Forest Climate Working Group Recommendations

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Expanding the Use of Wood in Buildings—Including Tall Wood Buildings—Helps to Support Climate Preparedness and Mitigation

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Background

Policies that promote sustainably managed forests and the use of sustainable forest products will help to reduce greenhouse gas emissions and mitigate the effects of climate change. The new technology to use wood in the construction of taller buildings creates opportunities to make a larger positive carbon impact by using more wood in construction. The recommendations in this paper are intended to supplement prior recommendations made to the Administration by the Forest Climate Working Group on April 4, 2014.

The Potential

There is considerable potential through increased use of wood to materially improve GHG balances and to help the nation attain the emissions reductions set by the Administration through the President's Climate Action Plan. Evidence of this potential to mitigate carbon emissions through forest management and promotion of wood products use is also evident in the following statements and studies:

- A Yale University-led study released in March 2014 found that "Using more wood and less steel and concrete in building and bridge construction would substantially reduce global carbon dioxide emissions and fossil fuel consumption." [1]

- Authors of the Climate Change Impacts in the United States Chapter of the Third National Climate Assessment state that, "The best estimate is that forests and wood products stored about 16% (833 teragrams, or 918.2 million short tons, of CO_2 equivalent in 2011) of all the CO_2 emitted annually by fossil fuel burning in the United States….Forest product-use strategies include the use of wood wherever possible as a structural substitute for steel and concrete, which require more carbon emissions to produce. The carbon emissions offset from using wood rather than alternate materials for a range of applications can be two or more times the carbon content of the product."[2]

- The potential impact of policies designed to encourage increased use of wood in all buildings suggests that the near term carbon benefit could be as high as 32.7 mmt[3] of CO_2-e per year in the United States.[4] This is equivalent to permanently shuttering 8.6 coal fired power plants.[5]

- A 2014 Swedish study by the International Union of Forest Research Organizations (IUFRO) observed the immense potential of the forest sector to mitigate climate change at low cost and determined that on average about 470 KG of carbon dioxide emissions are avoided for each cubic meter of biomass harvested.[6]

- According to the 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change, "Wood products can displace more fossil-fuel intensive construction materials such as concrete, steel, aluminum, and plastics, which can result in significant emission reductions."[7] Also, the report notes that, "Research from Sweden and Finland suggests that constructing apartment buildings with wooden frames instead of concrete frames reduces lifecycle net carbon emissions by 30 to 130 kg CO_2 per square metre of floor area".[8] In addition, it states that, "The mitigation benefit is greater if wood is first used to replace concrete building material and then after disposal, as biofuel."[9]

The studies show that policy change toward a carbon savings performance measure for building construction would incentivize greater wood use and significantly reduce carbon emissions. Promoting wood use is another way to invest in forest products markets and help reinforce healthy working forests and job growth in rural America, as was discussed during the White House Rural Council's workshop on March 18, 2014, titled "Building with Wood: Jobs and the Environment."

Expansion of Current Practice and Innovation

Wood has been used as a structural material in North America for hundreds of years, primarily for single-family housing and transportation structures such as bridges, but much less so for multi-family housing and commercial structures. The market share for wood in public buildings, such as schools, multi-family housing, commercial buildings such as mid-rise office structures, and industrial buildings has also been small compared with other materials. Structural use of wood in mid-rise and tall buildings is very low. Currently only 28% of all non-residential building market that could be wood by code are actually being designed in wood.[10] The other 72% are being built with products that are more highly fossil fuel intensive to manufacture. The use of traditional and innovative wood design, including hybrid-wood design, at a broad scale in these contexts is feasible and can be achieved safely and economically.[11]

Currently, the carbon stored each year in U.S. forest products reduces annual U.S. greenhouse gas emissions equivalent to about 1% of overall emissions[12], about 1.3% of all carbon dioxide emitted by fossil fuel burning in the U.S. each year, or 17% of annual U.S. building construction emissions.[13,14] Prior to the "Great Recession" this number would have been significantly higher due in part to the larger volume of annual housing starts.[15] But even at pre-recession volumes this is only a fraction of what is possible.

