**The Double Bottom Line:**

**Managing Maine’s Forests to Increase Carbon Sequestration and Decrease Carbon Emissions**

By Mitch Lansky

April 2016



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March 2016

At the World Climate Summit in Paris in 2015, 196 countries agreed to try to limit global warming to 1.5 degrees Celsius. Reducing carbon emissions alone probably won’t stop the warming process. According to a report from NASA, “carbon dioxide, among other greenhouse gases, will remain in the atmosphere long after emissions are reduced, contributing to continuing warming. […] Even if greenhouse gas concentrations stabilized today, the planet would continue to warm by about 0.6°C over the next century because of greenhouses gases already in the atmosphere.”[[1]](#footnote-1)

The Edinburgh Centre for Carbon Management(ECCM) created two simulations involving CO2 concentrations in the atmosphere. One assumed no changes in greenhouse gas emissions, but improved forestry practices; the other assumed reduced greenhouse gas emissions, but no changes in current forestry (including deforestation). Neither stopped global warming from reaching critical temperatures. An article from the FAO (Food and Agriculture Organization of the UN) reported, “The ECCM concluded that the only way to fight climate change was to combine vigorous fossil fuel emission reductions with a voluntary program for improving forestry management, forest conservation and reforestation.”[[2]](#footnote-2) In other words, we not only need less carbon emissions from fossil fuels, we need more carbon sequestration from forests.[[3]](#footnote-3)

While the biggest forestry concerns revolve around preventing deforestation of tropical forests, there is so much carbon in forests that moderate changes to managed temperate forests could significantly increase sequestration. Maine has 17.7 million acres, 82.5% of the state’s total land area, in forest.[[4]](#footnote-4) There has been more discussion, however, about the benefits of increasing use of *forest products* to lower emissions than to changing *forest practices* to increase sequestration. In promoting wood to take the place of steel, concrete, plastic, or fossil fuels, the underlying assumption is that forest practices are already “sustainable”—where the cut is balanced by growth—so the forest products are “carbon neutral.”

The issue of forest management is important because incentives to cut more wood to use for these “green” substitutions may reduce the capacity of the forest to sequester carbon. This report explores the potential for *increased carbon sequestration in Maine’s forests from forest management as well as reduced carbon emissions from production of forest products*.

***Forest role in carbon sequestration***

Forests are dominated by trees. Trees take up water and nutrients through their roots. Through photosynthesis, trees combine hydrogen from water with CO2 from the air to create carbohydrates, while emitting oxygen as a “waste product.” In contrast, we animals breathe in what trees emit and breathe out what they take up—a mutually beneficial relationship.

Forests not only take in CO2 through photosynthesis, they also expel CO2 through forest fires, biomass decay, and respiration—not just breathing by animals, but also by trees, other plants, and microorganisms in the soil.

The USDA Forest Service, in its 2008 Forest Inventory Analysis (FIA) for Maine estimated that Maine’s forests currently store about 1.48 billion metric tons of carbon, including aboveground, belowground, and soil pools. This represents an average of 83.6 tons of carbon sequestered per acre. The greatest portion (nearly half) is in the soil. Only 25% is in the live portion of trees above ground.[[5]](#footnote-5)

*Forest Soils*

Carbon enters forest soils through many routes. Leaves and needles, coarse-woody material, animal feces, and bodies of creatures from large to microscopic land on the soil surface as “debris.” This debris, as it breaks down, helps create the organic pad layer, where plant roots get most of their nutrients. Many trees and other plants send their roots deeper into the mineral soil. Since plants are made of carbohydrates (such as sugars, cellulose, and lignin), when they die, the soil organic carbon (SOC) is available for various small creatures, including microorganisms, to digest.

While soils can be a carbon sink, they can also be a carbon source, due to the activity of both roots and microbes. A Princeton study suggested that increased CO2 in the atmosphere could trigger a feedback loop: “As trees and other vegetation flourish in a carbon dioxide-rich future, their roots could stimulate microbial activity in soil that in turn accelerates the decomposition of soil carbon and its release into the atmosphere as carbon dioxide.”[[6]](#footnote-6)

The world’s forests annually sequester as much as 30% of the equivalent of human-caused carbon emissions. This is similar to the amount sequestered by oceans.[[7]](#footnote-7) Compared with other ecosystems, forests have some of the largest quantities of carbon per surface area of land. Nationally, forests sequester the equivalent of 10 to 20% of annual U.S. carbon emissions—13% in 2011, according to the U.S. Forest Service.[[8]](#footnote-8) Forests are by far the largest U.S. carbon sink, especially in the eastern states. Globally, more carbon is stored in forests than in the entire atmosphere.[[9]](#footnote-9)

*Forest fungi.* Fungi are among the most important organisms for moving organic carbon down to lower soil levels. While some fungal species are decomposers, breaking down coarse woody debris, other fungal species are important symbionts with trees. Endophytes can be in stems, branches, or leaves and can help protect trees from predators or diseases. Mycorrhizal fungi attach to tree roots and greatly increase the availability of water and nutrients to trees. In turn, trees supply the fungi, which are not plants and cannot create carbohydrates through photosynthesis, with carbon—another example of mutual benefits.

A recent study concluded that, “fungi have a bigger effect than most other factors, including the amount of plant growth, temperature, and rainfall” at storing carbon in forest soils. These fungi “exert major control on the global carbon cycle.”[[10]](#footnote-10) There are three broad categories of mycorrhizal fungi, and they vary in their abilities to sequester carbon and nitrogen. Some not only sequester carbon from tree roots, but can also limit the ability of soil microorganisms to break down organic matter and release CO2.[[11]](#footnote-11)

Not only do mycorrhizal fungi increase the effective surface area of tree roots, they also:

* make soil minerals more available;
* contribute to humus production;
* secrete organic glues that stabilize soil structure and permit movement of air and water; and
* protect trees from soil pathogens.

*Habitats for fungi.* As trees age, they support a succession of symbiotic fungal species. Older trees tend to support a greater diversity of such fungi. Mycorrhizal fungi can actually connect the roots of older trees to those of younger trees. There is evidence that dying trees can help feed surviving trees, even of different species.[[12]](#footnote-12) Not only do fungal threads (mycelia) spread through soil, but animals can spread the fungal spores. Many types of “mushrooms” are the fruiting bodies of mycorrhizal fungi. Deer, flying squirrels, voles, and mice eat the mushrooms and inoculate new ground with spores in their “droppings.”

*Late-successional forests*

Fungal diversity increases not only when individual trees are allowed to age, but when whole stands become “late successional”—having big trees, enough stocking to shade the forest floor, and large dead trees, both standing and down. Large woody debris is crucial fungal habitat. A literature review on eastern old growth forests stated that “old-growth forests, in contrast to second growth, contain many times more coarse woody debris, and it is continually created at a far faster and more even rate.”[[13]](#footnote-13) Old growth stands, with trees that are hundreds of years old, have the most carbon per acre of any successional stage.

Researcher William Keeton, of the University of Vermont has experimented to see if deliberate management could achieve multiple goals, including maintaining or improving fungi habitat. He calls this modified uneven-aged management approach “Structural Complexity Enhancement” (SCE). He found that:

“Eight years after treatment, fungal species richness was significantly greater in the SCE plots compared to conventional selection harvests and controls….The results suggested that dead tree and downed log recruitment, as well as maintenance of high levels of aboveground biomass, under SCE, had a particularly strong effect on fungal diversity. Our findings show it is possible to increase fungal diversity using forestry practices that enhanced stand structural complexity and late-successional forest characteristics.”[[14]](#footnote-14)

High volume older forests store more carbon in both living and dead wood, and they sequester more carbon than they release. Big, old trees, of long-lived species, it turns out, grow more wood and store more carbon than younger trees. A recent study found that “while they are alive, large old trees play a disproportionately important role within a forest’s carbon dynamics. It is as if the star players on your favorite sports team were a bunch of 90-year-olds.”[[15]](#footnote-15)

Old-growth forests in the mid-Atlantic region, to the surprise of researchers, sequestered 30% more carbon than neighboring younger forests.[[16]](#footnote-16) The researchers assumed that older forests should reach an equilibrium of net growth (growth balanced by mortality) and thus be “carbon neutral” (a theorem called “Odum’s framework”). Their explanation for such increased growth is that forest ecosystems have been taking in increased CO2 and nitrogen from anthropogenic emissions.[[17]](#footnote-17)

Another explanation, however, is that reaching such an equilibrium takes far longer than researchers had previously thought. Older forests have far more above-ground biomass (both living and dead) and far more soil organic carbon (SOC) than previously imagined. In one study in northern New England, “Biomass approached maximum values in stands with dominant tree ages of 350-400 years.”[[18]](#footnote-18) Another study of stands aged 177 to 374 years found no leveling off of snag basal area or coarse woody debris; rather both measures of dead wood increased linearly with stand age.[[19]](#footnote-19)

A study of a red spruce stand at Weymouth Point in Maine demonstrated the growth and sequestration potential of older stands. This was not a “virgin” stand, but it had not been cut in a long time. It consisted in two “cohorts.” One was trees regenerated from a budworm outbreak ending about 1920. The other was made of older trees—some about 275 years old.

The following chart shows that even for the older cohort, annual growth was greater than the “mean annual increment” (the average growth over a given period) since 1920. This is significant because foresters used to assume that growth “culminates” as trees age and then declines to be less than the average up to that point. The standing volume (live trees) per acre at the time of the study was 5,983 cubic feet, which is approximately 70 cords.[[20]](#footnote-20) Annual growth of the stand was about 1.2 cords per acre per year. In contrast, the average volume per acre in the northern three counties of Maine in 2008 was 14.3 cords, and the growth per acre per year was about 0.33 cords.[[21]](#footnote-21)

**Stocking and growth of a fully stocked, two aged, red spruce stand on the Weymouth Point Control Watershed, T4R12, Maine. Volumes are total stemwood: site index=40**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Cohort** | **Trees per Acre** | **Basal Area (ft2 per acre)** | **1995 Volume**  **(ft3 per acre)** | **1920 Volume (ft3 per acre)** | **1990-1994**  **Growth (ft3 per acre)** | **Mean Annual Increment since 1920** |
| 1920-Origin | 500 | 108 | 2,615 | 0 | 52.8 | 34.9 |
| Pre-1920 residual | 180 | 121 | 3,368 | 735 | 50.5 | 35.1 |
| Total Stand | 680 | 229 | 5,983 | 735 | 103.3 | 70 |

From “Growth and Yield,” by Robert Seymour in the

*1995 Annual Report of the Cooperative Forestry Research Unit.*

Reserves, in which harvesting is prohibited, are one part of the strategy for increasing sequestration. A UVM study on forest carbon fluxes posited that, “since passive management [i.e., no harvesting] resulted in the greatest net C storage,we recommend designation of unharvested reserves to offset emissions from harvested stands.”[[22]](#footnote-22) Currently Maine has 2% of forests in reserves.[[23]](#footnote-23) The national average is 7%.[[24]](#footnote-24) Maine has room for improvement.

