Carbon Farming with Timber Bamboo: A Superior Sequestration System Compared to Wood

*Why the time is **now** for the world to take advantage of nature's fastest growing structural fiber*

Hal Hinkle, PhD
Myles McGinley
Travis Hargett
Skye Dascher

BAMCORE®

Executive Summary

Our earth is on track to crash through the 1.5°C global warming budget set for 2030 and will likely even exceed the 2°C worst-case budget. If this occurs, the International Panel on Climate Change predicts dramatic negative consequences for human health, livelihoods, food security, water supply, physical security, and global economic growth (IPCC 2018). Every pathway the IPCC has proposed to fight climate change ***requires immediate and significant carbon dioxide removal (CDR) from the atmosphere****, i.e. sequestration. Yet practically nothing is being pursued because nearly nothing appears to work to reliably capture and store atmospheric* CO_2*--other than possibly wood-based biogenic sequestration implemented through afforestation and reforestation. In theory this can work, but only when harvests are turned into long-lived wood products to durably store the carbon. But wood sequestration is far too slow and wood harvests, if clear cut, themselves emit significant amounts of* CO_2*.*

We believe that timber bamboo's ***fast growth and short annual harvest cycle*** *can speed up carbon sequestration and* ***turn timber bamboo plantations into perpetual carbon farms*** *capable of producing high grade structural fiber. The demand for both carbon dioxide removal and the structural fiber is greater than ever! What's more, publically available data suggests that most of bamboo's carbon capture occurs in the first 15 years, decades earlier than trees.*

To confirm or refute our belief that timber bamboo is a superior sequestration option compared to wood, we built ***the first multi-species/multi-location bamboo growth model*** *and constructed a methodical decision framework to compare annual carbon flows of timber bamboo to wood, including robust sensitivity analysis, time valuation of carbon flows, and a comprehensive* ***comparison metric called the Carbon Benefit Multiple (CBM)****. The final CBMs showed that timber bamboo, with regular harvests of durable products, sequesters between* ***4.5 and 6 times the carbon that wood does****.*

To conclude, we calculate the cumulative climate change mitigation benefits from various levels of market substitution of durable timber bamboo building products like BamCore's Prime Wall System. Because of the superior thermal performance inherent to the Prime Wall System, as well as land-use conversion dynamics, substituting the Prime Wall for conventional wood framing in G-7 economies can ***lower atmospheric*** CO_2 ***by over 23 gigatonnes over the next 100 years****.*

The time is now for the world to take advantage of nature's fastest growing structural fiber.

Table of Contents

1. Addressing Climate Change Through Carbon Dioxide Removal

Mankind largely accepts the dangers of global climate change, but the stark reality is that collectively we show little likelihood of staying within the 1.5^{o}C or even the 2^{o}C carbon budgets adopted in the Paris climate treaty in 2015[1] (IPCC, 2018). In light of this, the private sector has made strides to mitigate its carbon footprint, through the combination of renewable energy development and energy efficiency improvements. These sum of these actions, however, will not be enough to prevent mankind from passing the presumptive safe harbor budget of the 1.5^{o}C increase, or worse, the redline budget of 2^{o}C global temperature increase (Bloomberg & Pope, 2017) (New, et al., 2011) (Rogerlj, et al., 2016). More must be done to keep our planet from breaking the temperature increase budget and rebalance the world's natural feedback cycles. Specifically, we must literally sequester carbon dioxide (CO$_2$) from the atmosphere. In their special study, *Global Warming 1.5^{o}C,* The United Nations Intergovernmental Panel on Climate Change (IPCC) makes this point clear: "All pathways that limit global warming to 1.5^{o}C…**use carbon dioxide removal (CDR)**." In conjunction with shifts away from fossil fuels, changes to dietary norms, and myriad of other items on the climate change mitigation menu, we must include significant, near-term carbon sequestration efforts. Not including CDR in the solution set will lead the earth's climate systems down a path of powerfully harmful and irreversible feedback cycles[2] that will make life on earth drastically different than it is today well before the end of the current century.

Many in the academic, policy, and corporate communities grasp this eventuality, but in the effort to understand and limit climate change, little focus has been given to what might be most important factor of all: the timing of mitigation outcomes. With the cyclical and irreversible nature of the earth's weather and atmospheric feedback loops in mind, it seems obvious that discrete periodic timing projections of *CO$_2$* emissions and capture are necessary to formulate an effective climate change mitigation plan. Yet, in the abundant research and in the development of plans and policies to mitigate climate change, only the projected cumulative amount of mitigation is typically considered, while the timing of the mitigation events is hardly ever formally incorporated - conceptually or analytically. Even the Paris carbon budget itself is expressed simply as a total amount of CO$_2$ (and other greenhouse gases) that can be released into the atmosphere without regard to *when* the gasses are in fact, emitted. Fighting climate change is not a contest that we can win with a late-in-the-game reversal and if we don't get ahead in the contest early, the likelihood of prevailing reduces to nil. Better-suited firefighters showing up once the building is in full conflagration can't save the building. To make sound decisions, individually or collectively, about actions that can lead to significant carbon sequestration, **we must develop better decision-making tools that incorporate the discrete timing of carbon flows.**

Among climate change CDR opportunities, capturing atmospheric carbon through afforestation and reforestation ("A/R")[3] sequestration is a proven, safe and immediately available option. Importantly, the sequestration benefit of A/R is limited largely to the initial years of forest growth because once a forest reaches maturity, many argue that its net carbon dioxide removal slows, and may approach zero as its continued growth is offset by natural forest atrophy resulting in a system with nearly balanced carbon flux.[4] If, however, some of the carbon-laden fiber is harvested from a mature forest's standing stock and stored, or sequestered, in harvested wood products ("HWP")[5], the forest can resume net capturing of carbon as it regrows. Harvested wood products range from paper and pulp with short product half-lives to furniture with intermediate half-lives, and to construction materials embedded in buildings with very long half-lives.[6] Only when a forest is periodically harvested, and the

---

[1] On October 8, 2018 the UN's Intergovernmental Panel on Climate Change (IPCC), after two years of work, released the Special Report: Climate Change of 1.5^{o}C. The broad conclusion with high confidence was that "Global warming is likely to reach 1.5^{o}C" as early 2030.

[2] Positive feedback cycles in global climate change accelerate the rate of climate change when they are activated, e.g. rising temperatures that melt the Greenland and polar ice covers, which reduces solar reflectance, resulting in further temperature gains, or the thawing of the sub-artic permafrost that releases CO$_2$, which further warms the atmosphere, resulting more CO$_2$ releases from the permafrost.

[3] In our work and discussion, our working definition of Afforestation/Reforestation focuses on incremental planting activity intended to produce commercial fiber via prescribed harvest cycles. The alternative of planting without intended harvest may produce ultimately higher sequestration results but only over periods longer than helpful for climate change purposes. Said differently, had we time enough, slow-growing, unharvested forests might well absorb far more atmospheric carbon than either harvested wood or bamboo A/R. Afforestation and reforestation, while factually different, have nearly identical carbon footprints by the time a wood or bamboo system is mature. Accordingly, we use the terms interchangeably, noting them simply as "A/R". Among climate policy professionals, afforestation applies to land that has not had a forest on it in 50 years, while reforestation applies to land that has been converted to non-forest uses prior to year-end 1989.

[4] We appreciate the input of Doug Heiken who shared that long-lived/old growth stands, without intervening harvests, may indeed continue to net sequester carbon. Unfortunately, climate change requires near term solutions.

[5] Harvested Wood Products are explicitly included in the UN's Framework Convention on Climate Change as a contribution to the mitigation results achieved through A/R projects. HWPs include lumber, panels, paper and paperboard as well as wood used for fuel. For the purposes of this analysis, we do not make a distinction between wood- or bamboo-based HWP.

[6] We do not discuss biochar as an HWP, even though its presumptive half-life is many hundreds of years because the global market demand for biochar is relatively small, thus limiting its role as a substitute product.

harvested product are put in use, can a forest or plantation[7] stay in a perpetual cycle of regrowth to continue capturing additional atmospheric carbon. **By storing carbon from each harvest into durable HWP, a one-time A/R project can become a perpetual carbon farm. By extension, the faster or more frequently the A/R project is harvested, the more carbon can be farmed from the atmosphere and the more carbon can be stored in durable HWP.**

It is precisely the fast growth and short harvest cycle of timber bamboo that makes it the ideal candidate for carbon farming A/R projects. However, to date timber bamboo has been largely ignored in global climate change mitigation A/R programs and policies in favor of wood-based A/R. This is hardly surprising because tree forests and wood products are exhaustively researched and analyzed both generally and regarding their climate mitigation potential. Moreover, the comparatively limited scope of bamboo research has kept its climate mitigation potential largely overshadowed. It would be difficult, if not in impossible, to make effective A/R policy decisions without projections for the timing of each discrete annual carbon flow, sequestration and emission, during both forest growth and HWP service life, which for wood are readily available through multiple sources. The UN IPCC has even published guidelines for calculating and projecting these carbon flows in its *Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006).

Our analysis aims to bring the biogenic power of timber bamboo into the spotlight. To do this, we used publicly available data sets on annual carbon sequestration rates across three species of timber bamboo that are already used to produce HWP to create a cradle-to-gate carbon flow model. The outputs of the model, as described below, are annualized net carbon flow projections over a 100-year time period that can be directly compared to those of various wood forests.[8] We analyze the potential role of timber bamboo in climate mitigation A/R projects in comparison to wood-based A/R projects. from the perspective of commercial or **rational decision making** where **the benefit maximized is near term capture and long-term storage of atmospheric carbon dioxide.**[9] The following outlines the sections of the paper.

Section 2. Carbon Capture Through Wood and Bamboo Afforestation

First, we review the state of existing multinational wood- or tree-based A/R adoption programs and report three observations: First, there is a significant shortfall between the broad goals of the programs and the specific commitments of the participants. Second, there is only faltering progress against the limited specific commitments that have been given. And third, there is a general indifference to timing considerations when implementing the schemes. Against this backdrop, we argue that timber bamboo is a strongly superior A/R solution. As nature's fastest growing structural fiber, **timber bamboo A/R programs, when compared to wood-based A/R options, are far more potent at generating near term carbon dioxide removal.**

Section 3: Projecting Carbon Flows from Wood and Timber Bamboo Afforestation/Reforestation.

Next, we introduce a modeling framework that allows us to project and then compare annual carbon flows from both wood and timber bamboo A/R projects.

a. For wood, we adopt the comprehensive carbon flow projection model developed by the US Forest Service ("USFS model"; Smith, *et al,* 2005), which projects 100-year+ carbon flows for 5 wood species and planting locations.
b. For timber bamboo, no model is available that projects any longitudinal carbon flows, yet less for comparable 100-year carbon flows. Accordingly, we developed *A Generalized Model of Timber Bamboo Carbon Flows* that projects 100-year carbon flows across a range of timber bamboo species ("BC model"; Hinkle, *et al*, 2018). The model and its development are discussed in the co-published paper of the same name.

Using projections from these two models, we illustrate and then **compare the annual carbon flows from wood and timber bamboo A/R projects, including all HWP carbon flows** (production, storage, and disposition), without regard to

---

[7] Characteristic distinctions between forests and plantations are small for our purposes. Forests may be naturally or culturally established but will have a higher degree of biodiversity. Plantations will be culturally established and managed with more focus on the immediately productive value. The manner of harvest likely has the biggest impact on the biodiversity with clear-cutting significantly disrupting biodiversity and inter-cutting impacting biodiversity far less.

[8] Model documentation is readily available upon request.

[9] The analysis is not conducted using the approach of any particular carbon sequestration certification or compliance program (e.g. Certified Development Mechanisms (CDMs) or Verified Carbon Storage (VCS)). We appreciate the insights of Camille Rebelo of EcoPlanet Bamboo on the various certification programs.

time valuing the carbon flows. Because the BC model is necessarily more speculative than the USFS model, we construct four scenarios for the BC model outputs to allay the risk of a dominating assumption driving insensible results for timber bamboo A/R.

Section 4: Rational Decision Making between Wood and Timber Bamboo A/R – The Carbon Benefit Multiple (CBM).

Then, based on the above-mentioned carbon flow projection models, **we establish a rational decision framework** that evaluates the relative carbon sequestration potency of timber bamboo versus wood A/R. The framework includes elements commonly found in commercial or financial decision-making including testing the sensitivity to specific assumptions, time valuing the benefit flows, and weighing the outlook across four possible scenarios. To reach a comprehensive but singular bottom line conclusion, **we create a single metric of the relative potency, the Carbon Benefit Multiple.** To test the robustness of the decision between timber bamboo and wood, we stress test the Carbon Benefit Multiple for three cases of projected bamboo potency, for three levels of concern about climate change (i.e. discount rates reflecting timing urgency), across four scenarios of certainty about the individual model inputs. The results show that **timber bamboo A/R, when harvested into durable HWP, provides 4.9x to 6x the amount of carbon dioxide removal that a similar wood A/R project does.**

Section 5: Conclusion 1: Carbon Farming with Timber Bamboo Significantly Outperforms Wood.

Based on our above work, summarized in the Carbon Benefit Multiple results, we conclude that **timber bamboo A/R is more potent than wood A/R providing both <u>near term</u> carbon capture** and **<u>more</u> CDR per hectare of land used.** We urge the adoption of timber bamboo as **a new global source of structural fiber and the only realistic near term CDR strategy we have on hand.**

Section 6: Productizing Timber Bamboo Into Durable Carbon-Storing Products.

Based on timber bamboo A/R's highly positive Carbon Benefit Multiple compared to wood A/R, we discuss the role and importance of the early and regular extraction of HWP to store captured carbon in durable products. **We explain how the productization of timber bamboo into durable building products will help supply mankind's growing need for a non-tree-based fiber while also driving perpetual carbon farming through demand for more timber bamboo A/R investments**. We demonstrate how superior bamboo-based building products, like BamCore's Prime Wall System can economically drive the establishment of a generation of timber bamboo carbon farms that, in turn, can deliver bamboo's carbon sequestration benefits without government subsidy or mandates.

Section 7: Conclusion 2: Timber Bamboo Products to Fight Global Climate Change.

Finally, we quantify what a shift in demand from durable wood to durable timber bamboo products would mean for the world's atmospheric CO_2 stock over a 100-year period using various levels of market penetration in the G-7 countries' new residential construction markets. In the analysis, we account for the cumulative impact on CO_2 emissions from both land-use conversion (wood to timber bamboo), and the thermally superior properties of BamCore's Prime Wall System. **We find that if BamCore's Prime Wall System captured 20% of new housing starts in the G-7 region, 23.5 gigatonnes of atmospheric CO_2 could be removed over the next 100 years. And to do so would only require the incremental planting of 852,000 hectares of bamboo. This area is just over 2% of today's existing bamboo stock and less than .02% of existing wood stock, indicating its reasonable feasibility.**

2. Carbon Capture through Wood and Bamboo Afforestation

Wood Afforestation. In our prior publication, “BamCore and Global Warming”, we concluded that among the range of options for carbon sequestration only afforestation[10], and its near-equivalent reforestation, is “ready, capable of scaling, low cost [with] few collateral negatives” (Hinkle, et al., 2017). The multiple potential benefits of A/R were recognized in 2011 when the original 2020 Bonn Challenge was adopted in Bonn, Germany (Bonn, 2018)[11]. The original Bonn Challenge was a structured multi-national commitment scheme that set targets for reforestation by 2020. In 2014, the New York Declaration on Forests added a second tranche of targets for 2030. The adopted goals are:

- 150 million hectares of reforestation/restoration by 2020 and
- 350 million hectares of reforestation/restoration by 2030.

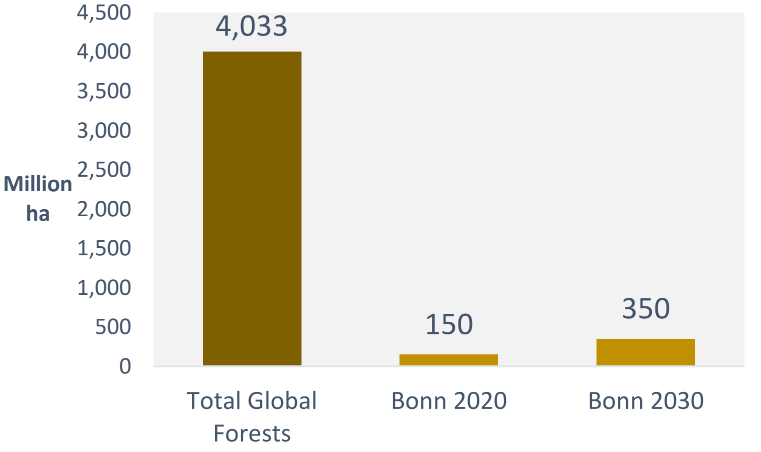
Globally, total forest cover is approximately 4 billion hectares of which bamboo forestation contributes about 37 million hectares, less than one percent (FAO, 2010). Thus, success in these goals would add 4% and 9% respectively, to total forest cover. (See Figure 2.1.)

