774.1 billion tons)	79.1 billion board feet (2.6 billion board feet)	532.6 million tons (774.1 billion tons)	226.0 billion board feet (7.5 billion board feet)
0.0%	0.20%	248.5 million tons (774.1 billion tons)	105.4 billion board feet (3.5 billion board feet)	710.2 million tons (774.1 billion tons)	301.3 billion board feet (10.0 billion board feet)
0.0%	0.25%	310.6 million tons (774.1 billion tons)	131.8 billion board feet (4.4 billion board feet)	887.7 million tons (774.1 billion tons)	376.6 billion board feet (12.6 billion board feet)
0.0%	0.30%	372.7 million tons (774.1 billion tons)	158.1 billion board feet (5.3 billion board feet)	1,065.3 million tons (774.1 billion tons)	451.9 billion board feet (15.1 billion board feet)

Summary

CO_2e Sequestration per Board Foot of Urban Wood

This report provides CO_2e measured in pounds per board foot by major hardwood species found throughout the nation's urban areas. This information will be very useful to urban forest departments, waste management agencies, state departments of natural resources, and local urban forest product businesses. It provides them with a quick and easy way of calculating both the actual and potential amounts of CO_2e that can be contained within urban forest products.

Total CO_2e Sequestration in Board Feet

Estimates of the number of board feet required to sequester CO_2e nationwide for thirty years are based on different assumptions about urban wood product longevity, urban forest carbon sequestration, urban forest product CO_2e sequestration, and urban wood utilization rates.

Limits on the estimates are set at three to four billion board feet of potentially usable urban wood per year and a maximum of 120 billion board feet over thirty years. These limits are based on two different but very close estimates in the three-to-four billion board foot range per year calculated by Bratkovich (2001) and MacFarlane (2009).

The most plausible results that fall within these set limits are based on longevity of wood products estimates by Smith (2005), no urban forest growth, and increases in utilization, therefore, product sequestration of 0.1 and 0.2 percent per year. The Smith in-use estimates are lower than what we expect for urban forest products thus yielding a conservative estimate of sequestration.

Board foot estimates are included in this study. Sequestering the baseline estimate of 124 million tons of CO_2e for three decades requires about 1.8 billion board feet annually and a total of about 53 billion board feet for thirty years. This is based on the assumptions that there are no changes in the sequestration capacity of the nation's urban forests, Smith's in-use estimates (Appendix B), and 0.1% potential annual urban product sequestration rate.

These two estimates (for one and thirty years) are well within the independent-research estimates of three to four billion board feet annually and 90 to 120 billion board feet, respectively, for thirty years.

By far, the single greatest impediment to research on urban forest products is the lack of data on the emerging industry itself. Our estimates are derived from the commercial timber and wood manufacturing industries and are not specific to the urban forest products industry. This should be considered the highest priority for future research.

Additional Observations

> *You've got to think about big things while you're doing small things, so that all the small things go in the right direction.*
>
> Alvin Toffler

The urban forest products industry is still moving through its formative stage. Over the past decade, it has become more organized on a local and regional basis and the number of businesses is growing and few are failing, so far as we know. Also, it is increasingly establishing an identity separate from the traditional forestry products industry.

Progress continues but has not yet become national in scope. Most likely it will organize nationally from the bottom up; that is, a national organization will be arise from local, state, and regional organizations and businesses as they see it in their self-interest to coalesce around a clear national identity that requires a formal national organization. As this time (2017), a formal non-profit organization of urban forest businesses has been created in California and a latent national organization exists, the Urban Forest Products Alliance, that can be activated as more local and regional efforts replicate what California is doing.

Lacking a separate identity and a formal nationwide organization, there is no way to collect fundamental data on even the number of urban forest product businesses currently in operation.

Hence, the most important research step recommended in this report is a rolling census of the industry. It is rolling in the sense that a roster of all known businesses should be assembled and used along with federal, state, and local sources to find as yet unidentified businesses. This will enable researchers to conduct surveys to collect basic business data and more accurately establish what products are being produced, what species are being used in different regions, how vertically integrated the existing businesses are (from felling to final product production), amounts of residues and related CO_2 generated, business problems, marketing challenges, and other issues that affect the growth and development of the urban forest products industry.

Like the hardwood sawmill industry in the eastern U.S., most urban forest product businesses are likely to remain relatively small operations.[24] Businesses will grow larger as they expand to meet increasing levels of demand for their products and by the vertical integration of felling, sawing, drying, and selling final branded urban forest products. Perhaps eventually, like most of the rest of American industries, some individual businesses will grow by acquisitions though, at present, this seems many years away.