*Biodiversity.*

Encouraging more volume and older trees in individual stands will not only increase the sequestration ability of the forest; it can benefit biodiversity—the diversity of life forms and interactions of life forms from the genetic to the ecosystem level. Trees don’t grow in isolation. Their survival depends on help from other species. Mycorrhizal fungi and bacteria help trees to grow and resist disease. Insects pollinate flowering plants. Birds and spiders eat insects and prevent severe defoliation. Fungi and invertebrates break down organic matter. Salamanders consume soil invertebrates. Trees thrive and are more apt to be healthy if the ecosystem has “integrity”—the full range of native species functioning to keep the forest self-sustaining.

These benefits are more likely if managers intentionally maintain or create habitats capable of supporting viable populations of the full range of species over the landscape. Managing for healthy forests, favoring longer-lived tree species, and having the full range of predator/parasite complexes can make forests resistant to extreme disturbances and increase their rate of recovery.

Major threats to forest biodiversity include practices that:

* simplify stands (in species composition and in structure),
* fragment the forest (creating habitats too small to support viable populations and landscapes that impede migration and dispersal), and
* convert the forest (to roads, development, and plantations of species that would not normally occupy the site).

Other threats include invasive species, pesticides, and pollution. Climate change exacerbates all of these threats.

Reliance on heavy cutting on relatively short rotations strays far from the historic range of variability to which native species have adapted. It does not allow full recovery of late-successional habitats and eventually reduces or excludes these across entire landscapes. At a time of increased climatic and other stresses, having a full range of habitats and species increases the chances for adaptation to change.

The loss of biodiversity, according to a study on biomass harvesting in Vermont, can reduce the “efficiency by which ecological communities capture biologically essential resources, produce biomass, decompose and recycle biologically essential nutrients.”[[25]](#footnote-25) If forests are more vulnerable to “insults”—from insect outbreaks to forest fires—this could lead to increased mortality and net emissions, rather than sequestration. A study from Oregon State University concluded, “Having an ecosystem as healthy as we can with what I would call all the players, the top predators down through the food web to other organisms – that would provide the best case scenario for buffering climate change.”[[26]](#footnote-26)

While major disturbances, such as forest fires, can lower growth rates and can lead to temporary net carbon emissions, they do not lead to carbon emissions as great as one might think. Most of the combustion consists of fine fuels, litter and duff, rather than large trees. Even severe fires that kill most of the trees emit only 5-30% of the stored forest as carbon dioxide.[[27]](#footnote-27) Dead standing trees and their roots are still sequestering carbon. Severe fires make up a small percentage of burn areas.

***Practices that reduce sequestration***

From learning what increases carbon sequestration—long-lived tree species, bigger trees, high volume stands, more dead wood and coarse-woody debris, and a full range of biodiversity from small organisms up—we can guess that doing the opposite might decrease sequestration, including in soils, which are the largest carbon pool in the forest. In the past, however, researchers generally ignored forest mineral soil carbon because they assumed that carbon in lower soil layers is fairly stable, even after intensive clearcuts.

*Intensive management.* New research suggests that “intensive management,” such as whole-tree harvesting that removes much of the above-ground biomass and disturbs the soil for site preparation, *does* lead to significant reductions of soil organic carbon (SOC) *at all soil levels* in a process that occurs over many decades. An article in *Nature* concluded, “Estimated carbon losses from forest soils suggested that intensive biomass harvests could constitute an important source of carbon transfer from forests to the atmosphere, partly neutralizing the role of a carbon sink played by forest soils.”[[28]](#footnote-28)

Removing most of the trees not only eliminates their role in sequestering carbon, it also impacts the fungi and other microbes that depend on living roots for nourishment. One study, of the impact of intensive harvests on fungal communities, concluded, “An overall loss of species richness after clear-cutting and significant changes in species composition indicate that clear-cutting can negatively alter the EM [ectomycorrhizal] fungal community, and this may have profound effects on ecosystem function.”[[29]](#footnote-29)

The *Nature* article stated, “This loss of carbon in forest floors appeared to be long lasting as it was still clearly apparent a decade after harvesting and possibly required more than half a century to be fully compensated.”[[30]](#footnote-30) A study by Dartmouth researchers concluded that “logging doesn’t immediately jettison carbon stored in a forest’s mineral soils into the atmosphere, but triggers a gradual release that may contribute to climate change over decades.”[[31]](#footnote-31)

Another study found that with clearcutting, increased temperatures from exposure to direct sunlight caused more rapid breakdown of organic matter (especially from slash piles), which released more carbon to the atmosphere. The increased temperatures also led to more respiration by soil microorganisms, which also resulted in increased carbon releases. Even *ignoring the carbon lost* from tree removal, the site emits more carbon than it takes in until it is adequately revegetated. One study estimated that clearcut boreal forests do not turn from carbon sources to sinks for at least 15 years.[[32]](#footnote-32)

***A quick overview of forest management in Maine***

To learn more about the potential to increase carbon sequestration in Maine, it helps to understand what type of forests grow in Maine, their natural disturbance cycles, how much wood is now standing, how much is growing, how much is being cut, how it is cut, and where wood is marketed.

*The Acadian Forest.* Maine’s forest is an intersection of northern hardwoods with red-spruce/balsam fir, plus cedar swamps, birch/aspen, and other minor types that vary depending on microclimates, soils, terrain, and disturbance history. This mix, also found in the Canadian Maritimes, is called the “Acadian Forest.” Most of the key species—red spruce, balsam fir, sugar and red maple, beech, hemlock, and cedar—are shade tolerant; they can regenerate and grow under the forest canopy. White pine and yellow birch are intermediate in shade tolerance; they can grow under partial shade. White birch and aspen are shade intolerant; they need direct sunlight and are adapted to regenerate in larger openings.

*Presettlement disturbance cycles*. Because the key species are shade tolerant to various degrees, they are adapted to growing and regenerating under canopies. Reconstructions of presettlement forest catastrophic disturbance cycles for northern Maine have concluded that major fires or windstorms were 800 to more than 1,000 years apart. Because of these long cycles of stand replacement, only 16% of the acreage of northeastern Maine forest stands were under 75 years old, 59% were over 150 years old, and 27% were over 300 years old.[[33]](#footnote-33) This does not mean the trees were all that old, but, rather, the forest had gone that long without a stand-replacing disturbance.

One review of the literature on old growth and presettlement disturbance patterns concluded, "If the goal is to emulate most northeastern natural disturbance regimes faithfully, then the majority of the landscape must be under some type of continuous-canopy, multi-aged silviculture that maintains ecologically mature structures at a finely patterned scale."[[34]](#footnote-34)

*Maine forests today (see sidebar)[[35]](#footnote-35)[[36]](#footnote-36)[[37]](#footnote-37)*

The vast majority of forestland is subject to timber harvesting, only 2% is reserved from cutting. The majority of Maine forestland is “corporate owned”—where economic returns are the highest priority. “Family” ownerships can range from little to light management, to multigenerational management, to heavy cutting for short-term returns. Government-owned lands are mandated to manage for multiple benefits—including wildlife and recreation.

Sideba*r*

*Maine forests 2014*

*Area*:

Forestland 17.55 million acres

Timberland (can be managed) 16.93 million acres

*Ownership*:

Corporate 58%

Family 31%

State 6.3%

Other private 3%

Federal 1%

*Average volume per acre* 17.7 cords

*Growth and cut:*

Net growth live trees784,462 cubic feet

Total harvest 554,130 cubic feet

Growth/cut 1.41

Change in growth since 2008 increase by 36%

Change in cut since 2008 decrease by 8.4%

*Volume cut per acre*  14.9 cords

*Markets*

Pulpwood 50%

Lumber 27%

Biomass 20%

Firewood and pellets 3%

*Changes in markets.* Some of the figures for 2014 are significantly different from just a few years before. For example, only 27% of wood cut in 2014 went for sawlogs (as opposed to 43% in 2001), and 20% went for biomass (as opposed to 7% in 2001). This means that about three fourths of all wood cut in Maine gets chipped and/or burned.

The decline in sawlogs was mostly from spruce and fir. The decline began in 2006, when the housing bubble started to burst. Pine sawlog harvest (which has been lower than spruce-fir) declined during the same period, but not as steeply, and has mostly recovered.

Another contribution to the decline of spruce-fir going to sawmills was the decreasing average diameters of the wood. In 2014, only 10% of balsam fir was sawlog size (over 9 inches in diameter)[[38]](#footnote-38). Red spruce cut has been more than growth for decades. In 2008, the statewide growth to removal ratio for red spruce was 0.67.[[39]](#footnote-39) This led to a decline in volume over time.

As spruce-fir sawlogs have gone into decline, so has exports of sawlogs. In 2001, 61% of spruce-fir sawlogs were exported from Maine, unmilled, mostly to Quebec,[[40]](#footnote-40) in 2008, 42% of spruce-fir sawlogs were exported,[[41]](#footnote-41) and in 2014 24% of these sawlogs were exported.[[42]](#footnote-42) The amount of spruce-fir milled in Maine in 2001 and 2014 was nearly the same.

A new spruce-fir stud mill opened in 2015 in Ashland that can utilize smaller-diameter spruce and fir wood. This type of wood is becoming more available from the stands regenerated after the heavy cutting during the budworm clearcuts of the 1970s and 1980s. Availability of this market might reverse the downward softwood lumber trend, but the overall value of products made from smaller-diameter wood is not as high as products made from larger-diameter wood.

The paper industry has also gone through major changes. While mills previously depended on spruce and fir, now they focus more on hardwoods. Nearly 40% of timberlands used to be owned by paper companies. Now much of that land is owned by timberland investors.

Over the last few years, paper mills in East Millinocket, Bucksport, and Lincoln have shut down. A paper mill in Madison just announced it will close. Several biomass electric generating plants in Maine are slated to shut this month because the cost of producing the energy with biomass is so much greater than producing it from fossil fuels.[[43]](#footnote-43) Four wood pellet mills have had to cut production because competing heating oil prices are low.[[44]](#footnote-44) Investments have occurred in other paper mills, saw mills, and engineered wood mills, but the closures are still impacting wood markets.