To date, however, only 40 countries and seven other parties have made commitments under the Bonn Challenge. (See Appendix One.) The present commitments total only 94 million hectares by 2020 (63% of the 2020 goal) and 168 million hectares by 2030 (46% of the 2030 goal). (See Figure 2.2) The total Bonn Challenge goals and even the partial commitments against those goals might seem like encouraging objectives. That is until they are put in the context of continuing annual deforestation. In 2016, the earth experienced record net deforestation of nearly 30 million hectares. Said differently, if the total 168 million nominal commitment is achieved by 2030, but deforestation rates continue near that of 2016, at the end of 2030, the earth will still have a net reduction of 221 million hectares of forest or about 10% of the earth’s remaining forests.

Under the Bonn Challenge, each participant is free to detail its reforestation and restoration as fits its local climate, growing conditions and economic exigencies. Unfortunately, many participants have barely begun their implementation and many participants still lack the funding to pursue their adopted goals. Interestingly, despite the reality that different tree species with different growth rates can serve as the base population for reforestation, no participant reports plans that incorporate the speed of reforestation. It is possible that the desire to preserve or restore perceived historical biodiversity is inhibiting tree species selection other than as is found in the legacy population. Moreover, fast growing timber bamboo is not explicitly included in the Bonn Challenge.

Regionally, Initiative 20x20, adopted in Lima, Peru in 2014, sets 2020 reforestation and conservation goals for 17 Latin American and Caribbean countries and three regional authorities. (See Appendix One.) Unlike other regions, nearly half of greenhouse gas emissions in Latin America and the Caribbean derive from deforestation, land-use change and agriculture. Thus, the parties in this region sought a reforestation/conservation approach that more aptly fits them but still counts towards their targets in the Bonn Challenge totals. Presently, about 50 million hectares are targeted under Initiative 20x20 (WRI, 2018). (See Figure 2.2.) Little information is available on the specifics of each participant’s plan, but no participant highlights the speed of forest growth or of carbon capture. Moreover, even though many of the Latin American countries are native habitats for multiple species of fast-growing timber bamboo, timber bamboo is also not explicitly included in the Initiative 20x20.

2.1 Global Forest Cover and Bonn Challenge Goals

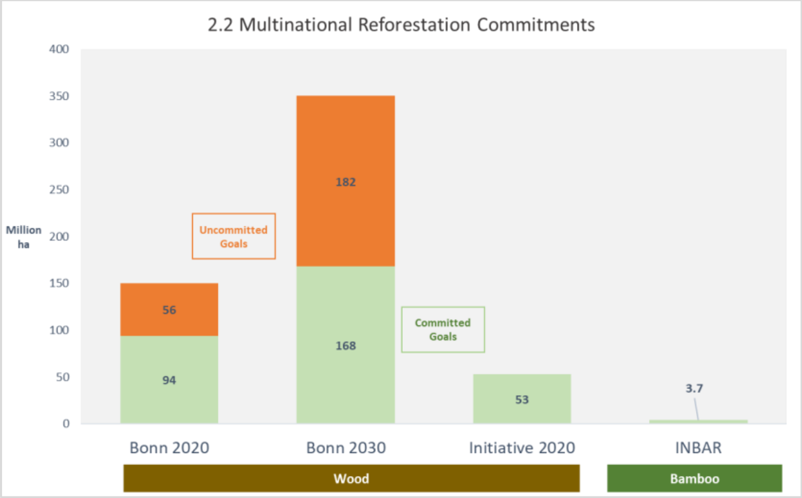


---

[10] Afforestation, strictly speaking, is the net addition of forest cover compared to that which exists today. In its 2020 Bonn Challenge and Initiative 2020 forms, it is operationalized as an increase in forest cover largely through reforestation and restoration of deforested and degrade ecosystems.

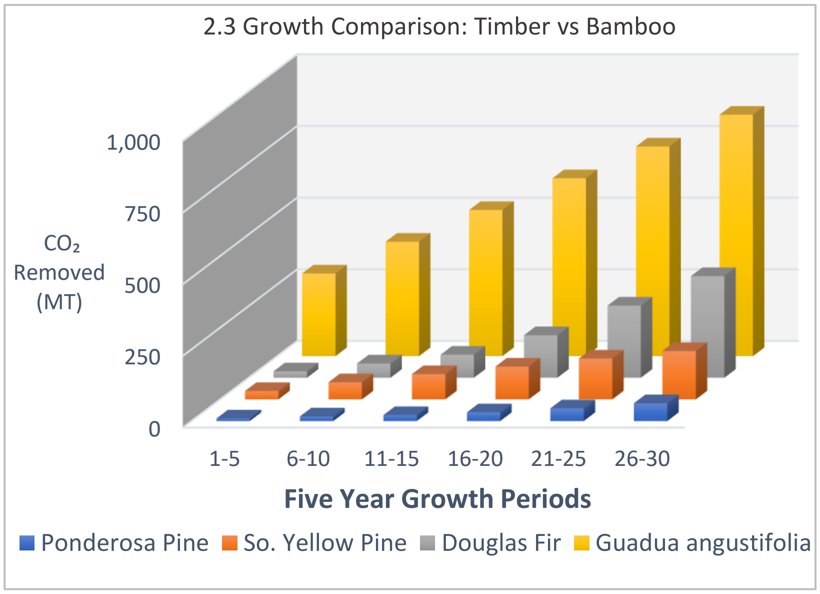
[11] The Bonn Challenge derives from the Earth Summit in 1992 and was advanced by the German government and the International Union for Conservation of Nature. The IUCN is comprised of 216 states and government agencies and over 1100 Non-Government Organizations.

Bamboo Afforestation/Reforestation. The only direct inclusion of timber bamboo into A/R mitigation plans has been through members of INBAR, the International Network for Bamboo and Rattan. INBAR, which counts 44-member nations including Canada, but not the United States, is part NGO and part diplomatic and development campaign sponsored by the People's Republic of China. Of the 44 members, 18 have expressed plans for bamboo-based reforestation totaling 3.7 million hectares by 2020, which represents an increase of about 10% of the present standing stalk of bamboo forests. (See Appendix One.) Of these 3.7 million hectares nearly 2.2 million are in Africa. A survey of INBAR members revealed that more than half of the INBAR respondents were impeded in their efforts to pursue timber bamboo restoration due to insufficient financial resources (94%), lack of knowledge of bamboo processing technologies (83%), and lack of technical knowledge of bamboo species, nursery establishment and plantation and management (72%) (INBAR, 2018). Obviously, to the extent that there is market rate commercial demand for the harvested "wood" products from timber bamboo plantations the most significant of these impediments lessens or disappears.



In "BamCore and Global Warming," we compared timber bamboo afforestation with tree afforestation. We noted that tree afforestation was immediately available and possible across a wide range of habitats, but that its total carbon capture was smaller per land-area used and was slower than timber bamboo sequestration. Our analysis showed that when regularly harvesting stands of a Latin American timber bamboo species, *Guadua angustifolia*, (by intercutting, not clear cutting) for use in durable building products timber bamboo A/R substantially outpaced the sequestration achieved by three North American tree species also used for durable building products. (See Figure 2.3.) Research by others has reached a similar conclusion, including that Asian timber bamboo (Moso), compared to several fast-growing Asian wood species, is at least 2.5x more potent as a sequestration engine than wood (Nath, et al., 2015) (INBAR, 2010).

If time is of the essence in fighting climate change and if timber bamboo is a more potent sequestration medium that trees, then why hasn't there been a broader adoption of bamboo A/R? Besides some of the answers reported above, we also think that there is a broad lack of awareness about the opportunity for mankind to harness nature's strongest and fastest growing botanical fiber. In part the lack of awareness could result from the fact that bamboo today occupies only 37 million hectares of global forest cover or less than 1% (FAO 2010)[12]. Moreover, bamboo habitats are predominantly in the developing world, in the tropics and subtropics, while much of the climate change research and policy directives derive from the temperate climate, developed nations. As a result, bamboo simply has less research, fewer publications and diminished resources focused on its opportunistic exploitation compared to wood.



Climate Change Mitigation (Sequestration) as an A/R Driver. The two international A/R initiatives discussed above derive their impetus from the Rio de Janeiro Earth Summit of 1992 and are more directed at sustainable development, biodiversity and ecosystem restoration, than they are at climate change or carbon sequestration. (UN, 1992)

---

[12] The area reported in Global Forest Resources Assessment 2010 is only 31.1 million ha, to which we have added 2 million has for Indonesia which was eliminated from the 2010 report but present in prior reports.

If the Bonn Challenge and Initiative 20x20 are effective as originally conceived, atmospheric carbon capture will most likely be a collateral benefit. The International Union for Conservation of Nature, a sponsor of the Bonn Challenge, estimated that achieving the 2020 goal would sequester 270 million tonnes of atmospheric carbon capture per year. This contrasts with the 28 to 280 billion tons that the IPCC recently projected will be needed from all sequestration options like A/R prior to 2100. (IPCC, 2018) That is, even if all the Bonn Challenge 2020 commitments were kept as wood A/R projects they would provide only 1% of the absolute minimum that IPCC indicates is needed from global CO_2 sequestration.

Specifically, relative to combined sequestration results from agricultural, forestry and land-use ("AFOLU") projects needing to capture CO_2 equivalents, the IPCC suggested that we need (IPCCC 2018):

- Up to 5 billion tonnes (gigatonnes) **per year by year 2030**,
- From 1 to 11 billion tonnes (gigatonnes) per year by year 2050, and
- From 1 to 5 billion tonnes (gigatonnes) per year by 2100.

In context that means that the failed 2020 commitments don't cover even one year of what the IPCC suggested is needed from forestry and other AFOLU sequestration projects.

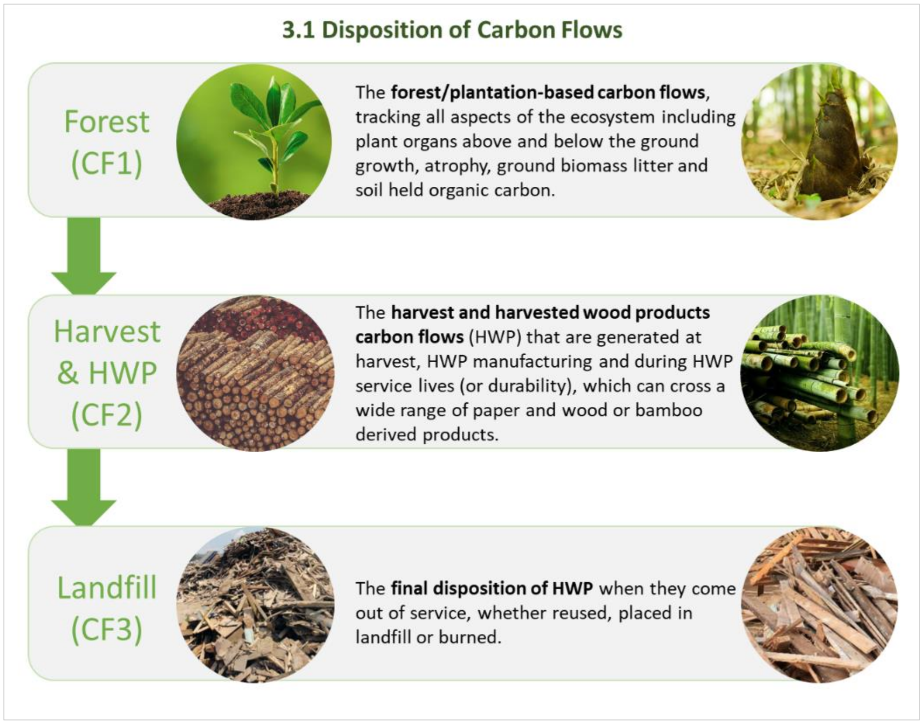
In the 26 years since the Earth Summit, the need to mitigate accelerating climate change has become paramount. Our view is that implementing A/R schemes must now intentionally anticipate and incorporate the need for near term carbon capture. To this end consideration of timber bamboo, which has significant sequestration timing advantages, needs to be embraced, studied and included. Regrettably the greater good of the earth, may not sensibly accommodate both a return to precise historical biodiversity and the imminent need for carbon capture and storage in A/R projects.

In the next section we compute estimates of the absolute values of carbon flows from timber bamboo and wood A/R. To do this, we employ a rigorous model for forestry sequestration developed by a team of researchers at the US Department of Agriculture Forest Service. Parallel to this we build the first generalized model for timber bamboo. Comparing the results will reveal the substantially greater sequestration potential of timber bamboo compared to wood in absolute cumulative terms, i.e. without any time discounting. In the final section we re-evaluate the absolute carbon flows by time weighting them to highlight the criticality of early action in fighting climate change. Once time-weighted, we complete a set of Scenario Analyses to test the robustness of the model's assumptions and the impact of time-weighting the annual carbon flows.

3. Projecting Carbon Flows from Wood and Timber Bamboo A/R

The urgency to choose the most potent and effective A/R alternative to achieve near term CDR is clear. The tools to compare alternatives, however, have not been available. Commercial wood forestry is well studied and has a deep published literature that has produced robust models with projections of longitudinal carbon flows from wood A/R projects, such as the USFS model. The climate policy and climate science communities assume that wood A/R is a ready and capable engine of CDR, but they have not asked if it is our most potent A/R alternative. Timber bamboo A/R has been overlooked by mainstream climate science and there exists no known timber bamboo A/R model that can project longitudinal carbon flows across multiple species to compare to wood A/R. To construct the comparison of timber bamboo and wood A/R alternatives, we begin with the USFS Forest Service's carbon flow model for wood A/R and then build a generalize carbon flow model for multiple species and locations of timber bamboo A/R that can be directly compared to the wood results from the USFS model. This newly built A/R model for timber bamboo is termed the generalized model of timber bamboo carbon flows or simply the "BC model."

The USFS model "Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States" is built from ten forestry-derived carbon pools constructed under the IPCC guidelines published in 2003 (Smith, et al., 2005). The USFS model is intended to provide open access for analysis of "other harvest quantities, stand ages and forest types," which allows us to directly compare USFS modeled wood-based carbon flows with BC modeled timber bamboo-based carbon flows across multiple species and growing locations. The calculation framework of both the USFS and the BC models incorporates all three sets of carbon flows that are attributed to an A/R project. (See Figure 3.1.)



3.1 Disposition of Carbon Flows

The **forest/plantation-based carbon flows**, tracking all aspects of the ecosystem including plant organs above and below the ground growth, atrophy, ground biomass litter and soil held organic carbon.

The **harvest and harvested wood products carbon flows** (HWP) that are generated at harvest, HWP manufacturing and during HWP service lives (or durability), which can cross a wide range of paper and wood or bamboo derived products.