The industry will grow as the levels of demand for urban forest products rises. Now the prevailing view is that downed urban trees are still fundamentally green waste and currently have no positive market value.

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[24] Leonard Guss Associates, Inc. (July, 2007). *Hardwood Lumber Manufacturing in the United States*. www.unece.lsu.edu/marketing/documents/2007July/3aNA_05.pdf

However, owners of downed trees and tree service companies may come to realize that there is a growing derived demand for urban trees as a marketable commodity and begin asking to be paid for their downed trees.

Over the twenty-year span of using urban wood, one author (Sherrill) was frequently offered trees for a price or asked if sawmills might be interested in buying yard trees for their log content. By far, these inquiries were motivated by the desire to sell the trees as a way of offsetting the costs of having them taken down. Without exception, the answer has been no to both questions. But as property owners and tree service companies begin realizing that at least some species (for example, walnut and cherry) have market value the pressure to sell instead of donate will increase.

Compared to the magnitude of CO_2 emissions just in the U.S., the amounts calculated here are relatively small but should be considered as one among many local ways to mitigate adverse climate change attributable to this particular greenhouse gas.

Informed consumers worry about global warming but perhaps feel there is nothing they can do personally about a very serious problem that blankets the earth. However, by purchasing urban forest products, buyers are acting locally in a way that over the years will collectively make a small but significant contribution to the mitigation of a global problem both by carbon sequestration and by serving as an example of what individual buyers and businesses can do.

As a related point, the EPA and other federal agencies until recently used estimates of the social cost of carbon (designated as SC-CO_2) to calculate the long-term damage attributable to a ton of CO_2 released in a given year.[25] In a benefit-cost analysis of policies and actions that result in carbon sequestration – as in the production of urban hardwood products – benefits are the monetized costs prevented by measures that reduce CO_2 emissions and their associated damages. Net benefits greater than zero dollars are an economically rational argument for all such effective measures. While further elaboration on this point is well beyond the scope of this report, estimating benefits and costs should be an important part of the future research agenda on urban tree utilization.

The volume of evidence that supports anthropogenic climate change is massive and consistent. Yet denial persists and seems to have intensified within the last year or so. One author (Sherrill) has been challenged more than once on the significance of carbon sequestration in urban wood products and climate change.

The most frequent argument opens with the question of how such a small amount of CO_2 -- 0.04 percent of the planet's atmosphere or now 410 parts per million (ppm) -- can make any difference in the climate. A complete answer is lengthy and complex and has to do with how the sun's electromagnetic radiation as visible light is both absorbed and reflected off of the earth's surfaces as infrared radiation and what happens when infrared meets CO_2.

[25] See EPA, *The Social Cost of Carbon: Estimating the Benefits of Reducing Greenhouse Gas Emissions*. Available at: https://archive.epa.gov/epa/climatechange/social-cost-carbon.html.

A quick answer comes from toxicology where it is said that "it is the dose that makes the poison". CO_2's cousin, carbon monoxide (CO) is an example. No one denies that CO is deadly. Both the Consumer Product Safety Commission and the Underwriters Laboratory require CO monitors to sound an alarm between 5 and 15 minutes after the CO concentration reaches 400 ppm in a closed space such as a bedroom at night where people are sleeping or in a closed garage where a gas-powered engine is running. CO is incapacitating at 800 ppm and fatal within two hours when it reaches 1,600 ppm or 0.16 percent of the air in a bedroom or garage. With CO, extremely small amounts can make a fairly quick life or death difference. In the opinion of the authors, although the impact takes a much longer period of time, the gradual accumulation of CO_2 may be similarly devastating on a global scale. In this context, urban tree utilization assumes greater global importance.

Appendix A
Amounts of CO_2e in Pounds per Board Foot for Common Urban Forest Tree Species*