Putting Forests and Wood Products to Work to Reduce Carbon Emissions

Wood material is about 50% carbon by dry weight.[16] One cubic meter of biomass contains 200-250kg of carbon, equivalent to about 700-900 Kg CO_2 depending upon wood density.[17] A growing tree draws CO_2 from the atmosphere, stores the carbon as wood and releases oxygen back into the atmosphere. In addition to sequestration (the physical storage of carbon in forests and wood materials) the use of wood products helps to improve GHG balances by:

- the avoidance of industrial process carbon emissions (such as in cement manufacturing);
- the consumption of less energy overall, and less fossil energy in particular, in manufacturing wood products compared with alternative materials;
- the use of wood by-products as biofuel to replace fossil fuels among others.[18]
- helping to avoid forest stocking beyond historical norms and the attendant increased risk of carbon liberation to wildfire or insect-caused tree mortality.

The estimates in Table 1 describe the near-term opportunity to sequester carbon and reduce carbon emissions through offsets based in increasing the amount of wood used in building. Another way to show the benefit is provided in Table 2 through breaking out stored carbon and avoided carbon.

Table 1: Near-Term Opportunities for Expanded Use of Wood as a Climate Change Solution

	Approximate Additional Wood Volume Annually	Additional Annual Carbon Benefit (CO_2e)[19]	Equivalent number of passenger vehicles off the road for one year[20]	Equivalent number of coal fired power plants shuttered for one year[21]	Percent of White House Reduction Goal Annually	Economic Benefit[22]
Low-Rise Non-Res[23]	4.5 BBF[24]	19 mmt[25]	4,100,000	~5	1.50%	$9 billion
Multi-family[26]	0.7 BBF[27]	3 mmt[28]	700,000	~1	0.24%	$1 billion
U.S. Buildings 7-15 Stories[29]	1.6-2.4 BBF[30]	7-10 mmt[31]	1,500,000-2,200,000	~2-3	0.6-0.8%	$3-5 billion
Aggregate[32]	6.8-7.6 BBF	29-33 mmt	6,300,000-7,000,000	~8-9	2.3%-2.6%	~$14 billion

Table 2: Stored Carbon vs. Avoided Carbon from Additional Carbon Benefit[33]

	Approximate Additional Wood Volume Annually	Stored CO2e	Avoided CO2e	Total Carbon Benefit
Low-Rise Non-Res	4.5 BBF	6 mmt	13 mmt	19 mmt
Multi-family	0.7 BBF	1 mmt	2 mmt	3 mmt
U.S. Buildings 7-15 Stories	1.6-2.4 BBF	2-3mmt	5-7mmt	7-10mmt
Aggregate	6.8-7.6 BBF	9-10 mmt	20-22mmt	29-32mmt

The Request: Create Incentives and Opportunities to Use More Wood in Buildings

Greater use of wood products in construction can contribute to improvement of the nation's GHG balance in a number of ways, something that is well documented in the scientific literature. The Federal Government has committed to reduce GHG emissions by 17% by 2020. The Administration is looking for recommendations to improve the GHG balance and help the nation meet its GHG reduction goals. Currently, United States policy does not recognize carbon sequestration in long-lived bio based products as one of the means of achieving these targets, and there is no policy or guidance that explicitly encourages the review and inclusion of carbon sequestration in the selection of building materials as a way to reach Federal GHG reduction targets. Internationally, the relevance of harvested wood products on GHG emissions is already widely recognized.[34] We recommend the following:

A. The Office of the Federal Environmental Executive and the Office of Management and Budget should issue a joint memo interpreting Executive Order 13514 to provide that (i) carbon sequestered in buildings owned or occupied by Federal Agencies and (ii) carbon emissions avoided by substitution of carbon friendly wood products for more carbon intensive products are recognized pathways by which Federal Agencies can achieve their greenhouse gas emissions reduction targets.