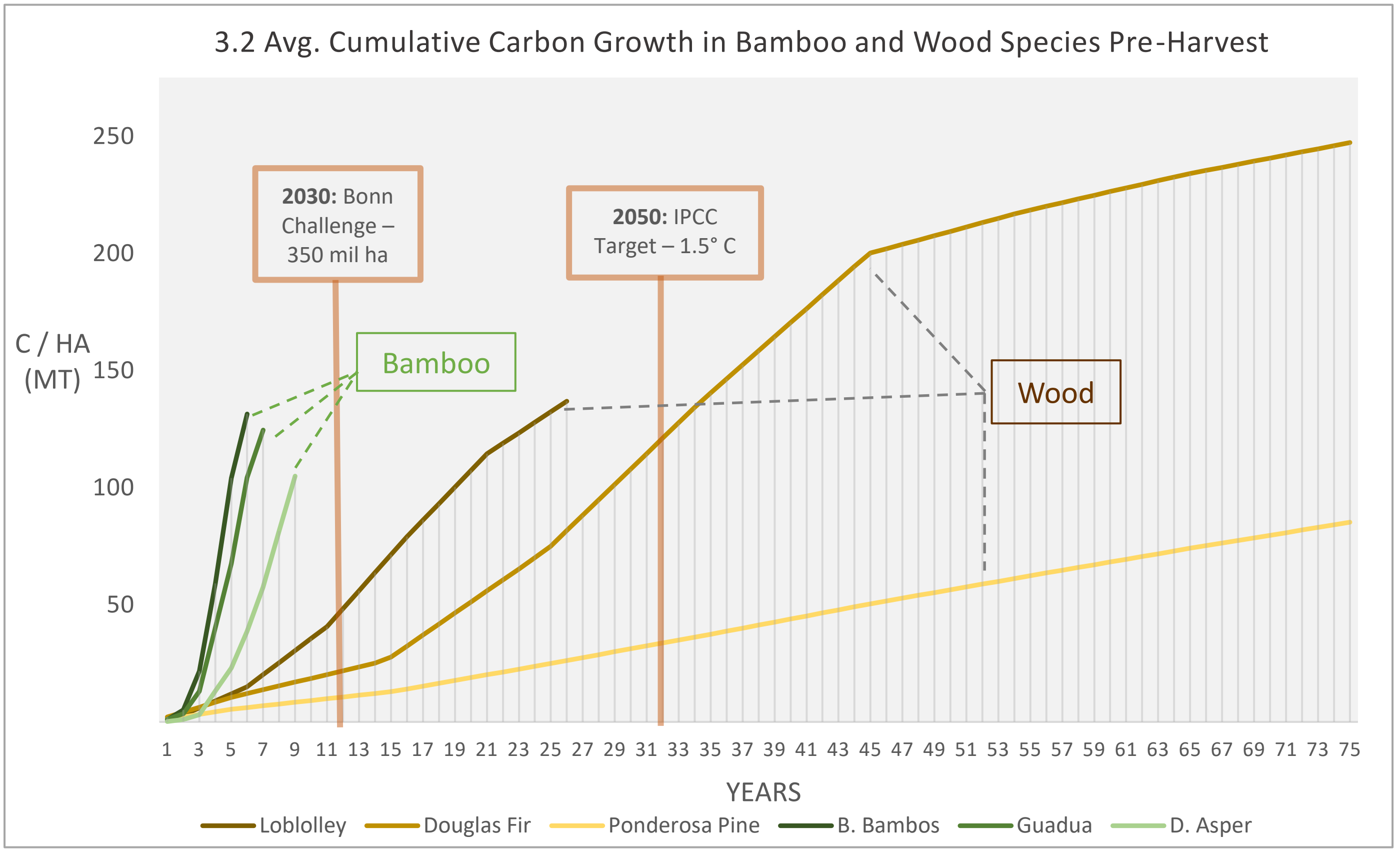
The **final disposition of HWP** when they come out of service, whether reused, placed in landfill or burned.

Because bamboo is a grass, timber bamboo grows very differently than wood, generating very different forest-based carbon flows (CF1). This growth and development-based difference then drives earlier but regular partial harvests and storage into HWP (CF2). When assumed HWP is taken out of service, the disposition of carbon flows is the same, except for the earlier timing of bamboo HWP (CF3). In presenting the results in this section, we use inputs to the models that we expect to be the most likely. The presented results are therefore the Expected or Base Case results. In Section 4, we will also present Low and High Cases to reflect an understanding of the sensitivity to various inputs. Finally, we construct a Scenario Analysis to reflect weightings of the various cases.

Modeling Forest/Plantation-based Carbon Flows (CF1).

For timber bamboo, as described in the BC model, we used available annual growth data for three species (*Guadua angustifolia, Dendrocalamus asper* and *Bambusa bambos*) and built a generalized model of timber bamboo A/R carbon flows. The model was then cross-fitted to an additional five locations for the three species for a total of eight species-locations projections. By fitting the model of one species to multiple locations for that species we are expanding the reliability and applicability of the generalized carbon flow projections. For wood, we chose three species from the USFS model: *Douglas fir*, the largest growing commercial timber species in North America, *Loblolley*, the fastest growing and most widely planted commercial species in North America and *Ponderosa Pine*, a commonly planted and widely used species. Using these three species, we extracted wood-based carbon flows from the USFS model for a total of seven species-locations.

Figure 3.2 below shows the accumulated carbon during the growth periods for the three timber bamboo species averaged across the eight locations and the three commercial wood species averaged across the seven locations. Notice how much faster the timber bamboo plantation can accumulate sequestered carbon per hectare. By the ninth year, all three species of bamboo have accumulated more than 100 tonnes of C/ha. In contrast, *Loblolley*, the fastest growing commercial species doesn't accumulate 100 tonnes/hectare until year 18, which is twice as long as the slowest of the three timber bamboo species. The largest growing wood species, *Douglas fir*, doesn't accumulate the 100 tonnes/ha until year 27, which is three times longer than the slowest of the three timber bamboo species. The third commercial wood species, Ponderosa Pine, hasn't reached the 100 tonnes/ha mark by year 75 when the plantation is presumed to be harvested. Immediately, these forest or plantation level comparisons point to timber bamboo as embodying a potent timing benefit compared to wood in A/R projects.



To model the carbon flows coming from growth and accumulation in the commercial wood plantation, we use the USFS model as configured for each species-location, but without harvest events or HWP production. To model the carbon flows coming from the bamboo plantations, but without harvest events or HWP production, the BC model incorporates a total of 42 variables.[13] Our intent is to manage all the known growth and accumulation dynamics that have been observed in both natural and commercial bamboo plantings while focusing on commercial plantings. Among the 42 growth and accumulation inputs separately modeled are:

- Annual growth and accumulation of biomass (and thus carbon) above and below ground separately,
- Distribution of growth and accumulation of biomass by plant organ,
- Ground litter development lag and prevalence,
- Age of first harvestable biomass from planting and age of culm when first harvested
- Gregarious or mast flowering by percentage, including pre-emptive harvestability and lag to replant
- Post maturity growth and accumulation rates and caps from maximum accumulation during "equilibrium"

Modeling Harvest Occurrence and HWP Production (CF2).

Harvest cycles for wood are as projected in the seven selected harvest locations and range from 25 to 75 years. In the USFS model each of the seven locations has a different

---

[13] We appreciate the insights and input of Hormilson Cruz Rios of SurBambu regarding plantation practices in timber bamboo.

allocation of the specific HWP produced based on historical data available to the USFS. However, to achieve comparability with bamboo, we constrain both wood and timber bamboo to only two HWP options--paper and oriented strand board OSB. These two HWP have maximally different service half-lives. This allows us to vary the relative portion of paper and OSB to test impact of HWP half-life on carbon flows and to isolate the projected CDR from location specific HWP histories for wood. Harvest cycles for bamboo across the eight locations are always annual, starting between six and nine years after initial planting and growing to a steady state upon the stand reaching final maturity, all of which is species dependent.

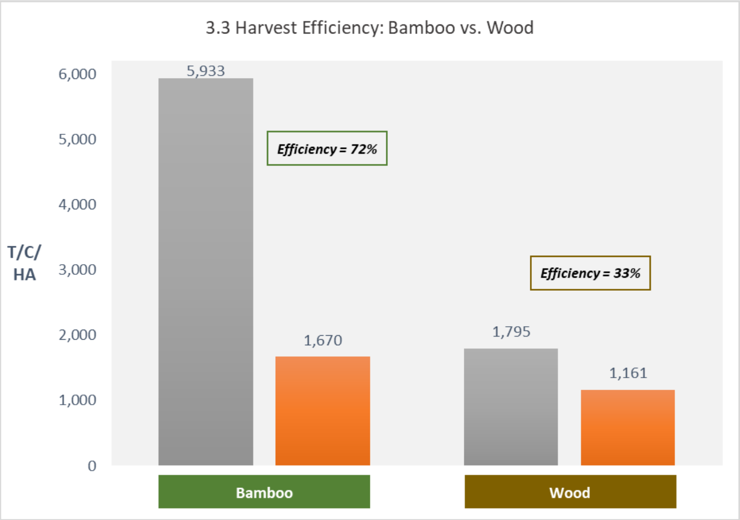
As explained above, both timber bamboo and wood stands (forests or plantations) exhibit declining annual net biomass accumulation once they enter their mature phase. Only if fiber is harvested and stored in durable Harvested Wood Products, can a forest or commercial plantation continue to capture significant amounts of carbon in the regenerated biomass. There are three significant differences between timber bamboo and wood relative to the harvest occurrence and any resulting HWP production.

(1) Commercial softwoods are harvested in much longer cycles ranging from seldom less than 25 years to often more than 75 years. In contrast, once a bamboo stand reaches initial maturity between seven and 10 years, mature culms that are two years or older can be harvested from paper and pulp, while culms three years or older can be harvested for more durable HWP production, such as building materials.

(2) Commercial softwoods are most frequently harvested by clear-cutting or very significant partial cutting. Admitted clear cutting accounts for 40% of all US forestry harvests and 90% of all Canadian forestry harvests. In North America, approximately 2.6 million hectares are clear cut annually. (Masek, et al., 2011) Partial and selective cutting may still be followed by a clear-cutting. In contrast, timber bamboo is never clear-cut. Once a bamboo stand is mature, it is usually intercut annually or biennially when structurally mature culms are harvested individually from clumps of culms. This allows the rhizome to continue pushing up new shoots to replace the harvested culm. For trees, successful competition for sunlight is a main determinant of growth since clear cutting allows all trees in a given area to be replanted without any competing canopy. In contrast, bamboo, like all grasses, regenerates a new plant from the same underground rhizome that has already accumulated the required nutrients to push the next new shoot up to a full height culm in the next growing season.[14]

(3) The efficiency that harvested softwoods are turned into HWP is low compared to timber bamboo. This is an important difference between wood and timber bamboo that is difficult to overstate. The lower the conversion efficiency the higher the carbon emissions at time of harvest.

For wood, the USFS model directly incorporates these three elements for each of the species and forest types covered. For timber bamboo the BC model incorporates these elements. The USFS model includes two stages of conversion efficiency. The first stage occurs in the field at the time of harvest. That is, what portion of the felled tree is converted to roundwood that is taken to the mill versus what portions are left on the ground to decay or otherwise emit carbon. The second stage is the waste that is produced during the production of the HWP. By restricting our HWP options to parallel relative amounts of paper and OSB, we avoid confounding factors from specific HWP production allowing us to focus on the core wood versus timber bamboo comparison.



Two perceptions about wood harvests should be mentioned. First, the general perception is that wood efficiently captures and stores CO_2 when harvested and converted to HWP. While wood A/R is proposed and pursued as an earth-wide CDR mechanism, its harvest and HWP conversion efficiency are disappointingly far from the general perception. It is also far from the projections of timber bamboo. Figure 3.3 shows the average gross and net capture and emission for harvesting wood and timber bamboo plantations over 100 years. These projections were made using data from the USDA model and the base case of the BC model. Moreover, in-field assessments demonstrate that disruptions from “harvest of mature …

---

[14] We appreciate the input of Roger Lewis of Resource Fiber LLC on the rhizomal growth of selected bamboo species.

forest[s]…generally result in a net loss of carbon storage that would not be offset by storage in harvested wood or regained by forest growth for more than a century." (Allred, 2008)

Second, there has been a specific perception among climate scientists that when wood is harvested and burned for bioenergy it can be considered carbon neutral because the stand of wood producing the fuel will in turn regrow and absorb the carbon emitted. This is reflected in the Global Warming Potential *bio* metric ("GWP_{bio}"), which presumes that the GWP from biogenic sources is zero or carbon neutral.[15] However, recent research questions the claim of carbon neutrality of biogenic sources because of the long rotation or harvest cycles for most wood. (Holtsmark, 2015). Only when the source is a very short harvest cycle like a perennial grass can the emissions from biogenic fuel be considered carbon neutral (Liu, 2017). Timber bamboo is a perennial grass with a short harvest cycle of 5 to 10 years compared to the fastest growing woods of 15-18 years, while most woods have harvest cycles that exceed 50 years.

To model the carbon flows coming from wood harvest and HWP production, we use the USFS model as configured for each of the seven species-locations but constrain HWP to paper and OSB as discussed above. To model the carbon flows coming from timber bamboo harvest and HWP production and emission waste, the BC model specifies:

- The vintage of the culms being harvested annually,
- The portions of the culm and above ground biomass that will be productized versus emitted as waste,
- A transit burden to transport timber bamboo raw material from harvest locations in the tropics, and
- The proportion of mast flowering as appropriate by species, and when occurring the portion of culms harvestable followed by a configurable planting lag.

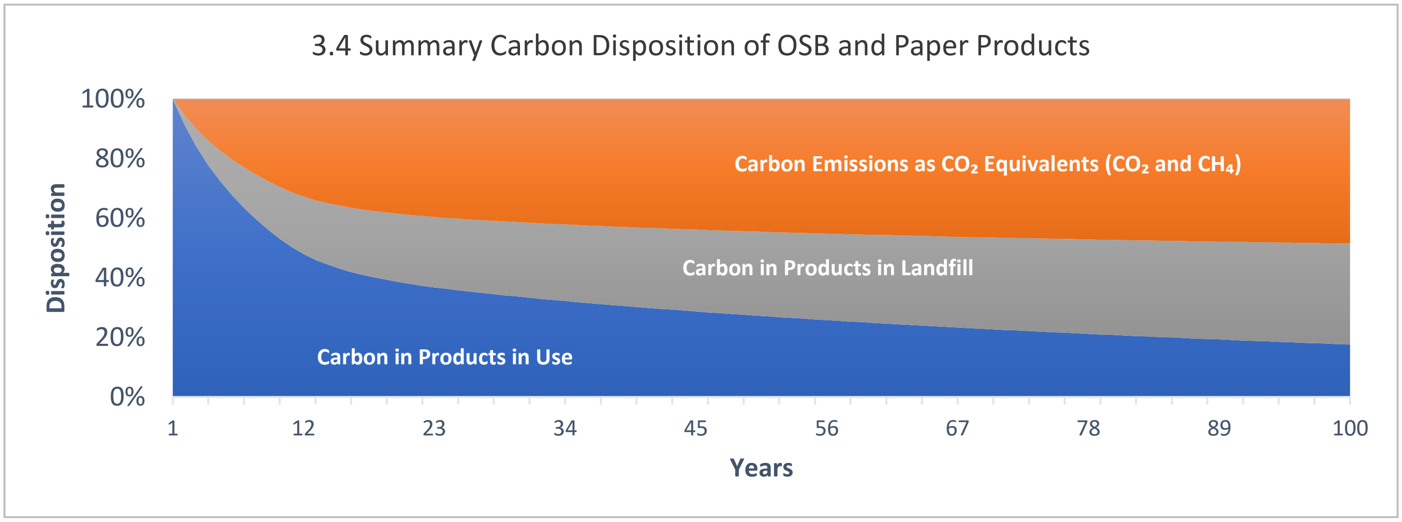
---

[15] We appreciate the input of Simon Gmuender of Quantis International on GWP_{bio}.