Species by Common Name	Weight of Lumber @ 12% MC	Weight of Lumber@ 0% MC	Amount of Carbon (48%) per 1,000 Board Feet	Amount of Carbon Per Board Foot	Amount CO_2 e by Weight in Pounds per Board Foot
Alder	2,330.0000	2,050.4000	984.1920	0.9842	**3.6087**
Ash, white	3,420.0000	3,009.6000	1,444.6080	1.4446	**5.2969**
Ash, black	2,830.0000	2,490.4000	1,195.3920	1.1954	**4.3831**
Ash, green	3,290.0000	2,895.2000	1,389.6960	1.3897	**5.0956**
Aspen, quaking	2,170.0000	1,909.6000	916.6080	0.9166	**3.3609**
Balsam**	2,200.0000	1,936.0000	929.2800	0.9293	**3.4074**
Basswood	2,170.0000	1,909.6000	916.6080	0.9166	**3.3609**
Beech	3,750.0000	3,300.0000	1,584.0000	1.5840	**5.8081**
Birch, paper	3,160.0000	2,780.8000	1,334.7840	1.3348	**4.8943**
Birch, yellow	3,670.0000	3,229.6000	1,550.2080	1.5502	**5.6841**
Cherry, black	2,930.0000	2,578.4000	1,237.6320	1.2376	**4.5380**
Chestnut**	2,500.0000	2,200.0000	1,056.0000	1.0560	**3.8720**
Cottonwood, black	2,000.0000	1,760.0000	844.8000	0.8448	**3.0976**
Cypress, southern**	2,700.0000	2,376.0000	1,140.4800	1.1405	**4.1818**
Elm, rock	3,670.0000	3,229.6000	1,550.2080	1.5502	**5.6841**
Elm, American	2,920.0000	2,569.6000	1,233.4080	1.2334	**4.5225**
Gum, black**	2,920.0000	2,569.6000	1,233.4080	1.2334	**4.5225**
Gum, red (sweet)*	2,850.0000	2,508.0000	1,203.8400	1.2038	**4.4141**
Hackberry	3,080.0000	2,710.4000	1,300.9920	1.3010	**4.7703**
Hickory, true	4,250.0000	3,740.0000	1,795.2000	1.7952	**6.5825**
Hickory, pecan	3,920.0000	3,449.6000	1,655.8080	1.6558	**6.0714**
Locust, black**	4,100.0000	3,608.0000	1,731.8400	1.7318	**6.3501**

Magnolia, southern	2,920.0000	2,569.6000	1,233.4080	1.2334	**4.5225**
Maple, sugar	3,670.0000	3,229.6000	1,550.2080	1.5502	**5.6841**
Maple red**	3,200.0000	2,816.0000	1,351.6800	1.3517	**4.9562**
Maple, silver	2,250.0000	1,980.0000	950.4000	0.9504	**3.4848**
Oak, red	3,670.0000	3,229.6000	1,550.2080	1.5502	**5.6841**
Oak, white	3,920.0000	3,449.6000	1,655.8080	1.6558	**6.0714**
Sweet Gum	2,830.0000	2,490.4000	1,195.3920	1.1954	**4.3831**
Tupelo, black	2,920.0000	2,569.6000	1,233.4080	1.2334	**4.5225**
Tupelo, water	2,920.0000	2,569.6000	1,233.4080	1.2334	**4.5225**
Poplar, yellow (tulip)	2,350.0000	2,068.0000	992.6400	0.9926	**3.6397**
Sycamore	2,830.0000	2,490.4000	1,195.3920	1.1954	**4.3831**
Walnut, black	3,170.0000	2,789.6000	1,339.0080	1.3390	**4.9097**

MEAN	3,043.5294				**4.7139**
STANDARD DEV.	604.4827				**0.9362**

*Weights by species in column 2 are from the two sources cited below. The weights in column 3 are from column 2 reduced by 12% to their respective weights at 0% moisture content (MC). Amounts of carbon in column 4 are the weights in column 3 reduced by .48: slightly less than one-half of a tree is carbon. Amounts of carbon per board foot in column 5 are weights in column 4 divided by 1,000 (board feet). Finally, in column 6, the amounts of CO_2e sequestered by species per board foot in column 5 multiplied by 3.667, equals the molecular weight of CO_2e. The molar mass of CO_2 is C @ 1 x 12 + O_2 @ 2 x 16 = 44: 44/12 = 3.667 (note: the 12 in the denominator of 44/12 represents C or carbon). 3.667 is the multiple by which 1 atom of C stored in a board foot of wood reduces atmospheric CO_2.