Harvest levels are down, due to the economy and market changes.[[45]](#footnote-45) Growth is up, due, in part, not only to a lower cut, but also because stands heavily cut during the 70s and 80s have reached measurable size (over 5 inches in diameter). Much of this new growth is in stands more suited to lowgrade markets, such as biomass and pulp, rather than sawlogs. Over 16% of all statewide tree growth came from balsam fir, which has less than 10% of total volume.

The closed paper mills are probably not coming back. This raises a policy issue: should the state encourage market development to use this small diameter wood for biomass electric plants, even if it means having to subsidize the biomass industry with tax breaks or above-market contracts, or should the state encourage more forest growth, leading to more carbon sequestration?

Answering this question requires understanding the impact of managing forests for biomass removal and of burning biomass for electricity production compared with natural gas or other alternatives.

***A short primer on forest practices***

The Maine Forest Service maintains statistics on three types of cutting—partial cuts, shelterwood cuts, and clearcuts. The Forest Practices Act (FPA) defines any cut that leaves more than 30 square feet of basal area (the cross section area of all tree trunks at breast height per acre), and is not a shelterwood thinning, as a “*partial cut*,” even though the result might be a poorly-stocked stand. A fully-stocked (reaching crown closure) softwood stand with trees averaging 8 inches in diameter could have close to 200 square feet of basal area.

Partial cutting can be a legitimate form of “selection” silviculture (which improves the quality and spacing of trees and can leave large trees in the residual stand)—or it can be some form of “highgrading” (taking the biggest and best and leaving the rest). The “selection” system is an uneven-aged form of silviculture—it leaves stands with three or more age classes of trees. True selection cutting is not common in Maine.

A more typical “partial” treatment is “diameter-limit cutting,” in which the logger cuts all trees over certain diameters (by species). A long-term comparison of this latter system with true selection found that repeated diameter-limit cuts degraded stands by shifting to lower-value species and lower-valued products.[[46]](#footnote-46)

*Shelterwood* cuts can start with a thinning, leaving seed sources and partial shade. Once the regeneration reaches a certain height, the landowner can do an “overstory removal,” in which all the merchantable trees can be cut. Sometimes the thinning operation is skipped if the stand already has advanced regeneration. The FPA specifies a minimal amount of height and stocking of the regeneration.

*Clearcuts* leave less than 30 square feet of basal area per acre without enough advanced regeneration to qualify as a shelterwood cut. The Forest Practices Act regulates the size and distribution of clearcuts, but has no area restrictions on partial cuts or shelterwood cuts. Both clearcutting and shelterwood are “even-aged” systems that regenerate new stands with heavy cutting.

Clearcuts and shelterwood overstory removals represent about one-third of all cuts in Maine for 2014. These heavy cuts regenerate new stands. Some “partial cuts,” however, are also so heavy that they regenerate new stands—a stand with 30 square feet of basal area per acre is so poorly stocked that the remaining overstory cannot create a closed canopy. Since even-aged management means having one or two major age classes of trees, it is possible that more than half of all cutting in Maine leads to even-aged stands. The average removal per acre (determined by dividing the total cords harvested by the total acres harvested) was close to 15 cords, which indicates heavy cutting.

Based on state definitions,

* 50.5% of all acres cut in Maine in 2014 were partial cuts,
* 42.7% were shelterwood cuts (35% of which were thinnings and 65% overstory removals), and
* 5.5% were clearcuts.

In 2008, 37% of the Maine’s northern three counties (Aroostook, Piscataquis, and Somerset Counties) forests were dominated by seedlings and saplings—an increase from 2003 of 664,800 acres. In the eastern three counties (Penobscot, Hancock, and Washington Counties) 36% of the area was in seedlings and saplings—an increase from 2003 of 539,100 acres.[[47]](#footnote-47) This indicates widespread heavy cutting that is far greater than the 5.5% figure for percent of harvests in clearcuts could possibly create.

*Maine logging systems*

Most tree cutting (about 80% by volume) in Maine is now done mechanically (by large machinery, rather than with manually operated chainsaws).[[48]](#footnote-48) The dominant mechanical logging system in the corporate-owned lands is the combination of feller-bunchers and grapple skidders (about 75%)[[49]](#footnote-49). The feller-buncher mechanically cuts down whole trees (including branches and tops) and lays them in piles (or bunches) to be picked up by grapple skidders, which grip the bunches with big jaws then drag them—branches and all—to the yard, where delimbers remove tops and branches and cut the logs to length.

Another mechanical system that is growing in favor (about 25%) is called “cut to length” (CTL) or “shortwood.” With CTL, the wood is usually cut mechanically by a single-grip harvester, which delimbs the tree in the woods, cuts it to length, then leaves the pile of logs for a forwarder. The forwarder loads and carries, rather than drags, the wood to the yard. CTL also includes systems in which the wood is cut manually with a chainsaw and then taken to the logging trail with either a cable winch or animal power.

On smaller acreages, loggers more often cut and limb trees with chainsaws and use either cable skidders or tractors equipped with cable winches to get the wood from the forest to the yard. Often logging with conventional skidders is done tree length.

The wood at the yard is sorted by market to get best returns, with low-valued biomass normally being the last choice. Often the biomass wood that goes to the chipper consists of tops, branches, and wood unsuited for pulpwood, but sometimes pulpwood-quality wood goes through the chipper to fill the chip truck or meet a contract. Sometimes the stand harvested is so degraded or small-diameter it lacks enough good wood to fill a truck headed toward higher-paying markets; sometimes regional markets favor biomass over certain species of pulpwood; and sometimes small-diameter wood with the potential to be higher-valued in years to come gets cut because the landowner doesn’t want to wait.

Since feller bunchers are the technology used to bring out whole trees, and since they remove about 60% of state-wide tree volume, and since tops and limbs represent only about 19% of whole-tree removals (see graph, pg. 15), and since some operations leave tops and branches in piles or on logging trails, tops and branches (logging “waste”) could not possibly account for all of what is consumed for biomass (20% of all volume) in Maine. Tree boles are going through the chippers as well as tops and branches.

***Logging machinery impact on sequestration***

*Footprint.* Whole-tree harvesting, although having the lowest labor per unit of output, also requires the most land cleared for big machines and for piles of trees than for any other logging system.[[50]](#footnote-50) It also removes all the tops and branches from the forest, whether the wood is going to biomass markets or not. The logging trails for feller-bunchers/grapple skidders are often a minimum of 17-18 feet wide to accommodate not only the machinery, but also the bunches of whole trees that are dragged to the yard. The branches can damage live trees retained on the sides of the trails as the grapple skidder pulls out trees with branches still attached. The wheels can damage tree roots along the trails.

The boom reach of feller-bunchers ranges from 22 to 37 feet. This means the stands between the logging trails range from 44 to 74 feet wide and the trails themselves take up a minimum of 20 to 29% of the logged land. This further means that 20 to 29% of potential crop trees are cut, often prematurely, just to make trails. With feller-buncher/grapple-skidder systems, if the logger cuts one third of the basal area of the stands between the trails, *this would lead to a total removal of about half the stand*. Cutting more than 50% of a stand is too heavy for true “selection” management.

Some mechanical cut-to-lengths, using single-grip harvesters and forwarders, can also have a significant ratio of trails to forest. The difference with whole-tree systems is that CTL can lessen the compaction/rutting damage by using “ghost trails,” where the forwarder uses every other trail. CTL can do less damage to residual trees along the trail because whole trees with branches are not being dragged out—the logs are carried. And with short-wood systems, the slash (limbs, tops, and unmerchantable pieces of trees) is left in the woods.

*Lowering impacts.* Low-impact loggers in Maine have been trying to develop systems that minimize the footprint and the damage from cutting and yarding wood. A wide array of machinery and even animal power are being explored. In one system, the tree is cut and limbed in the woods and the log is dragged to the trail with a radio-controlled cable winch. Once at the trail, a forwarder, which carries, rather than drags the wood, takes the logs to the yard. Small forwarder trails need be only 10 feet wide, and with a cable winch, the trails can be 150 feet apart. In this case logging trails would only take up about 7% of the stand.[[51]](#footnote-51)

The lower-impact system described is suited to smaller woodlot owners with concerns for the integrity of the residual stand. Productivity of removals (volume cut per person per day), however, is low compared with machinery used in more industrial settings. If the logging footprint becomes a higher priority for forest engineers, more productive but less damaging systems could be developed for ownerships of all sizes.

*Impact of removal of woody debris*

Removing tops and branches from the forest, whether or not for biomass markets, *intensifies* the harvest. Whole-tree clearcuts, the most intense practice in Maine, not only have the biggest impacts on carbon removal of above-ground material, they also have the greatest impact on the soil. The issue is not just carbon, but also the future productivity of the site. A Vermont review of biomass harvesting stated that “whole-tree harvesting can remove up to 96 percent of aboveground biomass, reducing stand structural elements and soil organic matter, and disrupting soil nutrient cycles.”[[52]](#footnote-52)

A University of Vermont study concluded: “Our findings demonstrate that mineral soil C can play an important role in C emissions, especially when considering intensive forest management practices. Such practices are known to cause a high aboveground C flux to the atmosphere, but there is evidence that they can also promote comparably high and long-term belowground C fluxes. If these additional fluxes are widespread in forests, recommendations for increased reliance on forest biomass may need to be reevaluated.”[[53]](#footnote-53)

Even though tops, limbs, and foliage only make up about 25% of tree volume removed in whole-tree harvesting (tops, limbs, foliage, and boles), they contain a disproportionate share of nutrients. A study from Nova Scotia found that whole tree cutting removed more than twice as much nitrogen, potassium, and phosphorus, and nearly twice as much calcium and magnesium as stem-only cuts.[[54]](#footnote-54) On poor soils this can significantly impact future productivity. Slash (including leaves and needles) and decaying wood are important sources of nitrogen to the soil, not only from the slash itself, but also from the work of bacteria that use rotting wood as a site for nonsymbiotic nitrogen fixation.[[55]](#footnote-55) According to the North East State Foresters Association, “[t]he most central concern with biomass harvesting is the potential loss of soil nutrients needed for plant growth.”[[56]](#footnote-56)

Downed wood is a major source of humus and organic matter for forest soils.[[57]](#footnote-57) Organic matter has multiple benefits for soil structure, and water retention. Debris helps protect the soil from direct exposure to sun and rain. Organic matter breaks down more rapidly in unshaded soil, leading to a flush of nutrients that can boost the growth of pioneer species after a disturbance. If these species are killed with herbicides, the nutrients can leach out of the soil. Decaying fine woody material also provides habitat for numerous small organisms and is important for fungal habitat as well.[[58]](#footnote-58)

The impact of equipment, therefore, depends on the intensity of the cut, the frequency of entries, the unavoidable footprint of the machinery, the objectives of the landowner, and the skill of the operator. Careful operators can minimize the potential damage from machinery.