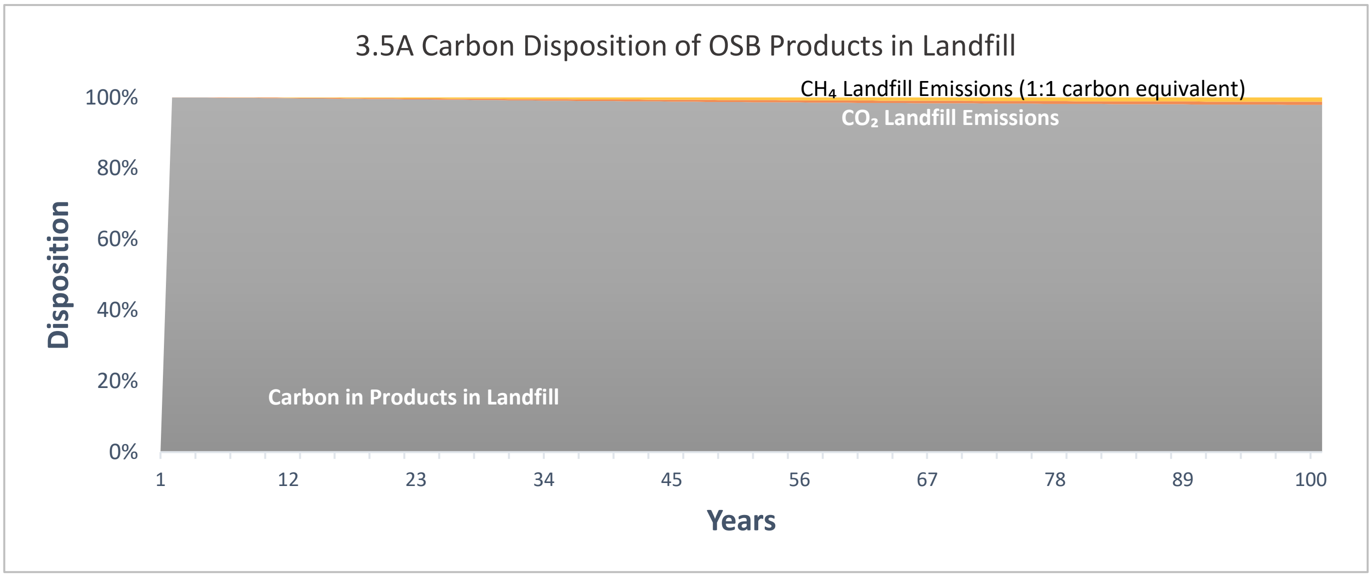
Modeling HWP Final Disposition, Landfill and Methane (CF3). Because we constrain HWP to only paper and OSB in the same proportions for both timber bamboo and wood, the modeling of HWP carbon flows is identical for wood and timber bamboo. The BC model and the USFS model both use the USFS half-life functions for HWP service life and the end of life allocations between emissions and landfill deposition. For the portion in landfills, however, we update the emission projections based on research that became available following the publication of the USFS model. The USFS model, as published, used simplistic assumptions for: (1) the portion of HWP that was degradable in landfills, (2) when the degradation initiates and (3) how long the degradation occurs before reaching the non-degradable residual state. More current research allowed us to make projections that treated each of these three inputs independently for paper versus OSB. (Ximenes, et al., 2015)

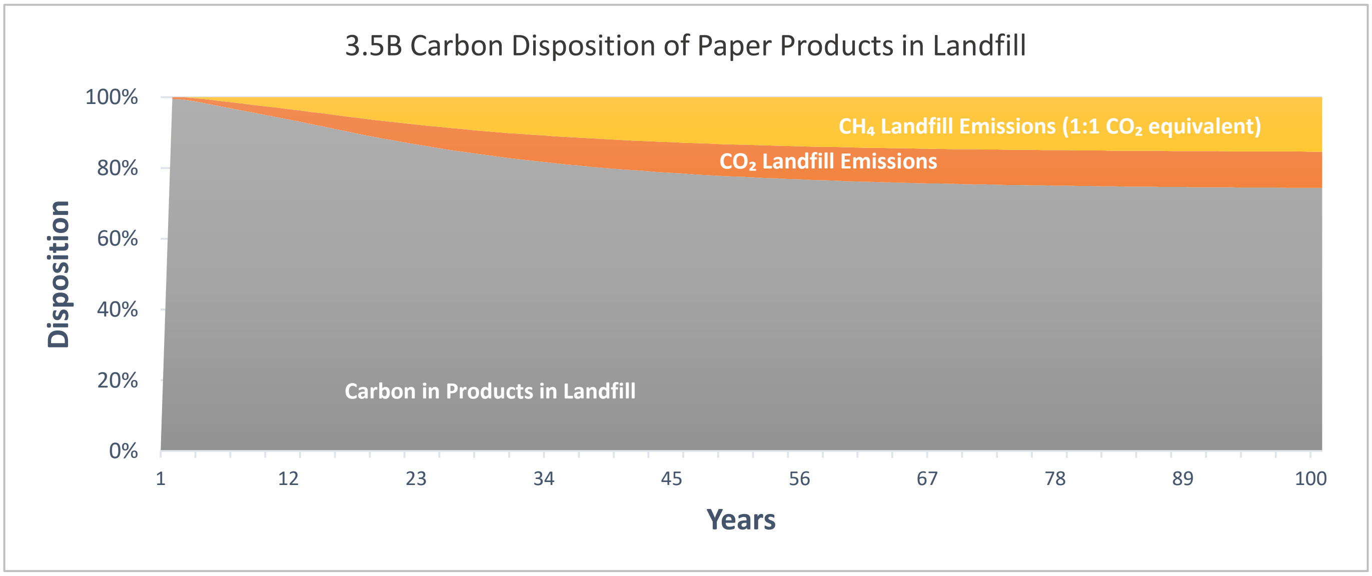
In addition, the USFS model assumed all landfill emissions were CO_2, resulting from commonly observed aerobic digestion in landfills. However, methane, a far more powerful greenhouse gas than CO_2, is known to be emitted from landfills as a result of anaerobic fermentation. The presumed potency of methane is a function of the framework analyzed and is not currently resolved in IPCC Inventory Guidelines or in the climate science literature. Methane potency is most frequently stated in terms of CO_2 equivalents. The CO_2 equivalent of methane ranges from one molecule of methane equaling one molecule of CO_2 to 72 molecules of CO_2. Given this large range and the fact that timber bamboo is producing HWP that ends up in landfill far sooner than wood HWP does, we felt it critical to test the impact of possible methane emissions resulting from HWP landfill accumulations. The result of sensitivity analysis on methane to CO_2 equivalents was revealing but generally did not diminish the conclusion below about the overall performance of timber bamboo compared to wood A/R projects. In fact, as we increased the CO_2 equivalent, the bamboo-based A/R produced better results than did the wood-based A/R. At 1:1, 21:1 and 47:1 CO_2 equivalents, the Carbon Benefit Multiple for timber bamboo relative to wood was 4.9x, 5.2x and 5.8x, respectively. At the high end of the CO_2 equivalents, 72x, the CBM for bamboo A/R rose to 10x that of wood A/R.

Figure 3.4 shows the disposition of carbon across the entire cradle-to-grave of timber bamboo and wood projects for our Base Case Scenario. Carbon flows through the product ecosystem as an in-use product before being discarded to either a landfill or burned and immediately emitted as CO_2.



Once carbon in a discarded product enters a landfill, it will begin the aerobic degradation process, emitting carbon dioxide based on a specified decay function or it will remain intact if the HWP is non-degradable. Because the same proportions of paper and OSB are used for both timber bamboo and wood, once the HWP is in landfill the half-life functions are identical for residual and emission proportions for both timber bamboo and wood. Figure 3.5A and 3.5B describe the disposition of carbon in, and emitted from, a landfill for both OSB and Paper product, respectively. Notice only a small fraction of OSB degrades. In reality very little (3%) of wood products and only (26%) of paper products degrade in landfills (Micales & Skog, 1996).



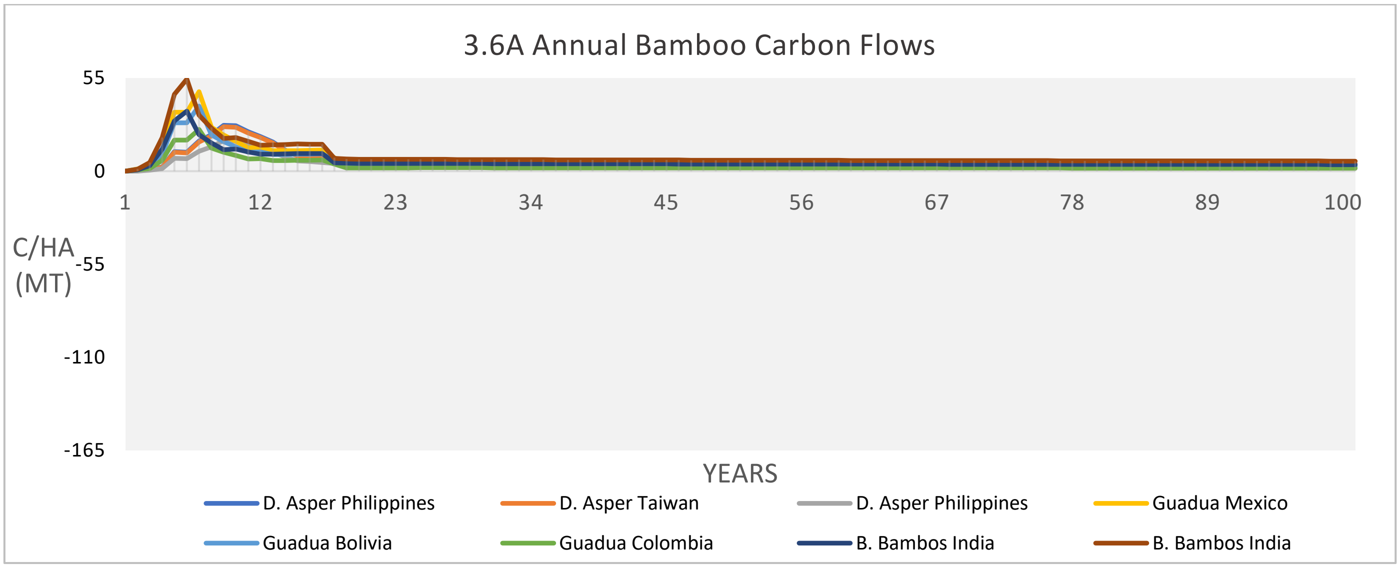


To model the carbon flows during HWP service life and landfill degradation, we use the USFS model as configured for each of the seven species-locations but constrain HWP to paper and OSB as discussed above. To model the carbon flows coming from timber bamboo harvest and HWP production and emission waste, the BC model specifies:

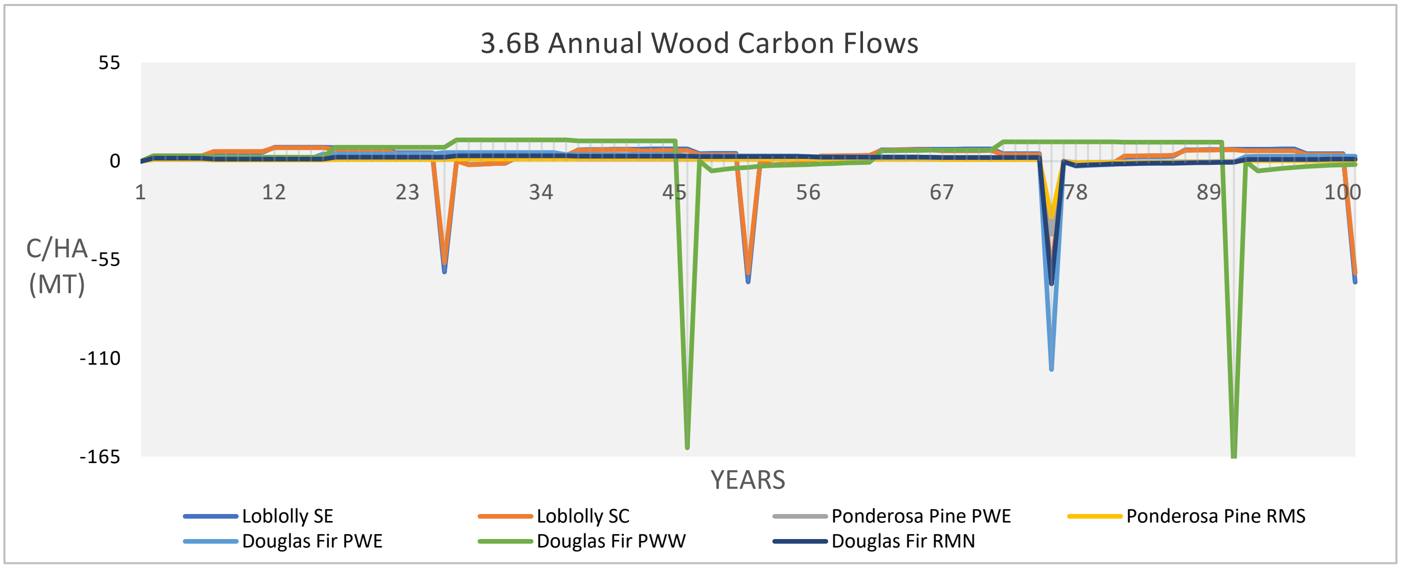
- The portions of paper and OSB that are discarded to landfills versus emitted following use by being burned,
- The portions of paper and OSB that are degradable versus the final inert landfill residuals,
- The separate half-life assumptions for the degradable portions of paper and OSB,
- The separate lag periods before degradation begins,
- The portions of the degradable portions that will be emitted as CO_2 versus methane, and
- The CO_2 equivalent level for the methane emitted portion.

Carbon Flow Projections (Expected Case) for Each Species-Location. The final output of the USFS and BC models is annual net carbon flows. Recognizing that numerous inputs are required for both models, we present only the Expected or Base Case projection in this section, and subsequently present additional Low and High Cases in Section 4. The net carbon flows can be presented visually in three ways: the net annual flows, the accumulation of the annual flows or as a present value summary (see Carbon Benefit Multiple, Section 4). In Figures 3.6 A & B we present the net annual carbon flows separately for timber bamboo and wood. The eight independent curves in Figures 3.6A and 3.7A and the seven independent curves in Figures 3.6B and 3.7B depict the net annual carbon flow projections for each of the species-locations for timber bamboo and wood, respectively.

For the timber bamboo annual carbon flow projections shown in Figure 3.6A, the protruding positive projections show the carbon capture during early period initial growth out to about year 16. Since these three species are not known to mast flower, there are no observable negative flows in the projections (though mast flowering is captured in the Low Case, see below). [16]



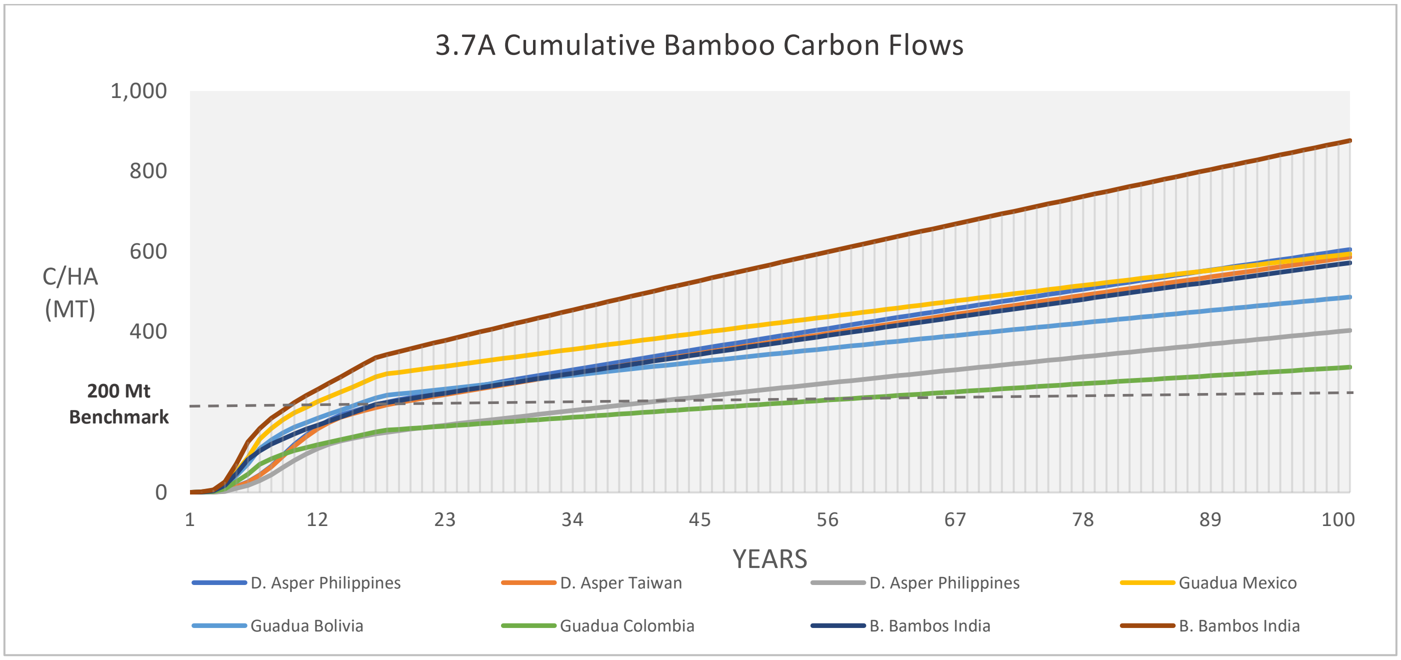
For the wood annual carbon flow projections shown in Figure 3.6B, there are no early positive protruding projections because of the slower growth of the wood. The large negative (downward) protruding projections for wood depict the significant net carbon emissions that occur at the time of harvest for wood.