Sources: Karl E. Wenger (ed.), *Forestry Handbook*, 2nd edition, 1984, John Wiley & Sons, Inc., Table 4, pg. 583.
** http://www.globalwood.org/tech/tech_wood_weights.htm

Appendix B
Average Proportions of Carbon Sequestered in Hardwood Products In-Use by Region for a Thirty Year Period

Year	North East	South East	North Central	South Central	West	Pacific West
0	0.614	0.609	0.585	0.587	0.568	0.531
1	0.572	0.565	0.544	0.543	0.529	0.481
2	0.534	0.526	0.507	0.503	0.494	0.438
3	0.500	0.491	0.473	0.468	0.464	0.400
4	0.469	0.459	0.443	0.437	0.437	0.367
5	0.440	0.431	0.416	0.409	0.412	0.338
6	0.415	0.405	0.391	0.383	0.390	0.312
7	0.391	0.381	0.368	0.360	0.369	0.289
8	0.369	0.359	0.347	0.338	0.350	0.268
9	0.349	0.339	0.328	0.319	0.332	0.248
10	0.331	0.321	0.310	0.301	0.316	0.231
11	0.317	0.307	0.296	0.288	0.304	0.220
12	0.303	0.293	0.283	0.275	0.292	0.208
13	0.289	0.279	0.269	0.261	0.280	0.197
14	0.275	0.252	0.256	0.248	0.268	0.185
15	0.260	0.243	0.242	0.235	0.256	0.174
16	0.250	0.234	0.233	0.226	0.248	0.168
17	0.224	0.225	0.224	0.218	0.240	0.162
18	0.230	0.216	0.215	0.209	0.233	0.155
19	0.220	0.207	0.206	0.201	0.225	0.149
20	0.212	0.201	0.197	0.192	0.217	0.143
21	0.205	0.195	0.191	0.186	0.211	0.139
22	0.198	0.189	0.185	0.180	0.205	0.135
23	0.191	0.183	0.179	0.174	0.200	0.130
24	0.184	0.175	0.172	0.168	0.194	0.126
25	0.178	0.170	0.165	0.162	0.188	0.122
26	0.173	0.165	0.160	0.158	0.183	0.119
27	0.168	0.160	0.155	0.153	0.179	0.116
28	0.163	0.155	0.150	0.149	0.174	0.113
29	0.152	0.150	0.145	0.144	0.170	0.110

Smith, James E., et al. (2005). *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States.* USDA Forest Service, North Eastern Research Station, General Technical Report NE-343. Taken from Table 6. Note: the original estimates were calculated in five-year increments starting with year ten. Annual estimates given in this table starting in year eleven are interpolations across each five-year increment to year thirty.

Appendix C

Solid Hardwood Products by End Uses For the United States in 1998 by Percent

End Use	Percentages
New residential construction	
Single family	3.9
Multifamily	0.4
Mobile homes	0.2
Residential upkeep and improvement	3.9
New nonresidential construction	
All except railroads	2.8
Railroad ties	4.7
Railcar repair	0.8
Manufacturing	
Household furniture	**23.5**
Commercial furniture	**4.8**
Other products	**9.5**
Subtotal	**37.8%**
Shipping	
Wooden Containers	**0.8**
Pallets	**34.9**
Dunnage	**0.7**
Subtotal	**36.4%**
Other uses	0.7
Total domestic use	91.7
Exports	8.3

Source: adapted from Table D2, page 206, Smith et al., James E. et al. (2005). *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States*. USDA Forest Service, North Eastern Research Station, General Technical Report NE-343.

Appendix D

Gasoline-Powered CO_2 Emission Estimates

Mower emission estimates vary. The one used in this report is 88 pounds per year attributed to the EPA as cited by, among others, People Powered Machines, *Cleaner Air: Gas Mower Pollution Facts*. http://www.peoplepoweredmachines.com/faq-environment.htm.

The highest found in a web search on this subject is a calculated estimate of 194 pounds from Andrea Becker. April 25, 2017. *How to Calculate the Carbon Footprint of Your Lawn Mower*. http://sciencing.com/calculate-carbon-footprint-lawn-mower-24046.html.

Other sources not listed here also cite the EPA estimate as being in the eighty pound range even though a search of the Agency's website uncovered no current CO_2 emissions estimates. The 194 pound estimate is by far the highest found and is twice what is attributed to the EPA.

Using the high estimate of 194 pounds will cut the EPA estimate (88 pounds) by half. In the example in this report, the oak table will offset one mower for four years (instead of eight years) or four mowers (instead of eight mowers) for one year. EPA estimates that CO_2 emissions from lawn mowers in 2018 will top 23 million tons. See Banks, Jamie and Robert McConnell. *National Lawn and Garden Equipment Emissions.* 2015. 2015 International Emissions Inventory Conference, San Diego, CA.
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The work upon which this publication is based was funded in whole or in part through a grant awarded by the Wood Education and Resource Center, Northeastern Area State and Private Forestry, U.S. Forest Service.