***Impact of biomass markets on forest carbon sequestration***

With whole-tree logging, comparing biomass harvesting to business as usual leads to a lot of gray areas. In either case, tops and branches are removed. With biomass, they are burned, whereas without that market, the wood will either rot in a pile or get redistributed, often onto logging trails. The major differences are *that biomass markets give an incentive to cut more heavily than would have been the case without that market*, and the carbon from logging debris that is not chipped for biomass markets is *released more slowly or sequestered in the soil*.

These two factors—cutting intensity and slash management—are related. The Forest Guild, a professional group that prioritizes “maintenance and enhancement of the entire forest ecosystem,” recommends, in its guidelines for biomass harvesting, that the more intense the cutting, the higher the proportion of logging slash that should remain in the woods.[[59]](#footnote-59)

The Guild is concerned not only with the percentage removal of biomass, but also with the length of the cutting cycle. The shorter the cutting cycle the more slash should remain in the woods. The guide recommends that environmentally sensitive stands and stands with poor or shallow soils or low nutrient capital should not be subject to whole-tree biomass removals, especially with short cutting cycles.

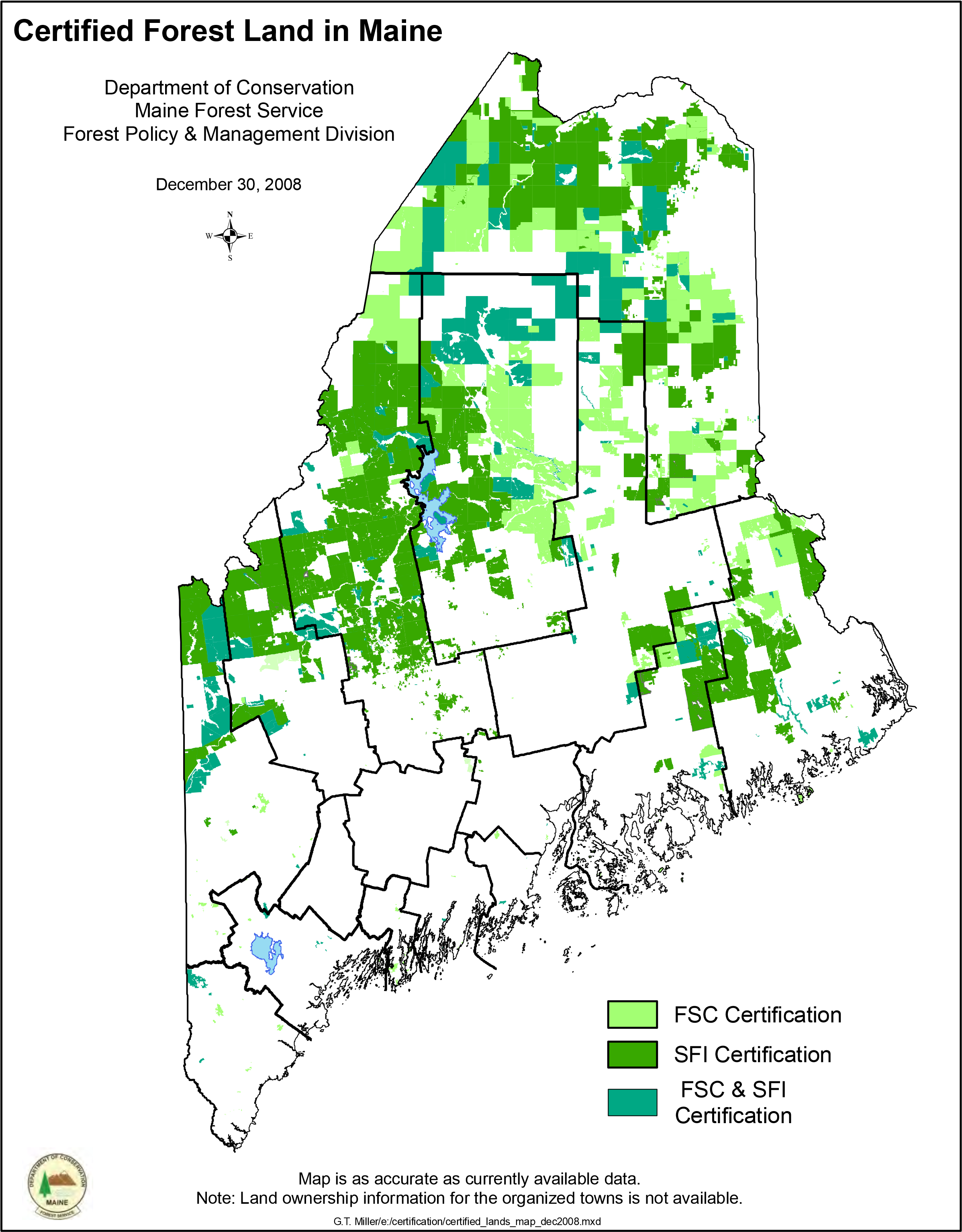
The Guild also recommends that management goals, regardless of whether the wood is going for biomass or not, should include maintaining biodiversity and tree quality. With these goals, it recommends leaving “legacy trees” (older trees, living or dead, that survive either harvesting or natural disturbance), improving forest structure, and managing for tree health and vigor.

Maine Audubon Society likewise has guidelines for residual dead wood—whether harvesting is for conventional use or biomass.[[60]](#footnote-60) To achieve such purposes, lighter cuts (less than one-third of the basal area), and uneven-aged harvest systems are preferable. As discussed, light cutting is difficult to accomplish with feller-bunchers that remove so much forest just to make room for equipment. A research report from Nova Scotia on selection systems in red spruce stands recommended 20% removals, which is less than what some mechanical systems remove for trails.[[61]](#footnote-61)

A major concern of the Guild is cutting small-diameter trees that have potential to improve in grade: “…the harvest of future crop trees for energy is the worst case scenario: such a harvest reduces on-site carbon, probably limits the economic productivity of the stand, and reduces the opportunity to produce higher-value products that provide long-term carbon storage and displace more carbon-intensive products.[[62]](#footnote-62)

***Sustainable Forest Management?***

A key assumption behind the argument that forest products are “green” or “carbon neutral” is that wood harvesting is “sustainable.” As the latest federal forest inventory shows, forest growth in Maine in 2014 was greater than the cut. Sustainability is more, however, than growth/cut ratios. Many organizations have tried to define the concept of forest sustainability and some even certify that forest practices are “sustainable.” The fact that in Maine 10.3 million acres,[[63]](#footnote-63) over half of all timberlands, are certified is offered as evidence that the assumption of sustainability is indeed a reality.



The two biggest forest certifiers in Maine are the Sustainable Forestry Initiative (SFI) and the Forest Stewardship Council (FSC). Both make clear that sustainable management is not just cut being balanced by growth—it also requires managers to attend to soil, water, biodiversity, workers, communities, and even carbon. [[64]](#footnote-64),[[65]](#footnote-65)

The majority of forest land in the northern three counties in Maine, Aroostook, Piscataquis, and Somerset are certified by these two organization. One would expect that these counties should have exemplary management and thriving communities that are based on the certified forests and associated industries. Unfortunately, the combination of mechanization and mill closures has drastically reduced jobs in the area. The result has been declining populations and tax bases, and closures of schools, civic organizations, and businesses. Many forest-based communities are not thriving.

One would also expect that certified managers, to assure that carbon sequestration is not diminished, regardless of the markets to which they sell, would avoid cutting more than growth over a 10-year period. Data from federal timber inventories in Maine show that hasn’t always been the case.

A summary of a study on certified lands in Maine by David Sherwood and Robert Seymour of the University of Maine concluded:

“On private, certified land, […] total removals exceeded net growth between 1999 and 2012, whereas growth and harvest were in balance on public certified land. The imbalances on private land appear to be driven by intensive harvest of hardwood trees, though sawtimber (larger trees used by sawmills) and the region's most valuable commercial species—red spruce and sugar maple—showed the most significant imbalances.”[[66]](#footnote-66)

Certifying lands as “sustainable” does not make them so.

As simple as it may seem, cut and growth ratios get complicated when one questions which, what, where, when, and how wood is cut and trees are growing back. The answers to these questions can have significance for carbon sequestration.

*Which species are being cut, and which are growing back?* Even assuming that growth and cut were balanced, if valuable, long-lived species are in decline, but less-valuable, shorter-lived species are increasing the goal of growing bigger, older stands that sequester more carbon will be harder to achieve. In the northern three counties, which the USDA Forest Service calls the Northern megaregion (Aroostook, Piscataquis, and Somerset Counties) in the 2008 Forest Inventory Analysis (FIA),[[67]](#footnote-67) the cut of sugar maple was 92% greater than growth and of red spruce, 78% greater than growth.[[68]](#footnote-68) In the same region, however, the *growth* of balsam fir (a shorter-lived tree vulnerable to rot, blowdown, and spruce budworm) was 36% greater than removals.

*What forest stand type is being cut and what is growing back?* Cutting mature stands of timber but growing back acres of young trees also impacts carbon balances. In 2008, Maine’s Northern megaregion had 37% (an increase of 664,800 acres since 2003)[[69]](#footnote-69) and the Eastern megaregion (Penobscot, Hancock, and Washington) had 36% of timberland acres in seedlings and saplings (an increase of 539,100 acres since 2003). Seedling/sapling ecosystems hold much less volume of trees, and thus carbon, per acre than later-successional stands, and in early stages are net carbon sources rather than sinks.

*Where is the wood cut and where is it growing?* From 2003 to 2008, annual tree growth for the whole state was 2% greater than removals. In the Northern megaregion, however, cut of all species was 27% greater than growth and cut of hardwoods was 59% greater than growth.[[70]](#footnote-70) Indeed, hardwoods declined in northern Maine by 6.4% in just five years. In the Southern megaregion (the eight southernmost Maine counties), growth to removals ratio of all species was 2.33 and growth to removals ratio of hardwoods was 2.86.

Continuing to cut more than growth in northern Maine has impacted the inventory, which has impacted growth rates and the capacity to sequester carbon. The Northern megaregion had about 14.3 cords to the acre in 2008, Southern Maine 21 cords, and federal lands 29. The annual growth rate of the Northern megaregion in 2008 was 0.33 cords per acre per year, in the Southern magaregion 0.6 cords—82% more.