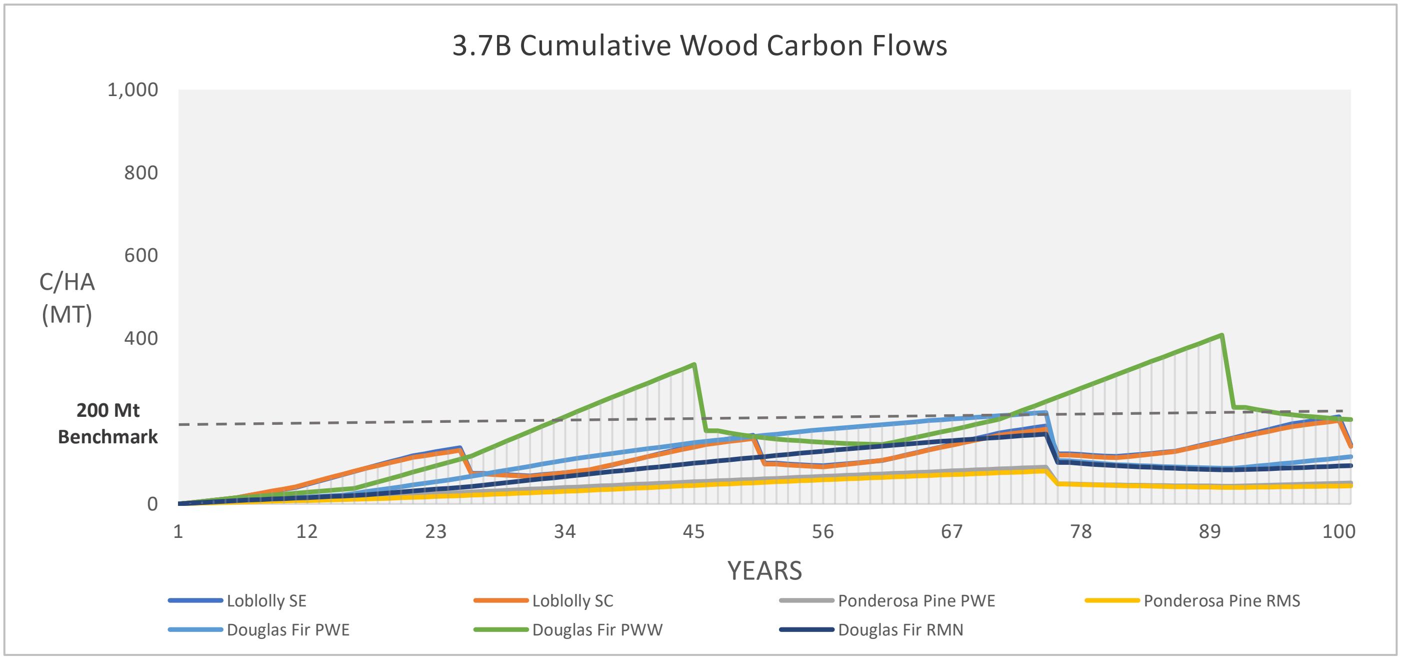
---

[16] Mast flowering or gregarious flowering, which has been observed in some bamboo species and not others, is the infrequent simultaneous flowering of a species across a large geographic area, following which the flowering members of the species die. Species known to mass flower do in long cycles ranging from 30 to over 100 years. (See Hinkle 2018 for more discussion.)

In Figures 3.7 A&B we present the accumulation of the above net annual flows. The eight independent curves in Figure 3.7A and the seven independent curves in Figure 3.7B depict the accumulation of net annual carbon flows for each of the species-location pairings for timber bamboo and wood, respectively. For timber bamboo shown in Figure 3.7A, the accumulation begins early and is continuous due to the presence of regular HWP and the absence of any mast flowering in the Expected Case (none of these three species have documented mast flowering). For a more complete discussion of the prevalence of mast flowering see the co-published paper. Notice that the six of the eight species-locations exceed a 200 Mt/ha benchmark by year 12.



For wood, shown in Figure 3.7B, the accumulation of captured carbon takes far longer and remains a lower level than for timber bamboo. The precipitous declines in cumulative carbon capture are the result of emissions that occur at harvest that substantially offset the otherwise cumulative carbon capture. Notice that none of the seven species-locations for wood reach the 200Mt/ha benchmark until year 45 (or approximately 2065, when CDR is of far less value) and then only the same species-location exceeds 200 Mt/ha again another 45 years later.



The average total of accumulation of carbon in mt/ha across the eight timber bamboo projections is 555 Mt, while for wood that average totals 112 mt/ha. The incremental accumulation of carbon by timber bamboo compared to wood is 443 mt/ha or 1,625 mt/ha when stated as CO_2.

4. Rational Decision Making Between Wood and Timber Bamboo AR – the Carbon Benefit Multiple

Assuming the carbon flow models presented above produce realistic projections to compare multiple species of timber bamboo and wood A/R alternatives, in order to complete a rational decision between the alternatives, we need to construct a framework that can incorporate the following:

1. Expected, Low and High Case projection that stress test the specific assumptions or inputs,
2. Time valuing carbon flows to weigh earlier carbon capture more significantly, accordingly to a decision maker's level of concern about climate change,
3. Weighted scenario analysis that include all three Expected, Low and High Cases, but in various weightings to reflect a fuller range of possible future outcomes than just the Expected case, and
4. The Carbon Benefit Multiple, a single point, bottom-line, metric that scales the relative benefit of timber bamboo A/R.

In the body of this section, we introduce each of these elements in the decision framework. Together, they allow us to reach a robust and rational conclusion between the ability of timber bamboo and wood A/R in their respective ability to deliver **near term capture and long-term storage of atmospheric carbon dioxide.** A discussion of the implications of the decision close Section 4.

Expected, Low and High Case Projections. For our timber bamboo carbon flow projections (BC model) we have set the various inputs to levels that best fit our current understanding and expectations. We call this the Expected Case or Base Case. However, because the BC model is novel and thus inherently speculative, we also constructed two outlying cases where inputs are adjusted to increase and decrease the CDR compared to the Expected Case projection. We call these the Low and High Case projections. Figure 4.1 details principal inputs for the Base Case and changes from the base case for the Low and High Cases.

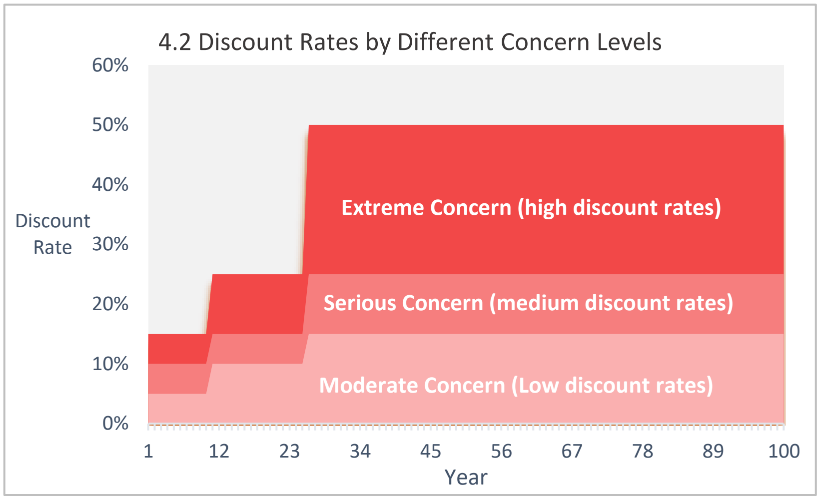
4.1 Principal Inputs for Low, Expected (Base) and High Case Bamboo Carbon Flow Projections

Principal Inputs	**Low**	**Base**	**High**
Mast flowering	Emit 100% of standing Carbon Stock at specified intervals after planting. *Guadua* at 60 years, D. asper and B. *Bambos* at 40 and 82 years respectively.	No mast flowering	No mast flowering
% of mature carbon harvested	30% (↓ 50%)	60%	85% (↑ 41%)
% of harvested carbon productized or emitted in field	70%, 30% (↓ 13%)	80%, 20%	90%, 10% (↑ 13%)
% of carbon in harvested culms turned into durable structural panels, particle board, paper, or emitted during production	50%, 0%, 25%, 25% (↓ 41%)	70%, 15%, 10%, 5%	80%, 15%, 5%, 0% (↑ 12%)
% of non-culm aboveground carbon turned into OSB, paper, or emitted during production	0%, 50%, 50% (↓ 38%)	0%, 80%, 20%	0%, 90%, 10% (↑ 13%)
Equilibrium growth rate scalar (% of the growth rate in the final year of the initial growth period)	30% (↓ 53%)	64%	64% (↑ 0%)

Time Valuing Carbon Flows. A great many of life's decisions reflect the higher value of near-term benefits and the lower value of more distant benefits. Generally, this disproportionate temporal valuation reflects having higher usefulness or confidence in near term benefits and lower usefulness or confidence in more distant benefits. Surprisingly, decision making between climate mitigation alternatives typically does not embrace this impact of time. "Most LCA studies [including carbon flows and footprints] are based on a static calculation, where life cycle balances are calculated including summation of all flows that occur during the study time horizon, regardless of when they occur. Very few LCA studies using time dependent approach are reported in the literature." (Glasare & Haglund, 2016) Advanced climate models implicitly incorporate a timing recognition when comparing alternative scenarios, but time discounted values are oddly not used in targeted decision making between two specific alternatives. Moreover, climate models are highly complex, and little understood by informed policymakers and the billions of individuals making decisions daily that incrementally impact our collective carbon footprints: small and large.

Present Values. To incorporate time value, each annual net carbon flow (capture or emission) is reduced by a percentage discount rate, compounded for the number of years the flow is in the future. The sum of all the discounted carbon flows results in a present period value of all the forward carbons flows. The present value of differently timed carbon flow alternatives can then be rationally compared as traditionally happens in finance and corporate capital investment decision making.

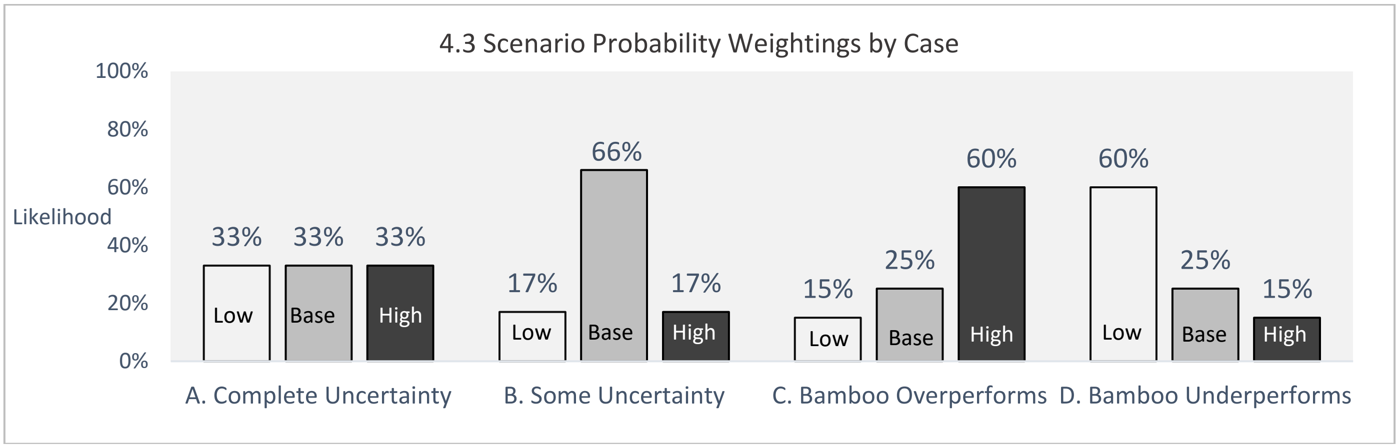
Discount Rates. The choice of the discount rate applied to the future carbon flows is obviously important. Financial discount rates vary by market cycle and perceived risk of the anticipated monetary flows. Broadly, higher discounts rates are used to reflect greater perceived risk or levels of concern about future events. Relative to climate change, if you consider the risk moderate, you would specify lower discount rates, perhaps ranging from 5-10%. If you consider the level of concern serious but not life threatening, you would specify higher discount rates, perhaps between 15 and 25%. Finally, if you consider the level of concern extreme and possibly existential for humanity, you would specify a severe discount rate, perhaps 50% or more. Note though, the specified discount rate does not need to be a fixed percentage for the entire time horizon (exponential discount rates). It can change with time to emphasize the significance of earlier or later outcomes. If you think that immediate action is vital and distant action is futile, then you would specify discount rates that step steeply with time. A large step function is consistent with concern about the accelerating and harmful feedback cycles present in climate dynamics, namely, melting the polar ice caps and the Greenland ice cover or thawing the permafrost soil in the northern hemisphere.


4.2 Discount Rates by Different Concern Levels

While time discounting is seldom incorporated into climate change mitigation analysis, the climate change academic literature has adopted the continuing debate from the finance about exponential versus hyperbolic discount rate streams. However, "the discount rate issue has become a source of significant disagreement." (Goulder & III, 2012) In our analysis here, because climate change mitigation decisions are not preferential decisions as much as they are existential decisions, we hold to the view that inverse hyperbolic discount rate streams is more reflective of the fate that many humans could face. Thus we use a simple step function of discount rates arising over time as rational even though rising discount rates over time are not expected from observations reported in the financial literature.

In our modeling, we construct three present value scenarios to reflect the level of concern of the decision maker about climate change. For each level of concern, the discount rates increase with time (See Figure 4.2 above.)

Weighted Scenario Analysis. When a decision maker is not certain of a particular future projection, it is sensible to combine a range of the possible projections or cases by weighting their respective likelihoods.[17]



In finance this is called scenario analysis – a way to sensitize results not only on a single assumed input but on a combination of inputs, which might otherwise operate independently of one another. Different weightings can be applied to reflect the decision maker's expectation and uncertainty. Equal probabilities assigned to each scenario suggests pure uncertainty about which projection case might occur. Weighting the outliers asymmetrically implies an identified bias across the projections. To complete the Scenario Analysis, we constructed four scenarios, one for complete uncertainty, one for uncertainty but a degree of confidence in the Base Case Scenario, one that biases toward higher timber bamboo CDR and one that biases against timber bamboo, while wood projections remain constant. (See Figure 4.3.)

The Bottom Line: The Carbon Benefit Multiple. The core question we are asking is: Does substituting timber bamboo A/R opportunities produce superior carbon capture and storage (CDR) compared to wood A/R? To answer this question, we developed the above modeling and decision framework that:

1. Generates fully comparable longitudinal carbon flow projections for timber bamboo that can be compared to wood projections for forest growth, harvest and HWP production, and for final disposition,
2. Combines multiple species from multiple locations for both timber bamboo and wood, to avoid cherry picking winners and losers,
3. Projects the timber bamboo carbon flows across Expected, Low and High Cases,
4. Time values the full longitudinal, multi-species net carbon flows across Moderate, Serious or Extreme levels of concern for climate change by using different time discount rates,
5. Constructs and weights compound scenarios to represent different degrees of confidence or bias in the projections.

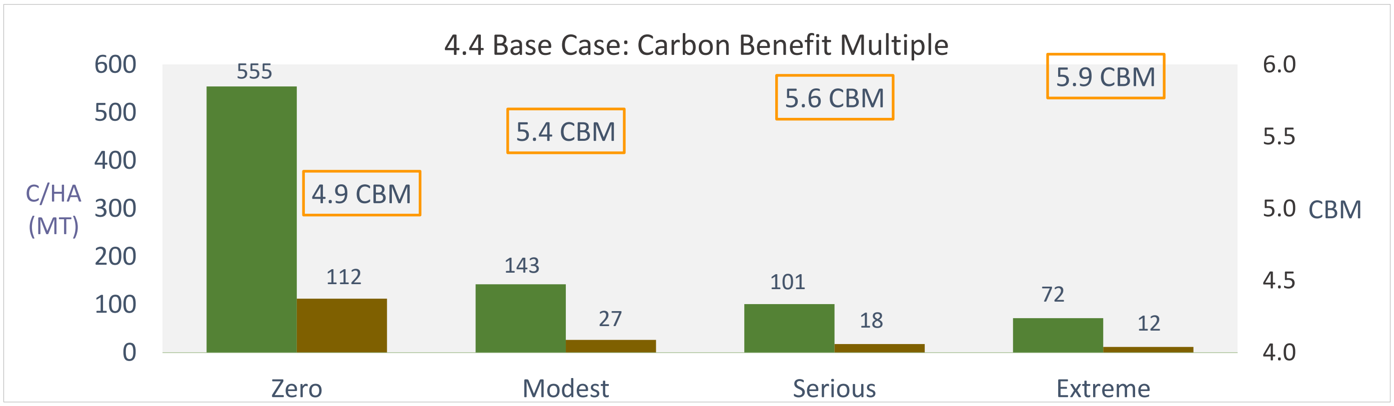
Yet, in the end, policy and decision makers famously require simple bottom line comparisons between alternatives, as in, "Can we just get to the bottom line, please?" We present a final bottom-line comparison in our Carbon Benefit Multiple (CBM), which expresses a ratio of the multi-species, time-weighted, and scenario-weighted carbon flow projections for timber bamboo A/R compared to the same for wood A/R. The multiple simply divides the results of 1-5 above for timber bamboo, by 1-5 above for wood. When the ratio is greater than one, timber bamboo A/R is more potent at delivering CDR than wood A/R is. When the ratio is less than one, wood A/R is more potent at delivering CDR than bamboo A/R is. For example, if the CBM is 1.15, then timber bamboo A/R is 15% more potent delivering time weighted CDR than wood is A/R. If the CBM is 2.75 then timber bamboo A/R is generating 175% more CDR than wood A/R.