B. The White House Council on Environmental Quality should direct USDA, through the U.S Forest Service, to build on existing guidelines to provide an accounting framework for carbon offsets provided by carbon storage and avoided emissions when wood is used in construction in place of specific alternate materials.

C. The White House Council on Environmental Quality should direct USDA, through the U.S. Forest Service, to work with the EPA and other Agencies to streamline adoption of these frameworks by Federal Agencies and States. We suggest commissioning development of a "federal buildings carbon savings calculator" that would include calculation of carbon offsets from building material selection.

Sustainably Managed Wood Will Enlarge the Capacity of the Carbon Sink

The uptake of atmospheric carbon by renewable wood products reduces the atmospheric carbon dioxide concentration. The carbon in wood products is stored for the useful life of the product. Using long-lived wood products actually enlarges the pool of available carbon storage when the wood products are derived from forests that are sustainably managed. [35] Periodic harvesting is a necessary component to maintaining and growing the rates at which forests sequester carbon. Absent active forest management, rates of carbon sequestration by our forests would slow.

U.S. forests and associated wood products now serve as a substantial carbon sink, capturing and storing more than 227.6 million tons of carbon per year.[36] In May of 2014, the U.S. Global Change Research Program (USGCRP) released a report confirming that U.S. forests and associated wood products currently absorb and store the equivalent of about 16% of all carbon dioxide emitted by fossil fuel burning in the U.S. each year.[37] This carbon is stored in different forms, sometimes called carbon pools. One such pool is in long-lived wood products. When wood used in producing wood products is sourced from sustainably managed forests, carbon storage pools actually grow because on the one hand, the wood used in buildings becomes a carbon reservoir and on the other hand, the forest carbon reservoir is replenished as trees harvested are replaced by regrowth. Regrowth absorbs additional carbon from the atmosphere and stores it as wood in new and growing trees. In recognition of this reality, the United Nations' 2007 Intergovernmental Panel on Climate Change ("IPCC") stated that, "In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest stocks, while producing an annual sustained yield of timber, fiber or energy from the forest, will generate the greatest {climate change} mitigation benefit."

The Substitution Effect and the Carbon Triple Play

The carbon benefits of using wood in long-lived wood products do not end with carbon sequestration within the wood. Use of wood products, over their life cycle, results in lower total greenhouse carbon emissions than alternative building materials including concrete and steel.[38] Accordingly, there is a beneficial substitution effect when wood is used in place of other types of building materials. "The magnitude of substitution effect varies by use and product, but on average every 1 ton of wood used avoids the addition of 2.1 tons of carbon (or 3.9 tons of carbon dioxide) to the atmosphere."[39] The Consortium for Research on Renewable Industrial Materials (CORRIM) has reported that a steel-framed Minneapolis house produces 120% more Global Warming Potential than a comparable wood-framed house and that a concrete Atlanta house produces 155% more Global Warming Potential than a comparable wood-framed house (Wood and Fiber Science, March 2010. V. 42). Life cycle assessment (LCA) studies consistently show that wood buildings require less energy from resource extraction through manufacturing, distribution, use, end-of-life disposal, and are responsible for far less greenhouse gas emissions than fossil fuel-intensive construction materials such as steel or concrete. The USGCRP states that, "the carbon emissions offset from using wood rather than alternate materials for a range of applications can be two or more times the carbon content of the product.[40]

Models for Success

Seattle, Washington – University of Washington West Campus Student Housing – Phase I

In 2012, the University of Washington (UW) completed a $109 million,* five-building construction project, adding nearly 1,700 student housing beds. Known as West Campus Student Housing – Phase I, the 668,800-square-foot project was the first of four phases planned by UW to add much-needed student housing to its Seattle campus, which has an enrollment of more than 42,000 students.