Was the heavy industrial cutting in northern Maine “sustainable” because it was “offset” by lightly-cut (or non-cut) woodlots in southern Maine? Is biomass harvested in northern Maine “carbon neutral” because it is “offset” by growth on another property in another region? Cutting “here” does not cause forests “there” to grow more. The two areas should be accounted for separately*. If the forests were not overcut in northern Maine, total state sequestration would be even more*.

*When is the wood cut and when is it growing?* Another approach to “sustainability” is to offset current removals based on expected future growth. Some large landowners have justified cutting more than current growth based on computer projections of increased growth due to investments in planting, herbicides, and pre-commercial thinning. This strategy is called “ACE” (Allowable Cut Effect). Because of future discounting (by using current discount rates projected into the future, the present is worth more than the future, and the remote future is worth almost nothing), the landowner will want to shorten the rotations as much as possible.

This approach ends up accelerating the cutting of older stands and replacing them with younger, more simplified landscapes that have less capacity to sequester carbon. This strategy is most likely pursued where governments subsidize early stand management (sometimes with favorable tax treatments). The landowner gets revenues from the cutting, and the public helps pay for “management.” One opportunity cost (the loss of potential gain by choosing one option over another) could be less investment in careful stand improvements in older stands.

*How is the wood cut and how is it growing?* If growth and removal rates are the same on average, does it matter if one uses an even-aged cutting system versus an uneven-aged cutting system? A hypothetical example illustrates the difference between two systems. With *system* *1*, when a stand has 30 cords to the acre, the landowner does a clearcut or overstory removal. In 60 years, the forest grows back to 30 cords per acre, averaging growth of 1/2 cord per acre per year.

With *system 2*, when a stand has 30 cords per acre, the landowner cuts 7.5 cords to the acre, reducing the stand volume to 22.5 cords to the acre. In 15 years the stand grows back to 30 cords, so this forest landscape also yields 1/2 cords per acre per year. Since both systems have the same yield rate, don’t they both sequester the same amount of carbon per year?

No. First, *system 1* averages 15 standing cords per acre (30=0/2), *system 2*, averages 26.25 cords per acre ((30+22.5)/2)—75% more standing wood per acre than *system 1*, and this is stored carbon. Second, *system 2* yields more large-diameter wood that can be used for lumber that is more apt to continue to sequester carbon than would biomass or pulp. Third, every 60 years a *system 1* site is subjected to heavy cutting that could lead to soil carbon losses as well as less sequestration by seedlings compared to large trees.

***Impact of forest products on carbon balance***

While manufacturers may promote their forest products as “green” because trees are “renewable,” to determine how wood products compare with alternatives requires “embodied energy” calculations, “energy return on investment” (EROI) estimates, or “life cycle analyses” (LCAs). These estimates consider energy and environmental impacts of production, raw materials, transportation, processing, packaging, use, maintenance, as well as disposal, burning, or recycling. They also look at the energy and environmental impacts of alternatives or “business as usual” (BAU). Another analytical topic is “leakage,” in which making less of a product in one place can lead to making more somewhere else. What is the impact of that somewhere else?

Unfortunately, no unanimity exists as to what to measure, how to measure it, and when to start and stop the measurements (variables, procedures, and time). Conclusions of different studies can vary, not just by degrees, but also by relative positions of alternatives, or even by whether net benefits exist. Not all impacts, especially environmental or social, are easily reduced to numbers.

*Long-lived wood products.* Still, these different analyses help look more deeply into the relative benefits of using wood products versus alternatives. Assuming “sustainable management,” many studies show clear energy, carbon, and environmental advantages of wood lumber over steel or concrete as building materials.[[71]](#footnote-71),[[72]](#footnote-72) Manufacturing lumber takes less energy, and lumber used for building continues to sequester carbon from the atmosphere. Cellulose insulation (also a product of trees) has far less embodied energy than alternatives, such as fiberglass, rock wool, or chemical foams.[[73]](#footnote-73) Like lumber, its carbon stays isolated from the atmosphere.

Even with longer-lived wood products, such as lumber, only a small percentage of the carbon in the harvested tree is sequestered in the final product. When the tree is cut down, only the bole is removed; the rest is logging slash. Only a certain percentage of the bole is turned into lumber; the rest is mill waste. And when one accounts for the carbon released during harvest, transportation, processing, and delivery of the finished product, the result may be only 15% net carbon storage.[[74]](#footnote-74)

*Short-lived wood products: biomass.* Analyses diverge radically on the impacts of harvesting whole trees *from existing forests* (as opposed to using mill waste, such as bark, edgings, sawdust, and shavings) instead of using fossil fuels to generate electricity. Proponents claim that biomass is “carbon neutral”—the tree takes in carbon through photosynthesis, and then either rots or burns—releasing that carbon and leading to no net gain or loss. By calling biomass electric generation “carbon neutral,” companies may get favorable tax treatments and higher-paying contracts if the energy produced qualifies for renewable energy targets. These benefits create an incentive to try to come up with “science” that supports the economics.

Discussing the carbon impacts of biomass markets raises three major areas of concern:

* impact to the forest (sequestration, emissions from soil microbial respiration and debris breakdown, biodiversity impacts, and productivity changes);
* carbon emissions associated with equipment used for harvesting, processing, and transporting; and
* carbon and other greenhouse gas emissions from burning biomass.

A life-cycle analysis (LCA) would also compare these impacts to those of harvesting for alternative markets or of using alternative fuels. These alternative fuels would have LCAs as well. Having already discussed impacts of forest management, what about emissions from equipment and from power plants?

*Equipment emissions.* The carbon emissions from harvesting, processing, and transporting biomass vary depending on the energy required for manufacture, the size of the equipment, and the distances products are shipped. One study estimated that 5 to 10% of the total carbon cost of wood-fired biomass plants is from such equipment. Pelletizing wood—a process that uses considerable heat and pressure, can add another 4 to 10% to the embodied energy of biomass.[[75]](#footnote-75) Some studies (cited in same source) suggest even higher emissions from the pellet process.

Some European countries, to meet their renewable energy targets, are shipping biomass fuel from the United States and Canada. A British biomass promotion site estimates that energy used to ship biomass fuel from southeastern United States to England makes up 20% of the total carbon emissions from using biomass.[[76]](#footnote-76)

*Biomass energy plant emissions compared with emissions from other fuels.* Maine generates more than a quarter of all its electricity from biomass, the largest percentage of any state.[[77]](#footnote-77) Most of these plants are “direct fired” and use wood to boil water to create steam to run a turbine to create electricity. The efficiency of most of these plants at converting total available energy into electricity is relatively low, in some cases 25% or lower.[[78]](#footnote-78) Most of the energy produced is “waste heat.” Wood chips have moisture and other impurities that must be burned off. The proportion of carbon in wood by weight is 45% to 50%.[[79]](#footnote-79) The proportion of carbon by weight in coal is 86% to 95%.[[80]](#footnote-80)

Biomass electric power plants, on average, *release considerably more carbon per unit of electricity than natural gas or even coal, increasing atmospheric carbon in the short term*. One study looked at stack emissions from existing biomass plants and concluded “that stack emissions from existing facilities are around 1.67 tCO2/MWh, or anywhere from 50-85% higher than emissions from existing coal plants.”[[81]](#footnote-81)

Biomass plants also emit some other pollutants at higher rates than do fossil fuel alternatives. The California Air Resources Board (CARB), for example, found that biomass combustion generates 17 times as much NOx and 27 times as much particulate matter per megawatt hour as power plants burning natural gas. Some plants not only burn wood but also trash that has even more pollutants. “Biomass plants, however, are not subject to [the same standards as large fossil fuel plants] until their emissions reach 250 tons per year or more of any criteria pollutant (…). This means that biomass plants can emit up to two-and-a-half times as much pollution as fossil fuel plants without any kind of regulatory review or permitting restrictions.” [[82]](#footnote-82)

*Biomass and time.* If biomass plants are constructed *in* *addition* *to* existing energy and wood processing plants instead of *replacing* them, then more regional wood will be cut than with business-as-usual, less carbon will be sequestered, more wood will be burned, and more carbon will be emitted during burning. The carbon cost of constructing the biomass plant should be added on to all the other emissions. In the short term, a new plant would clearly raise atmospheric carbon levels, even though the goal is to lower them.

The argument for more biomass plants is based on assumptions about time and space. If carbon accounting starts when the tree stand was regenerated, then one can argue that the stand when harvested has already sequestered the carbon. Burning the wood is just returning what the tree took from the atmosphere. Or, starting with the harvest, it can be argued that the harvested stand will grow back, resequestering carbon that was emitted during burning.

These arguments ignore the fact that burning takes minutes, releasing the carbon all at once, but sequestering takes decades. This difference in time makes a difference. It makes even more of a difference when impacts of soil carbon losses are included. One study stated, “Including even a moderate forest soil C loss can have significant impacts on calculating a C payback time when assessing bioenergy substitution scenarios for fossil fuel use comparing forest-based bioenergy with fossil fuel scenarios. Likewise, the timing of emissions is of considerable concern when aiming for climate change mitigating strategies even if the CO2 is re-sequestered at a later stage”[[83]](#footnote-83)

To avoid the issue of time, proponents argue that growth on existing, sustainably managed forests offsets biomass burning. But which forests? The stand that was cut? The total ownership? The county? The state? The region? Is growth in Baxter State Park and other reserves included? And if power plants burn natural gas instead of biomass, wouldn’t the same forests sequester the fossil-fuel carbon emissions, and wouldn’t the forests not cut for biomass sequester more carbon? Does it matter if increasing the cut for biomass markets reduces sequestration, and burning the biomass for electricity increases carbon emissions compared to business as usual?[[84]](#footnote-84)

A study on net carbon fluxes from biomass harvesting concluded, “… all bioenergy scenarios resulted in increased net emissions compared to the non-bioenergy harvests.” Some scenarios, such as using biomass for heat, shortened the time of the carbon imbalance from using biomass for generating electricity. The study argued that time matters. “The near-term of one to several decades may be particularly important for stabilizing atmospheric greenhouse gases, beyond which some scientists have suggested there may be irreversible disruption of the planet’s climate system even if atmospheric concentrations of greenhouse gases ultimately decrease.”[[85]](#footnote-85)

*Short-term products: pulp instead of biomass*? What if instead of going to biomass boilers, the logs went to the most likely alternative forest product—pulp wood? Pulp and paper mills consume large amounts of energy. The paper industry ranks in the top three greenhouse gas (GHG) emitters of U.S. manufacturing industries.[[86]](#footnote-86) Energy needed for heat and power pulp and paper mills can come from many sources, including fossil fuels, the grid, hydroelectric dams, and biomass. In the United States, pulp and paper mills get about 65% their energy from biomass called “hog fuel” (mill wood waste and black liquor, a liquid by-product of paper making that has lignins, cellulose, and various chemicals).[[87]](#footnote-87) The hog fuel is used mostly for heat, but many mills produce electricity as well through “combined heat and power” (CHP).