Using only the Expected Case for illustrative purposes, Figure 4.4 shows how the Carbon Benefit Multiple is derived by comparing the CDR for timber bamboo across each of the four concern levels. In absolute terms, notice how large the Carbon Benefit Multiple is for timber bamboo compared to wood across all possible concern levels (time valuing) for the Base or Expected Case. These results suggest that timber bamboo A/R systems can be five or more times as potent as wood A/R

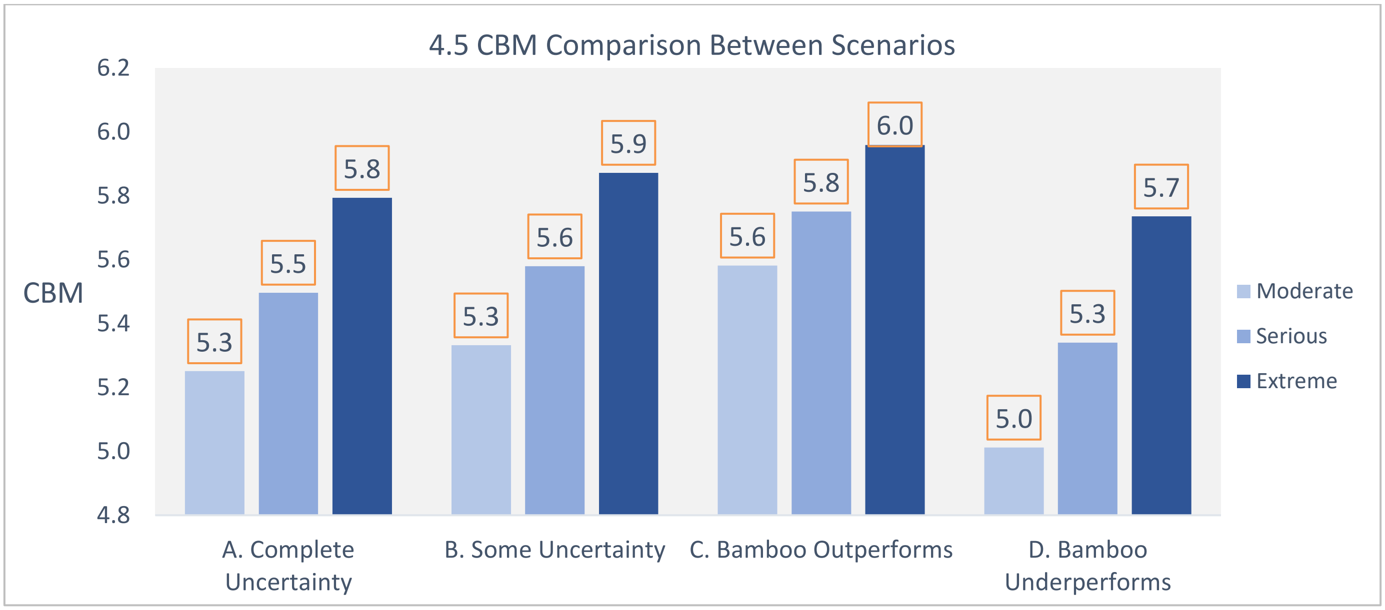
---

[17] In the extreme case of multiple scenarios, the weighted scenario analysis can become a Monte Carlo simulation, which is a common option pricing methodology in finance.

systems, when both systems are undergoing HWP extraction. When comparing the Expected Case results for the three levels of concern (I,e., time discounting), notice the following observations: (1) in the "Zero" time valuing comparison, timber bamboo A/R has a CBM of 4.9x that of wood, (2) in the "Modest " to "Extreme" comparisons, the overall effect of time valuing is to significantly lower the CDR of both timber bamboo and wood by about three-quarters, (3) across the three "Modest" to "Extreme" levels of concern, the CBM rises in favor of timber bamboo as the level of concern about climate change (using higher discount rates) increases. This last observation reflects that prevalence of near-term carbon flows from timber bamboo A/R compared to wood A/R.



When developing and testing the BC model, we did not anticipate that timber bamboo A/R would outperform wood A/R so significantly. Accordingly, when we saw timber bamboo's relatively dominating results, we added the Scenario Analysis to the decision framework to make sure the comparison was completed across a very wide range of inputs. Figure 4.5 shows the completed CBM projections for the four scenarios, which weigh out various likelihoods for the Low, Expected and High Cases.



The figure presents each weighted Scenario result with the three Levels of Concern (time valuing). The Scenario results again show timber bamboo A/R is robustly superior to wood A/R for all Scenarios A-D, generally producing five times the time-valued CDR/hectare of land, when HWP extraction is included for both A/R systems. This remains the finding even in D. Bamboo Underperforms Scenario, where repeated mast flowering is assumed to occur for all three species. As expected, within each of the triplets for all Scenarios, the greater the Level of Concern (higher time value) the greater the CBM for timber bamboo. Because of the critical importance of HWP in A/R systems, we next discuss our company's product contribution to HWP that can help turn bamboo plantations in perpetual carbon farms.

5. Conclusion 1: Carbon Farming with Timber Bamboo Significantly Outperforms Wood

We pursued our present work to establish a rational framework to answer the core question: **Does substituting timber bamboo A/R opportunities produce superior carbon capture and storage (CDR) compared to wood A/R?** At the outset, given the widely published research and focus on wood A/R sequestration, we did not expect the results to necessarily favor timber bamboo and certainly did not expect the magnitude nor robustness to be as we have now reported above. This magnitude is seen when comparing the Carbon Benefit Multiple calculated on the undiscounted Base Case carbon flows in Figure 4.4 with all the final CBMs in Scenarios A to D in Figure 4.5. **Across these comparisons, timber bamboo A/R, when harvested into durable HWP, provides 5x to 6x the amount of carbon dioxide removal than a similar wood A/R project does.** Moreover, the potency of timber bamboo's CDR is so great that in our carefully constructed decision framework, we can find no circumstance, no set of assumptions, no variance in landfill dynamics, no equivalency of methane to CO_2, no level of concern (time discounting) and no degree of scenario uncertainty that alters this basic conclusion.

It is notable that the previously mentioned debate over GWP_{bio} in the academic and policy-making communities may mostly miss the mark about the role of A/R in sequestering carbon and fighting climate change. Fretting about whether biogenic fuels take less than or more than 100 years to regrow in order to be considered "carbon neutral" seems to minimize the crushingly critical concern for current action in our climate crisis. We need to decide *now*, and to act *now*, with a clear understanding of how the results of our actions can achieve **the earliest and most potent carbon sequestration**. For centuries, the financial world has time discounted periodic forward costs and benefits to optimize current period decision-making. When this is done in our rational decision-oriented framework presented in the above sections, the answer to our core question is clear despite the debate over GWP and GWP_{bio}.

We fully understand the considered importance of wood A/R, mangrove ecosystem preservation, and the changes in soil cultivation practices that are needed to address climate change. But, as the US National Academies of Sciences concluded "there are natural limits to the amount of carbon that can be removed from the atmosphere through [wood-based] A/R." (National Research Council, 2015) As we demonstrate here through the Carbon Benefit Multiple results, these limits can be raised by at least several orders of magnitudes when the A/R is timber bamboo based instead of wood based. With very little doubt, our research leads us to these two conclusions:

1. wood and other natural systems-based CDR approaches cannot, and will not, succeed in making near term and meaningful carbon sequestration contributions, but that
2. **timber bamboo A/R significantly out performs wood A/R** providing both **badly needed <u>near term</u> carbon capture** and ultimately **<u>more</u> CDR per hectare of land used**.

If these conclusions are correct, or even half correct, the only way to provide for mankind's growing need for structural fiber and to begin to address global climate change is for policy makers and decisions makers, for consumers and commercial customers to accept and promote **timber bamboo as a new global source of structural fiber and the only realistic near term CDR strategy we have on hand.**

Earlier commenters familiar with bamboo's fast growth have pointed to timber bamboo as a valuable or maybe even superior sequestration system compared to wood. But these assertions have been single point comparisons, not subjected to sensitivity analysis, not time valued and not generalizable. Frequently these assertions simply viewed the carbon content of the standing stock of timber bamboo and compared it favorably to the carbon content of a standing stock of wood. But this also misses the mark. Critically, **successful carbon sequestration from A/R projects depends on the early and regular extraction of Harvested Wood Products and their placement into long-term storage, like the built environment**. Accordingly, in the final section below, we address the use of timber bamboo in the built environment, where the carbon storage can be maximized in both duration and amount.

6. Productizing Timber Bamboo into durable Carbon Storing Products

Timber bamboo's natural regeneration advantage over wood has long been known. However, as explained in Sections 3 and 4, the ability to turn an A/R project into a perpetual carbon farm requires regular partial harvesting and manufacturing of HWP with long service lives. By its fast growth and early and regular harvests, timber bamboo does this. By extension, to drive a new industry of commercially viable perpetual carbon farms requires substantial demand for long-lived bamboo-based HWP. With that demand, bamboo plantations will become commercially attractive and gain incremental A/R investments (where appropriate) thus becoming perpetual carbon farms while providing valuable HWP.

The UNFCCC has incorporated HWP "contributions" into the reporting of national GHG inventories. In addition, many scientists have already highlighted the importance of long-lived HWP toward achieving A/R sequestration. One study reported that HWP contributions in the US already equaled about 20% of all forest carbon capture and "could be increased by … increasing the fraction of wood used in the United States that is stored in long-lived products." (IPCC, 2006)

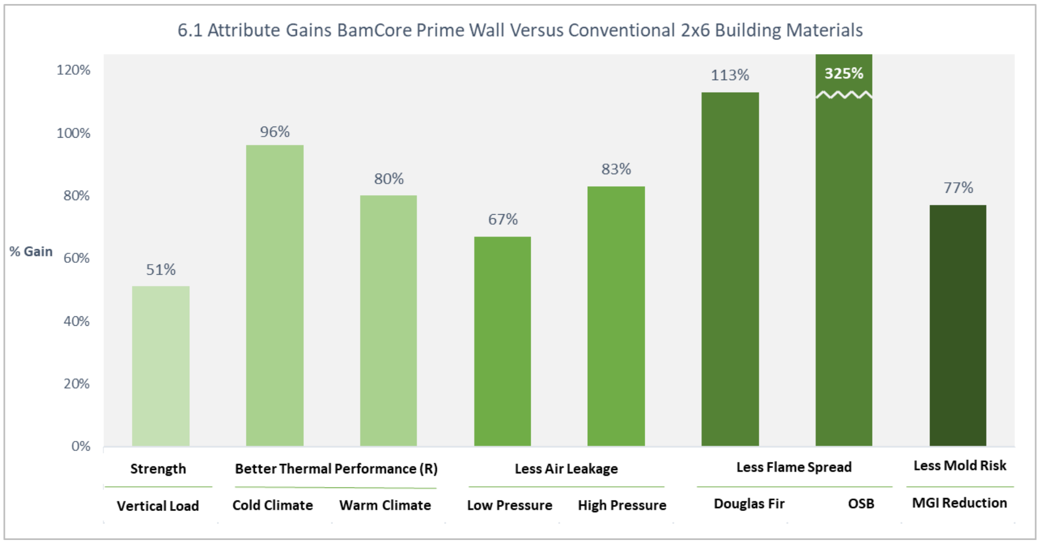
The built environment's long service life and enormous size provides the most potent carbon storage option for bamboo-based HWP. To date, even though bamboo flooring has become popular in many developed countries, its impact remains microscopic. Even when combining bamboo flooring and decorative panels, bamboo-based HWP imported into the US annually (nearly all from China) remains less than $304 million (INBAR, 2015). Besides being a small market, flooring and paneling are subject to taste-driven design decisions and they nearly always have a substantially shorter service life than the structural shell of the building. Thus, US demand for (mostly Chinese) flooring and decorative paneling is not the engine to help drive timber bamboo carbon farming.

In contrast to the limited sized flooring market, the overall US construction market is in excess of $1 trillion. BamCore's mission is to develop high value, durable products for the largest segment of the overall construction market, low-rise structural framing, which exceeds $100 billion annually in the US. Across the US and Canada, low-rise building accounts for about 90% of the built environment. Wood timber based structural framing, in turn, accounts for approximately 95% of all low-rise framing (US Census, 2017). When HWP is used in structural framing, as opposed to decorative panels or flooring, the structural and operating performance and not design preference can drive the specification decision toward superior performing timber bamboo. Moreover, once incorporated into the building's structure, the bamboo-based components enjoy the longest possible service life. Typical estimates of the service life of low-rise buildings in the US range from 50 to 75 years or more.

While our focus here is to demonstrate the potency with which timber bamboo HWP can drive carbon farming and carbon sequestration, that benefit alone will not drive large-scale substitution from wood to bamboo building and framing products. To drive large-scale substitution requires that bamboo-based products be completely cost competitive with wood while also offering a range of additional benefits, beyond simply the carbon footprint benefit.

BamCore's Prime Wall System. BamCore's recently launched Prime Wall System is both cost competitive and offers a wide range of additional benefits, beyond the carbon footprint. By designing high-performance load and shear-bearing panels, BamCore was able to introduce a hollow-wall system that eliminates most of the cross-cavity and vertical studs traditionally used in the low-rise construction market. When using the bamboo-based panels in a hollow-wall design, several additional benefits and attributes become evident. Across nearly every performance category, BamCore's Prime Wall offers a superior product.

Figure 5.1 illustrates the superior performance that is captured in BamCore's Prime Wall System for five quantifiable attributes when compared to conventional building products. Based on its timber bamboo core, the Prime Wall provides more compressive strength than a conventional 2x6 Douglas fir wall. For thermal performance, the wall assembly thermal resistance ("R") rating substantially exceeds a conventional 2x6 wall that has standard batt insulation in both cold and warm climate settings. Air leakage, which also impacts thermal performance, is substantially less for the Prime Wall in both low and high-pressure settings. The Flame Spread rating is nearly Class A and significantly exceeds Douglas fir and OSB. And the mold risk inherent in new construction is substantially less when Prime Wall is used in comparison to a conventional wall.


6.1 Attribute Gains BamCore Prime Wall Versus Conventional 2x6 Building Materials

In addition to the above-mentioned attributes, the Prime Wall provides an extremely high level of sound isolation compared to a conventional wall system. It enjoys a Level 1 rating from the National Institute of Justice for resistance to small hand guns. The Prime Wall System also saves substantial construction labor and lowers job site waste.

With this broad collection of performance attributes, when owners substitute the BamCore Prime Wall for a conventional wall for their building, they not only improve their individual carbon footprint significantly compared to conventional wood framing, but they also benefit from improved attributes for each of these features. The combination of thermal, air leakage and mold risk attributes will immediately drive superior operating performance, thus lowering operating costs. PassivScience, a building performance engineering firm, completed a 12 North American-city simulation of the performance of BamCore's Prime Wall in a standard new single-family residence. This simulation showed that single-family homeowners could save an average of $1,850 annually or $32,500 present-valued for 30 years in lower heating and cooling bills. Thus, buildings constructed with BamCore Prime Walls will enjoy both lowered embodied energy and lowered operating energy, resulting in an unmatched low combined carbon footprint with greater operating performance. Moreover, the speed and accuracy when installing the customized factory pre-fabricated wall system lowers the construction cost inputs to total costs.

Of course, any bamboo-based building product, BamCore's or otherwise, that is substituted for wood will lower the embodied energy and construction carbon footprint. However, as stated above, to drive adoption in the construction market, lowering the embodied carbon footprint alone is not enough. By providing faster and easier construction and by capturing operating advantages, the adoption decision becomes far easier.

Beyond Wood Framing-Concrete & Steel.