Sustainability appeals to an increasing number of students, and the UW prides itself as being 'one of the country's preeminent leaders in environmental practices,' committing itself to offer students what they call an 'urban eco-lifestyle.' One of the buildings received LEED Silver certification, while two others earned LEED Gold. Four of the five buildings also meet The 2030 Challenge (requiring 60 percent reduction over baseline fossil fuel energy consumption) with the purchase of green power.

Carbon benefit of wood use[41]
Volume of wood used = 208,320 cubic feet
U.S. and Canadian forests grow this much wood in = 17 minutes
Carbon stored in the wood = 4,466 metric tons of CO_2
Avoided GHG emissions = 9,492 metric tons of CO_2
Total Potential Carbon Benefit = 13,958 metric tons of CO_2
For the full case study, visit www.woodworks.org.

Marina del Ray, California – Stella Mixed-Use Development

A new luxury mixed-use development in California, Stella includes two buildings, one with five stories of wood-frame construction and the other with four, above a shared concrete podium. The 650,466-square-foot project features a total of 244 units.

The wood-framed portion of Stella consists of Douglas-fir dimension lumber along with parallel strand lumber (PSL), laminated veneer lumber (LVL), glued laminated timber (glulam) beams and engineered wood I-joists for the floor and roof structures. The project used both plywood and oriented strand board (OSB) structural wood sheathing.

Carbon benefit of wood use[42]
Volume of wood used = 193,619 cubic feet
U.S. and Canadian forests grow this much wood in = 16 minutes
Carbon stored in the wood = 4,495 metric tons of CO2
Avoided GHG emissions = 9,554 metric tons of CO2
Total Potential Carbon Benefit = 14,049 metric tons of CO2
For the full case study, visit www.woodworks.org.

San Francisco, CA – Drs. Julian and Raye Richardson Apartments

Designed to provide permanent residences for low-income, formerly homeless adults, this 65,419-square-foot project includes four stories of wood-frame construction over a concrete podium. The architect used wood as the primary structural material because of its relative cost savings compared with concrete and steel. Wood was also left exposed throughout the interiors to add warmth, variety and texture to the common spaces. This classic mixed-use urban infill project achieved GreenPoint Rated certification, and was a 2012 WoodWorks Wood Design Award winner.

Carbon benefit of wood use43
Volume of wood used = 45,429 cubic feet
U.S. and Canadian forests grow this much wood in = 4 minutes
Carbon stored in the wood = 1,014 metric tons of CO2
Avoided GHG emissions = 2,156 metric tons of CO2
Total Potential Carbon Benefit = 3,170 metric tons of CO2
For the full case study, visit www.woodworks.org.

Seattle, Washington - Bullitt Center's Heavy Timber Frame Is Example of Carbon Sequestration

Described as the greenest commercial building in the world, the Bullitt Center in Seattle, Washington pushes the envelope in urban sustainability. The six-story, 52,000-square-foot structure was designed to meet stringent requirements of the Living Building Challenge (LBC)—using photovoltaic cells to generate enough electricity to sustain the needs of its tenants, recycling its own water and waste, and reducing energy use by more than 80 percent compared to an average office building. And yet, at the heart of this state-of-the-art structure lies a heavy timber frame—a traditional building system that is increasingly being used in new and innovative ways.

Carbon Benefit of Wood Use in Bullitt Center[44]
Volume of Wood Used = 24, 526 cubic feet
U.S. and Canadian Forests Grow this much wood in = 2 minutes
Carbon stored in the wood = 545 metric tons of CO2
Avoided GHG emissions = 1,158 metric tons of CO2
Total Potential Carbon Benefit = 1,703 metric tons of CO2

For the full case study on Bullitt Center, visit www.woodworks.org.

Melbourne, Australia - Forte – Currently the World's Tallest Wood Apartment Building – At 10-stories

Both cost-effectiveness and environmental benefits are driving interest in the construction of taller wood buildings such as the Bullitt Center in Seattle, and there are several examples we can look to internationally that demonstrate the benefits of using wood in buildings of considerable height. One such example is provided by an apartment building completed in 2012 in Australia[45].