Despite how much biomass is used in pulp and paper production, an estimate of GHGs from pulp and paper mills gave CO2 emission figures only for grid electricity and fossil fuel, but not for biomass. The reason given: “carbon dioxide emissions from biomass combustion are not counted as GHG emissions, a convention common to most of the protocols examined in this review.” The study did show that methane emissions from biomass were three times greater than from coal and six times greater than from natural gas. Nitrogen oxides from the biomass were three times greater than from coal and 40 times greater than from natural gas.[[88]](#footnote-88)

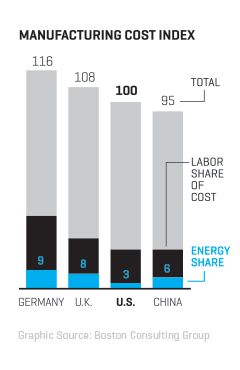
Another industry fact sheet listed fossil fuel and grid-based carbon emissions used in the paper industry and used the same excuse for not including biomass: “The industry also burns large quantities of biomass fuels but the CO2 released from biomass combustion is not included in greenhouse gas totals because it contains biogenic carbon [produced from living or recently living sources] that is part of a natural cycle. It is for this reason that biomass-derived CO2 is called ‘carbon neutral.’”[[89]](#footnote-89)

*Disposal.* While some paper gets stored a long time in books and documents, much paper use is short-lived. Single use followed by disposal is common. In 2013, according to the EPA, 63% of paper consumed in the United States was recycled.[[90]](#footnote-90) Recycling saves a lot of energy and water, but is still energy intensive. Much of the paper that is not saved or recycled enters landfills. Twenty nine percent of landfill space is taken up with paper and paper board.[[91]](#footnote-91) Paper in landfills normally breaks down in two to five months.[[92]](#footnote-92) Landfills are the third largest source of U.S. methane releases.[[93]](#footnote-93) A smaller percentage of waste paper gets incinerated.

Managing forests for pulpwood, rather than for biomass, might reduce carbon impacts in the forest but increase emissions and pollution from the product. Whether a landowner sends more wood to one type of market over another, however, is not going to change the emissions of the mills. These mills get wood—especially pulp wood—from a fairly large area, and they import material from other states or from Canada to get enough material to continue operating. Maine imports 11% of biomass burned and 21.4% of pulpwood used.[[94]](#footnote-94)

While biomass is a regional energy source, paper is a global commodity. Closure of paper mills in Maine is not lowering carbon emissions globally. While global production of paper and cardboard was impacted by the recession in 2007, starting in 2010, production recovered and has been growing.[[95]](#footnote-95) Most of the global growth has been in China, which has cheap labor and fewer environmental regulations. Chinese paper may have a higher carbon footprint than Maine-made paper, due to increased transportation costs of importing pulp and exporting paper as well as to a higher reliance on coal. Chinese mills, however use more alternative fiber sources and recycled pulp.[[96]](#footnote-96)

Ironically, recent reductions in natural gas and oil prices, due in part to fracking, are making U.S. paper more competitive.[[97]](#footnote-97) Some recent Maine paper mill closures are tied to increased imports from Canada, based in part on the low value of the Canadian dollar.[[98]](#footnote-98)



***False tradeoffs***

This report does *not* advocate cutting the forest more heavily in order to burn more “carbon neutral” biomass; nor does it advocate burning more coal, oil, or natural gas instead of biomass in order to sequester more carbon in the forest. There are good reasons to reduce reliance on fossil fuels with their accompanying mountain top removals, fracking, water pollution, methane releases, oil spills, railroad fuel car explosions, ocean oil spills, and wars. Also, the embodied energy in fossil fuels that take more energy to extract and refine is increasing. The double bottom line is that *we need to reduce carbon emissions (regardless of the source)* ***and*** *increase carbon sequestration*.

*Decreasing emissions*. The most obvious way to reduce carbon emissions is to use less energy, just as the most obvious way to sequester more carbon is to grow a greater volume of trees. Public money spent on eliminating waste and increasing efficiency in both use and production, in general, yields higher returns and faster paybacks than subsidies for new power plants—especially power plants that would not be competitive in the market without subsidies.

This strategy, which physicist Amory Lovins named the “Negawatt Revolution,”[[99]](#footnote-99) has already saved more in CO2 emissions than all the spending on renewables—and has had a quicker payback period. According to an article in *The Economist*, “’avoided energy’—the difference between the amount actually used each year and the amount that would have been used had there been no conservation since 1974—is now equivalent to two-thirds of annual consumption. That is almost as much as the world’s output of oil, gas and coal combined.”

The Negawatt strategy can continue to reduce energy use in homes, commercial buildings, and industrial plants, and the same strategy can reduce paper consumption as well.

The Energy Information Administration (EIA) offers the following about Maine energy (both heat and electricity) statistics from 2014:

* Maine is the only New England state in which industry is the largest energy-consuming sector.
* The industrial sector produces more than one-fourth of Maine's net electricity generation, the highest proportion of any state.
* Three-fifths of Maine's net electricity generation came from renewable energy resources, with about 25% from hydroelectricity, 27% from biomass (mainly wood products), and 8% from wind.
* Industry consumes around a one-third of all energy (including heating); residential and transportation each consume one-fourth; and commercial buildings consume one-sixth.[[100]](#footnote-100)
* Regarding just electricity, households in Maine consume 38%, commerce 36%, and industry 27%.[[101]](#footnote-101)
* More than 7 out of 10 homes in Maine heat in part or totally with oil, the highest percentage in the country.[[102]](#footnote-102)

Great opportunities exist in Maine for weatherizing and insulating to reduce heating costs. If you have a hole in the wall, it makes more sense to close that hole before purchasing a different heating system (such as a heat pump or an efficient wood gasifier boiler system) that requires a big, up-front investment. After you close the hole, if you still want to change heating systems, you can purchase a smaller, less expensive unit.

Great opportunities also exist at the household level to reduce electric needs by switching from inefficient to efficient lighting, refrigeration, washing machines, and water heaters. On the industrial level, the Federal Energy Star program has a comprehensive review of possible upgrades for pulp and paper production that covers all aspects of the manufacturing process, including steam, lighting, motors, pumps, fans, and much more.[[103]](#footnote-103)

A study from the Muskie Institute on *Energy Efficiency, Business Competitiveness, and Untapped Economic Potential in Maine*, concluded**, “Perhaps the single most effective action to enhance Maine’s business climate and economic competitiveness is to aggressively increase the energy efficiency of Maine’s economy.”** According to the study, if Maine businesses used known methods to reduce energy use, they could save, **“$230 million in energy costs, while businesses in the industrial (manufacturing) sector could save up to $129 million, for a total savings to the Maine economy of over $450 million per year at today’s energy prices and utilization rates.”**[[104]](#footnote-104) (bold from study)

Maine has 10- and 20-year energy savings targets established by statute that are far-reaching and that include:

* capturing all cost-effective energy efficiency resources available for electric and natural gas utility ratepayers;
* achieving electricity and natural gas savings of 30 percent within a decade;
* achieving heating oil savings of 20 percent in the same timeframe; and
* weatherizing 100 percent of homes and 50 percent of businesses by 2030.[[105]](#footnote-105)

These goals are doable if the state has the will to incentivize such commitments. Many of these investments pay back in double digits, and consumers and businesses can immediately reduce their monthly energy bills. Investing in new power plants benefits the plant owners, but not consumers.

*Efficiency in energy production and distribution.* Conservation and efficient consumption are a start, but more can be done to reduce the demand for both fossil fuels and biomass. The equipment and processes to generate heat and electricity can also have a big impact. Stand-alone electric power plants are extremely inefficient. The majority of the energy created by burning either fossil fuels or biomass gets lost as “waste heat.” Calling stand-alone biomass power plants “carbon neutral” does not change the fact that they waste resources.

Using wood for heat can be far more efficient than using the same wood to generate electricity. A 2005 review of commercial-scale wood biomass heating systems found efficiencies ranging from 55%- to 75%,[[106]](#footnote-106) but newer models, which have multiple chambers that burn combustion gasses, can approach 90% efficiency.[[107]](#footnote-107) The efficiency of burning wood products varies, depending on the design of the equipment, the moisture content of the wood, the time of year, stack temperatures, and burning strategies.

Some manufacturers (including paper mills), hospitals, commercial buildings, apartments, and even communities have set up power plants in which the heat is used rather than wasted. This process, called “cogeneration” or “combined heat and power” (CHP), can raise efficiencies from around 25% for stand-alone biomass to 70% to 90% for CHP.[[108]](#footnote-108)

In 2008, cogeneration accounted for 9% of total U.S. electricity generating capacity. The Oak Ridge National Laboratory calculated that increasing that share to 20% by 2030 would lower U.S. greenhouse GHG emissions by 600 million metric tons of CO2 (equivalent to taking 109 million cars off the road) compared to “business as usual.”[[109]](#footnote-109)

In a 2012 report for the Massachusetts Department of Energy Resources, the Manomet Center for Conservation Sciences called the excess carbon that would be emitted by biomass compared with fossil-fuel alternatives a “carbon debt.” Any reduction in GHGs was considered a “dividend.” The researchers calculated the time for pay back of these debts for various scenarios:[[110]](#footnote-110)

**Fossil Fuel Technology Carbon Debt Payoff (years**)

Oil (#6), Thermal/CHP 5

Coal, Electric 21

Gas, Thermal 24

Gas, Electric >90

Manomet calculated a 5 year payback (and then dividends) if biomass were used for high efficiency thermal or combined heat and power as a substitute for heating oil. But if biomass were used as a substitute for natural gas in a stand-alone electric generating plant, the payback would take more than a century. Based on this study, Massachusetts established minimum efficiency standards, below which a biomass plant would not be given favorable government treatments. To receive half of a Renewable Energy Certificate (see [[111]](#footnote-111) for explanation of REC), plants have to be 50% efficient; to receive a full REC, plants have to be at least 60% efficient.[[112]](#footnote-112)