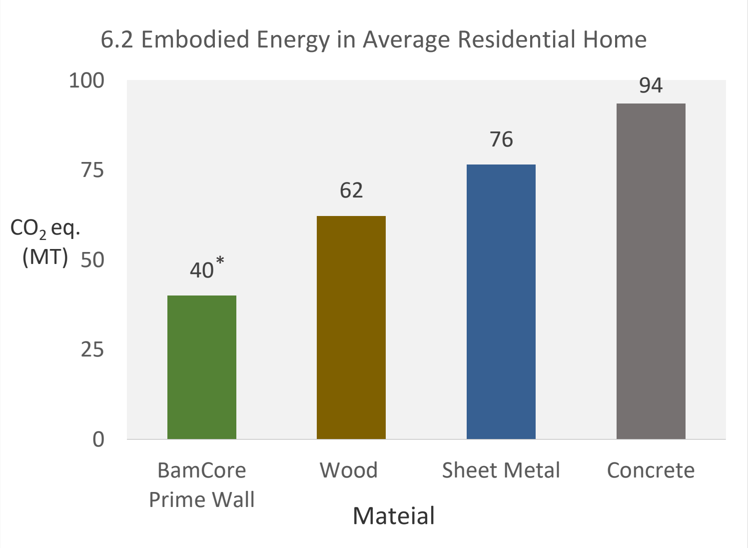
The main conclusion from our analysis in Section 4 is that by substituting timber bamboo for wood in long-lived HWP framing products, we can drive a new generation of potent carbon farms as bamboo A/R projects grow. But this bamboo-for-wood substitution is readily obvious only in those economies where wood-based framing dominates, namely North America. In the US and Canadian residential building market, wood framing commands about 95% of the market. Elsewhere in the world, concrete and other cementitious materials are "the most common construction material adopted for residential construction" (Dodoo, 2009) in non-rural markets. In a small percentage of instances, framing is even completed with steel studs. In both cases, abundant research argues for the carbon capture and performance superiority of wood compared concrete and steel. Below we summarize the benefits of wood compared to concrete and steel. Given the superiority of BamCore's Prime Wall to conventional wood framing, compared to concrete and steel the carbon and operating performance advantages of the BamCore Prime Wall are even greater still.

Framing with Concrete.

Globally, the manufacturing of cement contributes about 5% of global GHG emissions. The manufacturing process releases nearly equal amounts of carbon dioxide from the thermal input requirements (cement kilns operate at nearly 1500°C) and from calcination, the chemical reaction the produces cement and CO_2 from limestone. (Dodoo, et al., 2014)

Dozens of published research articles nearly uniformly decry cement's inordinately high-embodied energy when used as a building wall system where wood is easily a better option. Concrete, which contains 12% to 15% cement, doesn't typically offer a sufficiently superior operating performance to overcome this high-embodied energy. "Compared to wood construction, concrete construction [results] in significantly higher consumption of energy (+38%), emissions of greenhouse gases (+80%), emissions to air (+46%), and generation of solid wastes (+164%)." (Bowyer, et al., 2008)

The main thermal performance benefit cited for concrete framing is its much higher thermal mass compared to wood framing. Thermal mass can help save operating energy, but only in limited instances. Typically for thermal mass to lower energy costs it requires very careful design and placement in less common and highly specific local climate conditions. It is difficult to achieve thermal benefits from thermal mass in colder climates without elongated east-west floorplans. Overall, researchers from Oak Ridge National Laboratories concluded that high thermal mass concrete walls mostly perform better in warmer climates and not in colder climates. But even in warmer climates anticipated diurnal temperature swings must encompass the human comfort zone and when they don't significant energy can be required to re-establish the required temperatures (Kosny, et al., 2001).



Overall, multiple studies have found that wood-framed buildings have lower net carbon emissions than concrete after considering higher embodied energy, comparable nominal operating performance and thermal mass ((Koch, 1992), (Borjesson & Gustavsson, 2000) (Pingoud & Perala, 2000) (Gustavsson, Pingoud, & Roger, 2006)). Figure 6.2 illustrates the differences in embodied energy of an average home between those built with BamCore's Prime Wall System, traditional wood, sheet metal and concrete. Note that BamCore's figure (40* mt CO_2 equivalents) is an estimate based on the embodied energy calculated in just the Prime Wall System and has been adjusted to account for other materials in the average home.

As the climate change focus begins to bear on the built environment, policymakers and commercial decision makers will raise the bar for concrete walled structures compared to wood. Globally, many of the locations where concrete structures have been historically preferred are in or near to natural habitats for timber bamboo. The rising availability of engineered bamboo building products, like BamCore's Prime Wall System, provides an opportunity to shift directly from high embodied energy concrete to timber bamboo. The result will be extremely compelling carbon capturing benefits without any loss of function or performance.

Framing with Steel. The comparison of steel to wood-based to bamboo-based building materials is even more frightful than for concrete. The carbon footprint to produce steel framing products is about 20 times that of wood (Lippke, Perez-Garcia, Bowyer, & Wilson, 2004). Each tonne of steel made releases two tonnes of CO_2. A typical house using steel framing has released about 3.5 tonnes of carbon into the atmosphere, while wood framing stores over 3.1 tonnes of carbon. Moreover, the internal carbon efficiency of producing wood framing is quite high. When incorporating the energy costs to harvest, mill and manufacture, wood framing products store up to 15 times more carbon than the amount of carbon released in its production (Ferguson, et al., 1996). (This conclusion ignores the emissions at time of harvest as discussed in Section 3.) Once in operation, steel is also a notoriously powerful thermal bridge, thus requiring additional insulation materials and needed labor to reach a comparable thermal performance to standard wood framing.

Resource conservation is the main environmental argument for steel in framing buildings, since steel can be up to 100% recyclable. However, when the objective weighs climate change mitigation the conclusion is clear: steel doesn't work. Any effective response to climate change relies directly on timely mitigation results, waiting until the end of a service life to accrue the benefit of steel's perfect recyclability completely defeats the timing imperative that we now face fighting climate change.

Moreover, not factored directly into the climate mitigation outcomes is the fact that steel production produces ten times the amount of SO_2, three times the amount of particulates and nearly 40 times the amount of tainted water effluents (Lawson, 1996).

While steel framing constitutes only 1-2% of the low-rise framing market, steel framing members are frequently included in otherwise wood framed buildings because wood doesn't possess the requisite tensile or compressive strength to easily span long distances or serve as moment frames. Since bamboo enjoys far higher tensile strength and compressive strength than wood, properly engineered timber bamboo can help to supplant this common use of steel in low-rise framing. BamCore's Prime Wall System has been engineered to eliminate the need for additional steel moment frames, in certain designs. Thus, the general substitution of BamCore Prime Walls for traditional wood framing, can also eliminate the need for high carbon footprint and SO_2 polluting steel.

7. Conclusion 2: Timber Bamboo Products to Fight Global Climate Change

What does it all mean?[18]

Eight months ago, a team of four at BamCore, who were gravely concerned about mankind's response to global climate change, began the analysis presented above. In these eight months we have learned an enormous amount, as presented above:

In Section 2, we reported on the efforts to establish multi-national afforestation and reforestation programs globally and found them undersized and faltering. Initially these multi-national programs were directed at preserving biodiversity and pursuing responsible development. But as natural carbon sequestration systems, A/R has also been seen as a tool in the fight against global warming. Still, tropical deforestation continues nearly unabated and A/R projects are barely being pursued. **This means that even if wood-based A/R worked, it isn't working now, when it is most needed.**

In Section 3, we undertook a detailed and rigorous comparison of system-wide carbon flows from both wood-based and bamboo-based A/R systems. We found that the earlier and faster biomass accumulation and annual partial-harvest cycles of timber bamboo A/R gave it a significant advantage in capturing atmospheric carbon compared to wood-based A/R as modeled by the US Forestry Service. But we also found that that there is a critical weakness in wood-based A/R that limits its ability to even capture atmospheric carbon in the time frame that is needed, i.e. the next 10-30 years. Wood is grown and harvested to provide needed fiber to mankind, but the mechanics of the harvest event results in catastrophic releases of forest-stored and soil-stored carbon pools back into the atmosphere. This means, practically speaking, that **investing in wood-based fiber as a carbon sequestration system may produce the opposite effect of what is desired near term, when it is most needed.** Some forest scientists even hold that only forests that are unharvested for centuries will net sequester carbon.

In Section 4, we carefully built a decision model that compared annual carbon flows from timber bamboo and wood A/R systems that (1) compensated for sensitivity to input assumptions, (2) time-discounted annual carbon flows from both A/R systems and (3) provided a range of alternative scenarios to reflect different degrees of confidence in the likelihood of global warming. The work in Sections 3 and 4 are summarized in a single comparative metric called the Carbon Benefit Multiple ("CBM") that presents for the first time a broader comparison of multiple species and multiple locations between timber bamboo and wood A/R systems. From this decision framework we found that timber bamboo A/R enjoys a CBM that is 4.9x to 6x when compared than wood.[19] **This means that timber bamboo should take the place of wood as the preferred commercial fiber for mankind, whenever and wherever climate considerations influence the decision-making, which is precisely now.** Finally, time discounting of the annual carbon flows used in the CBM calculations allows us to weigh earlier carbon removal more heavily than later carbon removal. In conjunction, the more durable (long-lasting) the harvested product is, the greater the CBM of the fiber source. The larger the demand for the harvested product, the greater the carbon removal from the atmosphere. These last two points bring us to the built-environment and BamCore.

In Section 6, we presented an in-the-market timber bamboo-based building product, BamCore's Prime Wall System, that can create significant demand for timber bamboo fiber and, as a result, timber bamboo A/R. We showed that when engineering and innovation are overlaid on timber bamboo, **significant product performance advantages are available compared to wood framing** as well. Because the built-environment is the largest carbon and energy consuming sector, adoption of timber bamboo construction products in lieu of wood can drive significant amounts of carbon removal. When timber bamboo replaces steel or concrete, the carbon removal benefits are even larger. Below, we close by quantifying the total differential carbon capture and atmospheric CO_2 reduction achieved when timber bamboo, through just one product – the BamCore Prime Wall, is substituted for traditional wood use in residential building framing.

---

[18] We appreciate the input of Dr. Bob Epstein for suggestions and guidance on this section.

[19] Even in our worst case Scenario D where we tilt all assumptions against bamboo and in favor of wood, our multi-species, multi-location annual carbon flow analysis projects that timber bamboo enjoys a Carbon Benefit Multiple of 1.7, indicating that timber bamboo would sequester 70% more atmospheric carbon than wood systems will.

What Does it All Add Up To?

Finally, we quantify what it all adds up to. How much atmospheric carbon can be reduced in aggregate by substituting BamCore's timber bamboo-based Prime Wall System for traditional framing practices? The following quantification incorporates carbon capture at the forestry and product creation stage as well as carbon storage and emission reductions that result from the substitution benefits during the product-in-use-stage.[20] The quantification analysis occurs in four steps:

1. Market Sizing
2. Substitution and Emissions Savings Analysis
3. Land Use Conversion Sequestration Benefits
4. Estimation of Land Area Needed

Market Sizing. To assess the potential substitution of timber bamboo-based framing for wood-based framing, while retaining a conservative bias, we restrict our potential substitution markets in two ways: First, we limit our assumed substitution to only residential construction and completely ignore available low-rise commercial construction. Second, we only consider residential construction in the G-7 countries, leaving out many developing countries where demand for durable housing is high and substituting from cementitious framing products (e.g. brick, block or concrete) could produce outsized environmental benefits. After incorporating these two considerations we examine 1%, 10% and 20% substitution of residential building starts in only the G-7 countries.

Substitution and Emissions Savings Analysis. The carbon and broader environmental impact of substituting BamCore's Prime Wall System for conventional wood framing has been studied by the international sustainability consulting firm Quantis International through two different Life Cycle Analyses studies. In addition, the thermal (and thus carbon) benefits of BamCore's Prime Wall System has been studied in an advanced 12-city simulation analysis twice by the energy modeling firm PassivScience. In addition, BamCore's Prime Wall System has been tested in an ISO accredited testing facility in a side-by-side comparison to conventional wood wall assemblies for both thermal and air leakage performance. From these analyses and tests, it has been shown that the Prime Wall can thermally outperform otherwise comparable wood walls to a degree that an average home would enjoy a 40% reduction in thermal load. Applying this 40% thermal reduction on a per house basis, assuming the weighted average BTU conversion for the national average fuel mix, we estimate that a single new residence built with BamCore Prime Walls will reduce atmospheric CO_2 by 336 metric tonnes across a 70-year service life.[21]

Land use Conversion Sequestration Benefits. Timber bamboo, as projected in Section 3 above, captures carbon from the atmosphere at a must faster rate than wood. Our analysis shows that on average timber bamboo can capture and sequester as much as 1,625 more metric tonnes of CO_2 per hectare than wood.[22] To convert this per hectare carbon benefit to aggregate benefit, based on substitution for wood framing products, we estimate that each individual residence would require the equivalent of 1.295 hectares of timber bamboo.

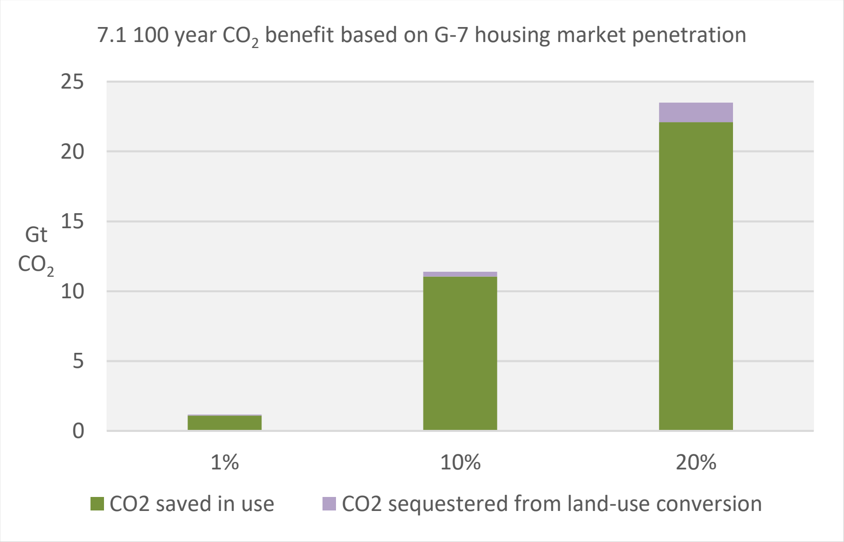

7.1 100 year CO_2 benefit based on G-7 housing market penetration

Figure 7.1 shows that combined effect of substitution and land-use change over the 100-year time period results in significant reductions of atmospheric CO_2. A 1% market substitution results in 1.2 fewer gigatonnes of atmospheric CO_2, a 10% market substitution results in 11.7 fewer gigatonnes, and a 20%

---

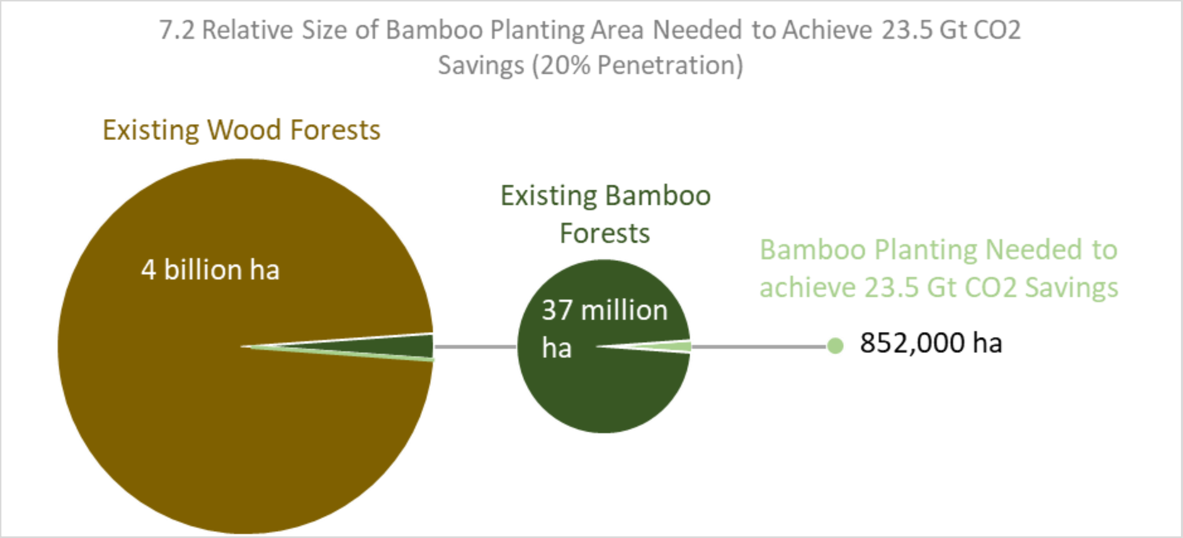
[20] Because the forestry level analysis here is built on the US Forestry Service model (Smith, 2006), we are also incorporating the end-of-life stage in landfill degradation, recycling or burning of the product once it comes out of service.