Forté, currently the world's tallest wood apartment building, is a 10-story commercial and residential building constructed from cross-laminated timber (CLT) panels. Forté boasts significant carbon benefits. The wood in the building directly stores 761 tonnes of CO_2, and when considering the emitted CO_2 that would have occurred if an equivalent concrete or steel building were constructed, the carbon storage advantage increases to 1451 tonnes of CO_2—the equivalent of taking 345 cars off the road for a year. By using wood, Forté also resulted in significantly less water use and a decrease in water pollution by 75 percent.[46]

In creating the building a total of 759 CLT panels, 5500 angle brackets, and 34,550 screws were used[47]. The use of large, prefabricated wood panels translated not only to environmental advantages, but speed of construction as well. "Commercially speaking, the biggest thing is speed," said Andrew Nieland of Lend Lease, the developer responsible for Forté. " With the building being pre-fabricated, all of the main penetrations were already taken care of, and fixing into timber is a lot easier than fixing into concrete, so for the electricians, plumbers, plasterers, and others, it's a lot easier job [working with a CLT structure] than working with concrete."[48]

Summary

Timber construction creates new carbon pools concurrent with maintenance and expansion of carbon stocks in growing forests. At the same time, substantial carbon emissions are avoided due to the fact that wood can be converted into useful products using far less energy, and particularly less fossil energy, than more energy intensive alternatives such as steel and concrete.

Allowing federal agencies to credit carbon emissions reductions realized from wood construction toward attainment of greenhouse gas emissions reduction targets would help the Federal Government achieve its goal of reducing GHG emissions 17% below 2005 levels by 2020 as set forth in the President's Climate Action Plan. We recommend establishment of formal recognition of carbon sequestered in buildings owned or occupied by Federal Agencies, and of carbon emissions avoided by substitution of carbon friendly wood products for more carbon intensive products. Also recommended is development and adoption of mechanisms for quantifying and crediting wood-construction-related emissions reductions toward GHG emissions reduction targets.

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[1] "Carbon, Fossil Fuel, and Biodiversity Mitigation With Wood and Forests, " Chadwick Dearing Oliver, Nedal T. Nessar, Bruce R. Lippke, James B. McCarter, School of Forestry and Environmental Studies, Yale University, New Haven, Connecticut, and College of Environment, University of Washington, Seattle, Washington, USA. March 28, 2014. http://news.yale.edu/2014/03/31/using-more-wood-construction-can-slash-global-reliance-fossil-fuels

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http://nca2014.globalchange.gov/report/sectors/forests

[3] mmt is an abbreviation for million metric tons.

[4] The detail supporting this estimate is in Table 1 of the present paper.

[5] EPA Greenhouse Gas Equivalency Calculator last updated April 2014.
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[6] Lundmark, Tomas; Bergh, Johan; Hofer, Peter; Lundström, Anders; Nordin, Annika; Chandra Poudel, Bishnu; Sathre, Roger; Taverna, Ruedi and Werner, Frank. "Potential Roles of Swedish Forestry in the Context of Climate Change Mitigation," p. 14. *Forests* ISSN 1999-4907 at 558. http://www.readcube.com/articles/10.3390/f5040557

[7] Nabuurs, G.J., O. Masera, K. Andrasko, P. Benitez-Ponce, R. Boer, M. Dutschke, E. Elsiddig, J. Ford-Robertson, P. Frumhoff, T. Karjalainen, O. Krankina, W.A. Kurz, M. Matsumoto, W. Oyhantcabal, N.H. Ravindranath, M.J. Sanz Sanchez, X. Zhang, 2007: Forestry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

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[10] Wood & Other Materials Used to Construct Nonresidential Buildings, 2011 – McKeever and Adair.