*Grid optimization.* The grid was not originally designed for intermittent sources, such as wind and solar, but for centralized generators that burn on demand. Now the grid receives complex mixes of energy sources that are difficult for utilities to track fully. How can this mix be optimized to minimize reliance on carbon emissions? At least six variables exist:

* diversify distance (wind may die down in one place but be blowing somewhere else);
* diversify sources (combine wind, solar, hydro, waves, etc., so that some sources are producing when another is not);
* store energy (e.g., pumped storage on a big scale, or batteries on a household scale);
* use backup power (e.g., fossil fuel, biomass, or hydro sources that are already connected to the grid and can quickly supplement wind or solar when storage is inadequate);
* curtail loads (adjusting use to what is available, encouraged through price incentives and disincentives).[[113]](#footnote-113)

Success in reducing demand and optimizing grid use should be measured in reduced carbon emissions, and in closings of most inefficient fossil-fuel plants. Because sun and wind are intermittent, the full capacity of conventional power plants needs to be available for when the wind does not blow and the sun does not shine. The potential exists to put at least some fossil-fuel power plants on “spinning reserve” during windy or sunny periods and this could lower emissions, though it may reduce the efficiency of the fossil fuel plants. Currently (pun not intended), a greater incentive exists to add more wind than to actually reduce fossil fuel carbon emissions. Many of the wind energy electricity credits are sold to out-of-state consumers in Southern New England wanting a higher proportion of renewable energy in their energy mix.[[114]](#footnote-114)

*Negalogs*. The same approach of efficiency and conservation can be applied to paper consumption to reduce the need for cutting more and more wood to meet increasing demands. Instead of Negawatts (avoided need to generate more electricity), we would have Negalogs (avoided need to cut more trees for pulp). Strategies to reduce the need for cutting forests include:

* using more recycled paper (while the U.S. recycles more than 60% of paper,[[115]](#footnote-115) Germany recycles 87% of *all* trash[[116]](#footnote-116));
* eliminating unnecessary uses (such as instant throwaway fast-food wrappers, secondary packaging, or unwanted junk mail, most of which is unread);
* using more electronic communications and information storage;
* using paper more efficiently by setting copiers and printers for double-sided printing and using paper printed on one side for drafts or scrap;
* using the lowest weight paper appropriate;
* adding other materials, such as kenaf, hemp, or agricultural waste to reduce raw wood in the pulp mix;
* look for more efficiencies in production.

*For increasing sequestration* this report has mentioned a number of management goals:

* First do no harm. Transition away from intensive cutting that turns forest sinks into carbon sources.
* When cutting, plan for a residual stand that has, when possible, higher-grade, longer-lived species in wind-firm stands. Favor dominant trees (with better crowns and root systems) over suppressed trees (with smaller crowns and root systems).
* Plan toincrease, over time, higher volume, later-successional forests.
* When cutting, retain some individual trees (protected by surrounding trees) to grow old and die.
* Increase the percentage of un-cut reserved stands that can develop old-growth characteristics.
* In managed forests, encourage fungi-friendly habitats—retaining large-old trees and dead-downed trees.
* Practice low-impact logging to minimize damage to residual stands and to soil.
* Leave most of the tops and branches on site, especially for thin soil or low fertility sites.
* Encourage forest engineers to design equipment that minimizes logging footprints, not just maximizes logging removals.
* Cut less than growth to allow the forest to recover in size, volume, and structure.
* Live within what is biologically sustainable in our forests—what is available from such management should determine mill capacity—mill demand should not determine management output.
* Manage for biodiversity and forest integrity so that forests are more resistant to and resilient from disturbances over the long run.
* Use wood products in the most efficient ways and give preference to markets, such as lumber, that do not convert wood (by burning) to CO2 in the short term.

Maine’s Bureau of Public Lands has demonstrated, to some extent that such a strategy can work. For many decades, the Bureau has cut less than growth, low-graded (cut the worst and left the best), and encouraged retention of legacy trees and older stands. Most of the cutting has been for uneven-aged stands, using selection. The result has been higher average volumes (23 cords per acre as opposed to 17 for the rest of the state), 20% higher growth rates, a higher percentage of sawtimber, and 75% more average volume of red spruce per acre than the rest of the state.[[117]](#footnote-117) Unfortunately, the year the state issued that report (2013), the administration tried to greatly ramp up the cut.

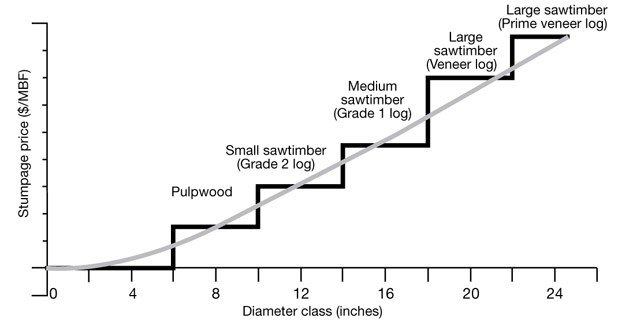
***Challenges of getting there from here***

*Current state of forest.* Serious challenges impede getting there from here. For example, large areas of the northern forest of Maine that previously were clearcut are now loaded with young fir. Fir is not a long-lived species and is subject to rot, blowdown, and spruce budworm. Unless more longer-lived species, such as red spruce, can fill the gaps when the fir stands collapse, the cycle can start again. This system could be unstable for a long time.

*Incentives to cut.* Much of northern Maine has very low average tree volume per acre. Increasing that volume and helping stands recover would require reducing the overall cut and the average removal per acre per year. But strong economic incentives encourage continued heavy cutting. First, the turnover of land has accelerated over the last two decades. Each time the land changes hands, the new landowner is strongly tempted to increase cutting to help pay back the purchase price. Second, logging in Maine is very capital intensive. Loggers have a strong incentive to cut as much as possible to pay off the cost of machinery. Loggers are paid more for what is removed for than the quality of what remains.

*Forest as resource.* When forest land is an investment, getting a return on the investment is the investor’s primary goal. Ecological and social goals can be pursued only to the extent that they do not interfere with the primary goal. The goals of the economy are not the same as the goals of ecosystems—but economic goals often determine which trees get cut.

Corporate timberland managers have to show adequate quarterly returns for their investors. For such landowners, the sequestration strategy, which would lead to less money than with heavier cutting in the short term, is hard to justify. Our economic system discounts the remote future. If we value the future as being worth very little that might, unfortunately, be the unintended result. Yet, with decent management, time can improve value as diameters and grades increase.



General pattern of stumpage prices and grade shifts for hardwood timber of different diameters.

<http://extension.psu.edu/natural-resources/forests/finance/forest-tax-info/publications/forest-finance-8-to-cut-or-not-cut-tree-value-and-deciding-when-to-harvest-timber>

*Lack of adequate regulatory restraint.* Landowners are not cutting heavily or highgrading on hundreds of thousands of acres because they hate forests or they want to heat up the planet, but to make money and because it is legal. It is a logical consequence of the goals and priorities of our economic system. Except for restrictions around water bodies and deer yards, few restraints exist to stop unsustainable harvesting—save, perhaps, for recessions. Landowners can legally cut more than growth, highgrade, leave poorly-stocked residuals, and even do whole-tree clearcuts up to 250 acres in size.

*Existing incentives*. Tools exist that are supposed to be incentives for sustainable management—including current-use taxation, zoning, easements, and certification—but so far these have not countered market-based incentives for heavy cutting. Biomass power, classified as “renewable energy,” is eligible for federal, state, and ratepayer subsidies and for tax breaks. These include:[[118]](#footnote-118)

* Renewable Energy Credits,
* Energy Production Tax Credit,
* Investment Tax Credit,
* Exemption from Carbon Allowances, and
* Biomass Crop Assistance Program fuel subsidies.

Now federal and state initiatives are being debated that will further subsidize stand-alone biomass electric power plants. One, an amendment to the Senate’s Clean Power Plan, declares that biomass is “carbon neutral,” regardless of the manner in which it is harvested and regardless of the efficiency with which it is burned.[[119]](#footnote-119) So, biomass will qualify for more subsidies and tax breaks and will be favored for renewable energy portfolios.

A bill before the Maine State Legislature would qualify biomass power plants to receive utility contracts that artificially lowers bids, to make biomass more competitive.[[120]](#footnote-120) This would make electricity more expensive for consumers in the name of carbon emission reductions. Maine biomass plants are trying to deal with the double whammy of low fossil fuel prices combined with loss of Massachusetts markets starting in 2016. In 2012, Massachusetts established standards that require a minimum efficiency of 60% for biomass uses to receive full Renewable Energy Certificates—a standard that Maine’s biomass electric power plants cannot meet.

*Market distortion*. Subsidizing an industry that is neither economically viable nor ecologically sound is a questionable policy. A 2012 report, *The Carbon Footprint of Electricity from Biomass a Review of the Current State of Science and Policy*, anticipated such proclamations and warned, “Declaring all biomass carbon neutral by definition sets the stage for a massively perverse incentive under any form of carbon regulation or legislation, and could cause large market distortions for both local and international feedstocks.”[[121]](#footnote-121)

***Conclusion***

How landowners cut their forests depends on a lot of variables:

* Who are the landowners and what are their objectives?
* What are the available markets for forest products?
* What size and quality trees are available for markets?
* What logging technologies will they rely on and how will they pay the logger (based on volume of what is removed or on the quality of what is left behind)?

In the last few decades, all of these variables have been undergoing major shifts:

* Millions of acres have changed hands, and new investors have incentives to cut heavily to pay off debts.
* Local markets have been influenced by global markets. Paper mills have been shutting down. Biomass and pellet markets are threatened by competing low oil and natural gas prices. Communities are losing tax bases and employment opportunities.
* Logging and mill technologies have gone mechanical with a primary goal of productivity, leading to major losses in employment. Whole-tree systems have increased logging footprints in the woods.
* A major recession, combined with lower average diameters led to a decline in selling spruce sawlogs for lumber.
* A spruce budworm outbreak has started in neighboring Canada and may spill into Maine at a time when markets for fir (the most vulnerable species) are declining.

In recent years, the question most people have been asking is not what new mills to build but how to prevent existing mills from closing. The forest industry is in a crisis. Some people and communities are suffering, and will continue to suffer from the economic fallout.