[21] The analysis here does not attempt to time discount the carbon benefits as discussed in the A/R comparison above in Sections 3 & 4.

[22] We estimate that on average bamboo sequesters 443 more metric tonnes of carbon (see section 3). Thus, we calculate 1,625 metric tonnes of CO_2 using a 3.67 conversion factor

market substitution results in 23.5 fewer gigatonnes. Land-use change to timber bamboo contributes 1.4 gigatonnes of the total while substitution benefits contributes 22 gigatonnes.

Estimation of Land Area Needed.
It is relevant to ask if a 20% G-7 residential framing substitution is feasible given the incremental planting area that will be needed for timber bamboo. We estimated that incremental plantings needed to support the 20% substitution would be 852,000 hectares. While that area might seem large area in absolute terms, it is actually rather small when compared to existing plantings of wood and bamboo. For perspective, globally forests and plantations of wood total just over 4 billion hectares, while bamboo totals only about 37 million hectares--less than 1% of wood. The incremental bamboo area needed is just over 2% of existing bamboo and about 0.02% of existing wood. For further perspective, the Bonn 2030 goal calls for 350 million hectares of new A/R projects. Targeting less than one-quarter of 1% of the Bonn 2030 goals would establish the needed area to support the 20% substitution. Thus, relatively small incremental plantings of timber bamboo can results in a meaningful impact in the fight against climate change.



Finale: What We Do?

The conclusion of our modeling and analysis indicates that, if mankind is truly motivated to address global climate change, the biogenic sequestration system that timber bamboo offers is not only feasible, but also land-use efficient. And, when manufactured into superior durable products, timber bamboo can be significantly impactful in the fight against global warming. Our G-7 residential market analysis suggests that a modest demand-driven shift can save the planet over 23 gigatonnes of CO_2 over the both the short and long-term.

The latest IPCC report published in October 2018 lays out timelines and emissions reductions targets to achieve a global carbon stock budget that limits global warming to the 1.5°C goal by year 2100. To do so, the report indicates that we must reach a state of net zero emissions by 2040 through (1) reductions in fossil fuel usage, (2) reduced dependence on animal agriculture and (3) an increase in Carbon Dioxide Removal (like timber bamboo A/R). (It is important to remember that to this date there are no large scale, low-risk CDR projects or initiatives yet underway globally.) As of the reports' publication, annual global emissions stand at ~42 Gt CO_2. If timber bamboo products like BamCore's Prime Wall System were to take a 20% market share in just the G-7 residential markets, the balance of emissions saved would equate to almost 3% of the IPCC's emissions reduction goal. (assuming 20-year time period). Among the climate mitigation solution suite, timber bamboo represents a powerful tool to achieve the ultimate global objective.

Beyond our above research and analysis, we ask the following question: Given that mankind must continue to build in order to support a growing population and replacement existing building stock, what will our primary building material become? Intelligently engineered, timber bamboo can offer superior performance and carbon capturing values. The time is now for the world to take advantage of nature's fastest growing structural fiber. There is no dollar amount calculable that quantifies the return on mankind's investment in nature's strongest and fastest growing fiber.

BAMCORE®

Building an environment that captures CO_2 emissions.

Founded in 2008, BamCore's products are driving a paradigm shift in low-rise residential and commercial construction that result in building stronger, faster, greener and less expensive buildings up to five stories. By manufacturing cutting edge framing products from fast growing timber bamboo, **BamCore products turn bamboo plantations into nature's most potent perpetual carbon farms**. Besides delivering a uniquely promising carbon footprint, BamCore's fast install Prime Wall System significantly improves thermal performance (44%) and lowers mold risk (77%) while providing a super quiet enclosure made from nature's most sustainable materials.

Hal Hinkle

Hal is the driving force behind the conceptualization and commercialization of BamCore. After 22 years at Goldman Sachs, Hal founded, led and sold BrokerTec Global, one of the world's largest fully electronic financial trading platforms. As the CEO of BamCore, Hal is driving the adoption of stronger, faster, and environmentally friendlier building materials through the productization of timber bamboo.

Hal graduated from UC Irvine where he received a BS in Biochemistry. He also earned an MBA, two Masters degrees and a PhD from Columbia University. In the few minutes he has away from BamCore, Hal serves on the advisory boards for the (UC) Berkeley Food Institute and the Sonoma County Regional Climate Protection Agency.

Myles McGinley

Myles became interested in bamboo's potential and BamCore specifically after walking through a BamCore home in his hometown of Washington, D.C. The owners of the home introduced Myles to Hal and Myles was eager to help. As a former investment banking analyst and consultant, Myles played a major role in developing the cradle-to-cradle modeling framework that the *Generalized Model of Carbon Flow from Timber Bamboo.*

Myles earned a BA from Princeton's Woodrow Wilson School of Public and International Affairs and received a certificate in Chinese language. He played soccer for Princeton served as the team Captain and was selected All-Ivy League twice.

Travis Hargett

Travis began his work with bamboo in Nicaragua, while serving in the Peace Corps. After meeting Hal at an American Bamboo Society conference in Mexico, Travis joined BamCore to develop a global network of timber bamboo exporters and to research a wide range of critical topics for the company. He is enthusiastic about being involved with a company that can fundamentally shift how buildings are constructed, and at the same time make new construction more environmentally sustainable.

Travis served as a Congressional Page in the office of the Speaker of the House while in high school and then graduated from North Carolina State where he received a BA in Political Science. His first job was for the Sierra Club working on He is fluent in Spanish and has a firm grasp on Latin American culture and business practices.

Skye Dascher

Skye joined BamCore in the summer of 2018 as an intern to further his knowledge of sustainable materials and construction. While growing up in the small town of Santa Fe, New Mexico, the surrounding mountains and nature became his second home and instilled in him an intrinsic motivation to protect the environment.

Skye will graduate from California Polytechnic State University, San Luis Obispo with a BS in materials engineering.

References

Allred, C. S. (2008). *Western Oregon Region Plan Revision Final EIS.* Portland: Bureau of Land Management.

Bloomberg, M., & Pope, C. (2017). *Climate of Hope: How Cities, Businesses, and Citizens Can Save the Planet* (1 ed.). New York City: St. Martins .

Bonn. (2018, 11 08). *Bonn Challenge*. Retrieved from Bonn Challenge: www.bonnchallenge.org

Borjesson, P., & Gustavsson, L. (2000). Greenhouse gas balances in building construction: wood versus concrete from life-cycle and forest land-use perspectives. *Energy Policy, 28*, 575-588.

Bowyer, J., Bratkovich, S., Fernholz, K., Howe, J., & Lindburg, A. (2008). *How does it compare to wood, steel?* Minneapolis: Dovetail Partners, Inc.

Dodoo, A., Gustavsson, L., & Sathre, R. (2014). Lifecylce carbon implications of conventional and low-energy multi-storey timber building systems. *Energy and Buildings*, 194-210.

FAO. (2010). *Global Forest Resources Assessment 2010.* Rome: FAO.

Ferguson, I., La Fonttaine, B., Vinden, P., Bren, L., Hateley, R., & Hermesec, B. (1996). *Environmental Properties of Timber.* Victoria: Forest and Wood Products Research and Development Corporation.

Glasare, G., & Haglund, P. (2016). *Climate impacts of wood vs. non-wood buildings.* Stockholm: The Swedish Association of Local Authorities and Regions.

Goulder, L., & III, R. C. (2012). The Choice of Discount Rate for Climate Change Policy Evaluation. *Resources for The Future*, 12-43.

Gustavsson, L., Pingoud, K., & Roger, S. (2006). *Carbon dioxide balance of wood substitution: comparing concrete and wood-framed buildings.* Ostersund.

Hinkle, W., Hargett, T., & Bailon, W. (2017). *BamCore and Global Warming.* Windsor: BamCore.

Hinkle, W., McGinley, M., Hargett, T., & Dascher, S. (2018). *A Generalized Model of Timbe Bamboo Carbon Flows.* BamCore LLC. Windsor: BamCore.

INBAR. (2010). *Bamboo and Climate Change Mitigation : a comparative analysis of carbon sequestration.* Bejing: INBAR.

INBAR. (2015). *Trade Overview 2015: Bamboo and Rattan Products in the International Market.* Bejing: INBAR.

INBAR. (2018). *Updates on INBAR BONN Challenge Committments.* Bejing: INBAR.

IPCC. (2006). *Guidlines for National Greenhouse Gas Inventories.* Geneva: IPCC.

IPCC. (2018). *Global Warming of 1.5 C.* Incheon: Intergovernmental Panel on Climate Change.

Koch, P. (1992). Wood versus nonwood materials in U.S. residential construction: Some energy-related global implications. . *Forest Products Journal, 42*(5), 31-42.

Kosny, J., Petrie, T., Gawin, D., Childs, P., Desjarlais, J., & Christian, J. (2001). *Thermal Mass- Energy Savings Potential in Residential Buildings.* Oak Ridge: Oak Ridge National Laboratory.

Lawson, B. (1996). *Building materials, energy, and the environment: Towards ecologically sustainable development. .* Red Hill: Royal Australian Institute of Architects.

Lippke, B., Perez-Garcia, J., Bowyer, J., & Wilson, J. (2004). CORRIM: Life-Cycle Environmental Performance of Renewable Building Materials. *Forest Products, 54*(6).

Lobovikov, M., Paudel, S., Piazza, M., & Wu, J. (2005). *World Bamboo Resources: A thematic study prepared in the framework of Global Forest Resources Assessment 2005.* Rome: FAO.

Masek, J. G., Cohen, W., Leckie, D., Wulder, M., Vargas, R., de Jong, B., . . . Smith, W. (2011). Recent rates of forest harvest and conversion in North America. *Journal of Geophysical Research, 116*.

Micales, J., & K.E. , S. (1996). *The Decompostion of Forest Products in Landfilles .* Madison: USDA.

Nath, A. J., Lal , R., & Kumar Das, A. (2015). Managine Woody bamboos for carbon farming and carbon trading. *Global Ecology and Conservation, 3*, 654-663.

National Research Council. (2015). *Climate Intervention - Carbon Dioxide Removal and Reliable Sequestration.* National Academies of Science. Washington, DC: National Academies of Science.

New, M., Livereman, D., Schroder, H., & Anderson, K. (2011). Four Degrees and beyond: the potential for a global temperatur increase of four degrees and it implications. *Philosophical Transactions of The Royal Society*, 6-19.

Pingoud, K., & Perala, A. (2000). *Studies on greenhouse impacts of wood construction. 1. Scenario analysis of potential wood utilization in Finnish new construction in 1990 and 1994. 2. Inventory of carbon stock of wood products in the Finnish building stock in 1980, 1990, and 1995.* Espoo: Technical Research Center of Finland.

Rogerlj, J., den Elzen, M., Fransen, T., Fekete, H., Winkler, H., Riahi, K., . . . Sha , F. (2016). Paris Agreement climate proposals need a boost to keep warming well below 2 C. *Perspective*, 631-639.

Smith, J. E., Heath, L., Skog, K., & Birdsey, R. (2005). *Methods for Calculating Forest Ecosystem and Harvested Carbon w. Standard Estimates for Forest Types of the U.S.* Washington, DC: USFS.

UN. (1992). *NON-LEGALLY BINDING AUTHORITATIVE STATEMENT OF PRINCIPLES FOR A GLOBAL CONSENSUS ON THE MANAGEMENT, CONSERVATION AND SUSTAINABLE DEVELOPMENT OF ALL TYPES OF FORESTS.* Rio de Janeiro: United Nations Conference on Environment and Development.

WRI. (2018, 11 08). *Iniative 20x20*. Retrieved from Iniative 20x20: www.iniative20x20.org

Ximenes, F., Bjordal, C., Cowie, A., & Barlaz, M. (2015). The decay of wood in landfills in contrasting climates in Australia. *Waste Management, 41*, 101-110.

Appendix: International Forestation Commitments

Country/Party	Bonn Commitments			Initiative 20x20	Bamboo Reforestation Projects (INBAR)		AFR100
	2020	2030	Total		Since 2014	Planned (2018-2020)	
Latin America & Caribbean							
Argentina	1,000,000		1,000,000	1,000,000			
Belize							
Bosques Modelo				1,600,000			
Brazil		12,000,000	12,000,000	22,000,000			
Brazil's Atlantic Forest Restoration Pact	1,000,000		1,000,000				
Chile	500,000		500,000	500,000			
Colombia	1,000,000		1,000,000	1,000,000			
Conservacion Patagonica				1,000,000			
Costa Rica	1,000,000		1,000,000	1,000,000			
Cuba							
Dominican Republic				89,000			
Ecuador	500,000		500,000	500,000			
El Salvador	1,000,000		1,000,000	1,000,000			
Guatemala	1,200,000		1,200,000	1,200,000			
Guatemala Private Natural Reserves	40,000		40,000				
Honduras	1,000,000		1,000,000	1,000,000			
Jamaica					2	20,000	
Mexico	8,470,000		8,470,000	8,470,000			
Mexico (Campeche)		350,000	350,000				
Mexico (Chiapas)		180,000	180,000				
Mexico (Quintana Roo)		400,000	400,000				
Mexico (Yucatan)		300,000	300,000				
Nicaragua	2,700,000		2,700,000	2,800,000			
Panama	1,000,000		1,000,000	1,000,000			
Paraguay							
Peru	3,200,000		3,200,000	3,200,000	2,660	1,000	
Suriname							
Uruguay				2,500,000			
Total	**23,610,000**	**13,230,000**	**36,840,000**	**49,859,000**	**2,662**	**21,000**	**-**
North America							
American Bird Conservancy				100,000			
United States	15,000,000		15,000,000				
Total	**15,000,000**		**15,000,000**	**100,000**			**-**
Asia							
Asia Pulp and Paper	1,000,000		1,000,000				
Armenia		260,000					
Bangladesh	750,000		750,000		730	8,340	
Benin	200,000	300,000	500,000				
Georgia		10,000					
China						1,000,000	
India	13,000,000	8,000,000	21,000,000		100,000	200,000	
Indonesia							
Kazakhstan		1,500,000					
Kygyzstan		320,000					
Malaysia						1,000	
Mongolia	600,000		600,000				
Nepal					1,500		
Pakistan	100,000		100,000				
Pakistan (KPK)	350,000	250,000	600,000				
Phillipines					6,257	225,746	
Sri Lanka	200,000		200,000		1,000	15,000	
Tajikistan		70,000					
Uzbekistan		500,000					
Vietnam						95,000	
Total	**16,200,000**	**11,210,000**	**27,410,000**		**109,487**	**1,545,086**	
Africa							
Benin							500,000
Burkina Faso							5,000,000
Burundi	2,000,000		2,000,000		300	345	2,000,000
Cameroon		12,060,000	12,060,000				12,000,000
Central African Republic	1,000,000	2,500,000	3,500,000				3,500,000
Chad		5,000,000	5,000,000				1,400,000
Côte d'Ivoire		5,000,000	5,000,000				5,000,000
Democratic Republic of Congo	8,000,000		8,000,000				8,000,000
Ethiopia	15,000,000		15,000,000			500,000	15,000,000
Ghana		2,000,000	2,000,000		14,100	46,000	2,000,000
Guinea		2,000,000	2,000,000				2,000,000
Kenya		5,100,000	5,100,000			200	5,100,000
Liberia	1,000,000		1,000,000				1,000,000
Madagascar	2,500,000	1,500,000	4,000,000		150	1,600,000	4,000,000
Malawi	2,000,000	2,500,000	4,500,000				4,500,000
Mozambique		1,000,000	1,000,000		120	1,600	1,000,000
Niger	3,200,000		3,200,000				3,200,000
Nigeria		4,000,000	4,000,000			36,000	4,000,000
Republic of Congo		2,000,000	2,000,000				2,000,000
Republic of Sudan							14,600,000
Rwanda	2,000,000		2,000,000		100	300	2,000,000
South Africa							3,600,000
Tanzania					90	5,000	5,200,000
Togo							1,400,000
Uganda	2,500,000		2,500,000		60	3,000	2,500,000
Total	**39,200,000**	**44,660,000**	**83,860,000**		**14,920**	**2,192,445**	**110,500,000**
Totals							
Total Commitment	**94,010,000**	**69,100,000**	**163,110,000**	**49,959,000**	**127,069**	**3,758,531**	**110,500,000**
Total Goal	**150,000,000**	**350,000,000**	**500,000,000**		**5,000,000**	**5,000,000**	**100,000,000**
% Commitment	***63%***	***20%***	***33%***		***3%***	***75%***	***111%***
Number of Parties	**33**	**26**	**47**	**18**	**14**	**19**	**23**