[11] ReThink Wood http://www.rethinkwood.com/ and WoodWorks http://www.woodworks.org/

[12] Environmental Protection Agency, April 2013, National Greenhouse Gas Emissions Data (1990-2012) http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Chapter-7-Land-Use-Land-Use-Change-and-Forestry.pdf

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[14] Forest Climate Working Group, Forest-Climate Working Group 2014 Policy Recommendations: U.S. Forests and Forest Products As Climate Change Solutions, April 2014, https://www.treefarmsystem.org/stuff/contentmgr/files/1/c9f7bd7818f389312bf6b99a5a4fc2ad/misc/fcwg_final.pdf

[15] Federal Reserve Bank of St. Louis, Graph "Housing Starts: Total: New Privately Owned Housing Units Started," data compiled from U.S. Department of Commerce: Census Bureau, shaded areas show U.S. recessions. http://research.stlouisfed.org/fred2/series/HOUST/

[16] Sathre, R. and O'Connor, Jennifer (*A Synthesis of Research on Wood Products and Greenhouse Gas Impacts 2nd Edition* FP Innovations. 2010).

[17] The International Union of Forest Research Organizations (IUFRO) has observed the immense potential of the forest sector to mitigate climate change at low cost. Lundmark, Tomas; Bergh, Johan; Hofer, Peter; Lundström, Anders; Nordin, Annika; Chandra Poudel, Bishnu; Sathre, Roger; Taverna, Ruedi and Werner, Frank. "Potential Roles of Swedish Forestry in the Context of Climate Change Mitigation." *Forests* ISSN 1999-4907 www.mdpi.com/journal/forests page 571.

[18] As discussed in the Forest Climate Working Group 2014 Policy Recommendations, strong forest product markets are part of the fabric of support needed to help keep forests as forests. Markets create economic support for long-germ forest ownership and sustainable management, which in turn results in carbon benefits keeping forests as forest and improved forest management and health. See Policy Recommendation #3-Restore and Reforest and Recommendation #4- Retain Forests.

[19] Wood & Other Materials Used to Construct Nonresidential Buildings, 2011 – McKeever and Adair. Table ES-4 Net Potential Change in Lumber, Engineered Wood, & Wood Panel Volume Ranked High to Low. The values are based upon data from the "Wood & Other Materials…" study mentioned here as well as the average results from five (5) real non-residential project material lists that were analyzed using the WoodWorks Carbon Calculator tool and then applied to the total wood volume estimates. Carbon impact was cross checked by Dovetail Partners, Inc., using a different calculation method and both approaches yielded the same results.

[20] EPA Greenhouse Gas Equivalency Calculator last updated April 2014. http://www.epa.gov/cleanenergy/energy-resources/calculator.html

[21] EPA Greenhouse Gas Equivalency Calculator last updated April 2014. http://www.epa.gov/cleanenergy/energy-resources/calculator.html

[22] Assuming a material distribution of 52% lumber, 30% panels, and 18% engineered wood panels and using annual average Random Lengths prices per thousand for each material.

[23] Non-Res includes non-residential low-rise buildings like offices, stores, schools, public buildings and hotels. For simplicity, 100% conversion of only the near term opportunity to wood is assumed. The annual opportunity is expected to grow as the US Market Recovers from the Great Recession.

[24] Wood & Other Materials Used to Construct Nonresidential Buildings, 2011 – McKeever and Adair. Table ES-10 Net Potential Change in Lumber, Engineered Wood, & Wood Panel Volume Ranked High to Low. http://www.fpl.fs.fed.us/documnts/pdf2013/fpl_2013_adair001.pdf

[25] Wood & Other Materials Used to Construct Nonresidential Buildings, 2011 – McKeever and Adair. Table ES-10 Net Potential Change in Lumber, Engineered Wood, & Wood Panel Volume Ranked High to Low. http://www.fpl.fs.fed.us/documnts/pdf2013/fpl_2013_adair001.pdf

[26] Multi-family includes multi-family residential building such as 3-5 story apartment buildings and condominium-style buildings. For simplicity, 100% conversion of near term opportunities to wood is assumed. Market penetration for wood is approximately 80% currently. 3.2mmt is just the volume of the additional conversion of 20%. The annual opportunity is expected to grow as the US Market Recovers from the Great Recession.

[27] BBF is an abbreviation for billion board feet. Source: McGraw Hill Construction Data, 2014 predicted square feet of new multi-family construction. An assumption of 8 BF/sqft was used to calculate board feet. Conservatively, 20% of this volume is assumed as the approximate conversion potential to wood.

[28] The range is based upon the average results from five (5) real non-residential project material lists which were analyzed using the WoodWorks Carbon Calculator tool and then applied to the wood volume estimates. Carbon impact was cross checked by a Dovetail Partners, Inc., using a different calculation method and both approaches yielded the same results.

[29] See FP Innovations Report, *Quantifying Tall wood Demand in North America, April 2013,* Pablo Crespell and James Poon which quantifies the near term construction predicted in this market segment. Note that this projection does not include the 16-30 story opportunity even though international trends and new wood technologies and building systems indicate that tall would buildings of 20 stories or more could be built from wood.

[24] FP Innovations Report, *Quantifying Tall wood Demand in North America, April 2013,* Pablo Crespell and James Poon

[31] The range is explained by in the FP Innovations Report *Quantifying Tall wood Demand in North America, April 2013,* Pablo Crespell and James Poon. A portion of this carbon is stored in the wood products (2.161-2.470 mmt) used and a portion of carbon is avoided by using primarily wood in place of more energy intensive materials like concrete and steel (4.588-5.243 mmt).

[32] Assumes high end of the range.

[33] 4.5 billion bf has 6 million tonnes CO_2e stored in the wood (32%) and 13 million tonnes of avoided CO_2e emissions (68%) or a total of ~19 million tonnes CO_2e. The percentage breakdown is approximately the same for the other columns.

[34] United Nations Framework Convention on Climate Change (UNFCCC, *Decisions adopted by the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol,* March 2012, *http://unfccc.int/resource/docs/2011/cmp7/eng/10a01.pdf.* Also consider Sadler, Piers and Robson, David. *Carbon sequestration in Buildings. (2012).* *http://www.asbp.org.uk/uploads/documents/resources/ASBP_Carbon%20sequestration%20by%20buildings.pdf*

[35] Historical trends indicate that the standing inventory (the volume of growing stocks) of hardwood and softwood tree species in US forests has grown by 49 percent between 1953 and 2006. Alvarez, M. 2007. *The State of America's Forests.* Bethesda, MD: Society of American Foresters.

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[42] Estimated by the Wood Carbon Calculator for Buildings, based on research by Sarthre R. and J. O'Connor, 2010, A Synthesis of Research on Wood Products and Greenhouse Gas Impacts, FPInnovations. Note: CO_2 refers to CO_2 equivalent.

[43] Estimated by the Wood Carbon Calculator for Buildings, based on research by Sarthre R. and J. O'Connor, 2010, A Synthesis of Research on Wood Products and Greenhouse Gas Impacts, FPInnovations. Note: CO_2 refers to CO_2 equivalent.

[44] Estimated by the Wood Carbon Calculator for Buildings, based on research by Sarthre R. and J. O'Connor, 2010, A Synthesis of Research on Wood Products and Greenhouse Gas Impacts, FPInnovations. Note: CO2 refers to CO2 equivalent.

[45]http://www.rethinkwood.com/sites/default/files/wood-resourse-pdf/Survey%20Tall%20Wood_REPORT%20WITHOUT%20APPENDICIES_web.pdf

[46] http://www.woodsolutions.com.au/Inspiration-Case-Study/forte-living

[47] http://www.woodsolutions.com.au/Inspiration-Case-Study/forte-living

[48] http://designbuildsource.com.au/reflections-on-building-the-worlds-tallest-timber-building-using-clt