Subsidizing biomass burning to increase markets for salvaged (or “presalvaged) fir, might temporarily save some jobs, but it would increase carbon emissions compared to business-as-usual and encourage increased cutting for the lowest value product. A University of Arizona study found that large areas of insect-killed trees did not result in an expected spike of carbon emissions. The dead trees continue to hold carbon and no longer respire CO2 at night. Soil microbes, without a source of carbon from live roots, also reduce respiration.[[122]](#footnote-122) Burning vast areas of fir in biomass plants, however, would put all the carbon from the trees into the atmosphere. The same money that would go to subsidize biomass could instead go to increase the efficiency of energy production, transmission and use while creating jobs.

There is no simple fix. It took many decades to create the forest and markets that we now have. It will take decades to change. A crisis, however, can be an opportunity. We can make choices that improve the climate and support local communities for the long term. First we have to change directions.

For example, the need to have more energy efficient buildings could lead to new markets for wood products. One challenge to building super insulated buildings is having walls and rafters thick enough to hold enough insulation to create the desired R-factor. This can be achieved using small dimensional lumber to make trusses or I-beams. Other engineered wood products, such as laminated wood beams, can allow builders to span long distances or even make curved ceilings or walls. These markets could expand in Maine. There is some interest in the region about using Cross Laminated Timbers as a substitute for steel in construction taller buildings.[[123]](#footnote-123)

In deciding where to go from here, it makes sense to assume that in the future we will need to:

* reduce carbon emissions and increase carbon sequestration;
* better protect biodiversity, including late-successional habitats;
* have industries that pollute less and that make products that are less toxic; and
* have forests with bigger trees suitable for higher-value forest products.

If these assumptions turn out to be wrong, in the future people will still be able to cut down and chip older forests and bigger trees. But if heavily cut landscapes are mostly what we bequeath to future generations, then bigger, older forests, with their biological and economic benefits, won’t be an option for them. We have a moral obligation to try to keep options open for future generations. If these assumptions about the future turn out to be right, Maine companies and communities that make changes based on these assumptions will have an economic advantage.

If we want to get there from here, we need to make sure that we are making real, measurable progress, not just rhetorical progress. If we are serious about making a positive difference in addressing global climate change, we have the challenge of meeting two bottom lines: increasing carbon sequestration and decreasing carbon emissions. The goal of increased carbon sequestration is measured by increases in the standing volume of live and dead trees, increases of average tree size, increases of average growth per acre per year, increases in soil organic matter, and increases in the diversity of tree allies, such as mycorrhizal fungi. Calling millions of acres “sustainable,” if these metrics are not even criteria for that definition, is not the solution.

The goal of reduced carbon emissions is measured by reduced emissions from burning of any carbon-based fuels, including biomass. This can be achieved through increased efficiencies in production, distribution, and use, and switching to lower carbon-emitting power sources. Calling biomass “carbon neutral” and then ignoring biomass carbon emissions is not the solution.

Time matters. We need to progress toward these double goals *now*. Decreasing carbon sequestration and increasing carbon emissions now, with the promise of improvements decades from now, is not the solution.

We are using technologies in the Maine woods that make carbon sequestration management difficult. We have markets for wood products that are heavy carbon emitters. We need to transition toward lower emission alternatives that will create a higher percentage of wood products that continue to sequester carbon. We need to meet the bottom-line goals *and* create employment opportunities. Subsidizing use of high-carbon-emitting technologies or markets that have low added value in the name of protecting jobs is not the solution.

Feedback to society from changes in forest practices and carbon emissions is delayed by decades. We are now responding to the consequences of actions of previous generations. What we do now will have consequences to future generations. We need to manage more for forest diversity and stability, as well as for quality, keeping options open for future generations. Managing forests for the future based on current low-grade markets is not the solution, especially when that management leads to simplifying forest stands and reducing future options. Trend is not destiny. Markets change.

Because of delayed feedback, we will not know if we have exceeded ecosystem or climatic limits until decades after we have surpassed them. Surpassing the limits will trigger positive feedback loops where the more it warms, the more carbon is emitted, and the more that carbon is emitted, the more it will warm. Such loops include increased: melting of permafrost, decomposing of peat bogs, melting of ice caps and glaciers, and drying and burning of tropical forests.[[124]](#footnote-124)

It makes sense to adopt an attitude of humility in the face of such complexity and such potential hazards. Countries around the world have recognized the need for a precautionary approach to global climate change. We need to do the best we can to meet the double-bottom-line goals with what we have, *now*. Assuming that short-term economic concerns can continue to have a higher priority than ecosystems or the climate is not the solution. Assuming that some as yet undiscovered technological breakthroughs will save future generations (so that we don’t have to change our current direction) is not the solution.

The greenhouse effect is global, but Maine’s forest is local. Changes in Maine would have small impacts on the global climate. We can easily adopt the attitude that nothing we can do can make a difference. Finding excuses to continue taking actions known to make the problem worse, while avoiding taking actions that might help, is also not the solution.

We are reaching the end of an age when “cheap” resources can be squandered in grossly inefficient ways. Three-fourths of the volume of trees harvested in Maine’s forests get chipped and/or burned. And much of what doesn’t get burned is turned into paper that has a single use and then is thrown away. Rather than look for cheap substitutes to continue that trend, it is time we start managing forests and energy as if the future mattered. As Einstein is reputed to have said, “We cannot solve our problems with the same level of thinking we used when we created them.”

1. <http://earthobservatory.nasa.gov/Features/GlobalWarming/page5.php> [↑](#footnote-ref-1)
2. <http://www.fao.org/docrep/005/ac836e/AC836E03.htm> [↑](#footnote-ref-2)
3. There is also interest in increasing sequestration in agricultural lands. Currently, agricultural practices are responsible for 30% of GHG emissions. See <http://www.fao.org/soils-portal/soil-management/soil-carbon-sequestration/en/> [↑](#footnote-ref-3)
4. <http://www.nrs.fs.fed.us/pubs/rb/rb_nrs48.pd> [↑](#footnote-ref-4)
5. <http://www.nrs.fs.fed.us/pubs/rb/rb_nrs48.pd> [↑](#footnote-ref-5)
6. <http://www.sciencedaily.com/releases/2014/12/141223114233.htm> [↑](#footnote-ref-6)
7. <http://www.nature.com/news/carbon-sequestration-managing-forests-in-uncertain-times-1.14687> [↑](#footnote-ref-7)
8. <http://www.fs.usda.gov/ccrc/topics/forest-carbon> [↑](#footnote-ref-8)
9. <http://www.nature.com/articles/srep15991> [↑](#footnote-ref-9)
10. <http://summitcountyvoice.com/2014/01/09/study-fungi-play-key-role-in-global-carbon-cycle/#more-62655> [↑](#footnote-ref-10)
11. <http://www.sciencedaily.com/releases/2014/01/140108133303.htm> [↑](#footnote-ref-11)
12. <http://blogs.scientificamerican.com/artful-amoeba/dying-trees-can-send-food-to-neighbors-of-different-species/> [↑](#footnote-ref-12)
13. <http://vnrc.org/wp-content/uploads/2012/08/VNRC-Old-Growth-pub.pdf> [↑](#footnote-ref-13)
14. <http://www.uvm.edu/rsenr/wkeeton/pubpdfs/Dove%20and%20Keeton%202015.%20%20Structural%20complexity%20enhancement%20increases%20fungi%20richness_Fungal%20Ecology..pdf> [↑](#footnote-ref-14)
15. <http://www.werc.usgs.gov/outreach.aspx?RecordID=199> [↑](#footnote-ref-15)
16. <http://harvardforest.fas.harvard.edu/news/new-study-carbon-surprise-old-growth-forests> [↑](#footnote-ref-16)
17. <http://www.nature.com/news/carbon-sequestration-managing-forests-in-uncertain-times-1.14687> [↑](#footnote-ref-17)
18. <http://www.uvm.edu/rsenr/wkeeton/pubpdfs/Keeton%20et%20al.%202011_Forest%20Science.pdf> [↑](#footnote-ref-18)
19. <http://vnrc.org/wp-content/uploads/2012/08/VNRC-Old-Growth-pub.pdf> [↑](#footnote-ref-19)
20. For pulpwood, the rule of thumb is 85 cubic feet of wood to the cord. [↑](#footnote-ref-20)
21. [Maine's Forests 2008: Statistics, Methods and Quality Assurance (PDF)](http://www.fs.fed.us/nrs/pubs/download/MaineForests2008_StatisticsandQualityAssurance.pdf) extrapolations from data [↑](#footnote-ref-21)
22. <http://www.uvm.edu/rsenr/wkeeton/pubpdfs/Mika%20and%20Keeton%202014.%20%20Net%20carbon%20fluxes%20from%20bioenergy%20harvests_GCB%20Bioenergy.pdf> [↑](#footnote-ref-22)
23. <http://www.nrs.fs.fed.us/fia/data-tools/state-reports/ME/docs/MaineForests2008.pdf> [↑](#footnote-ref-23)
24. <http://www.fia.fs.fed.us/library/brochures/docs/2000/ForestFactsMetric.pdf> [↑](#footnote-ref-24)
25. <http://www-assets.vermontlaw.edu/Assets/iee/IEE_PSD_FinalReport_WoodyBiomass_2015.pdf> [↑](#footnote-ref-25)
26. <http://www.latimes.com/science/sciencenow/la-sci-sn-predator-decline-ecosytems-20140110-story.html> [↑](#footnote-ref-26)
27. <http://forestlegacies.org/images/projects/biomass-report-2015-11.pdf> [↑](#footnote-ref-27)
28. <http://www.nature.com/articles/srep15991> [↑](#footnote-ref-28)
29. <http://nature.berkeley.edu/wfrg/main/lecture01/Parker3.pdf> [↑](#footnote-ref-29)
30. <http://www.nature.com/articles/srep15991> [↑](#footnote-ref-30)
31. <https://www.dartmouth.edu/press-releases/loggingdestabilizes120314.html> [↑](#footnote-ref-31)
32. <http://www.borenv.net/BER/pdfs/ber9/ber9-199.pdf> [↑](#footnote-ref-32)
33. <http://harvardforest.fas.harvard.edu/sites/harvardforest.fas.harvard.edu/files/publications/pdfs/Lorimer_Ecology_1977.pdf> [↑](#footnote-ref-33)
34. <http://forest.umaine.edu/files/2009/05/seymour-et-al-fem-2002.pdf> [↑](#footnote-ref-34)
35. <http://www.fs.fed.us/nrs/pubs/ru/ru_fs52.pdf> (extrapolations from data) [↑](#footnote-ref-35)
36. <http://www.maine.gov/dacf/mfs/publications/annual_reports.html> [↑](#footnote-ref-36)
37. <http://www.maine.gov/tools/whatsnew/attach.php?id=661706&an=1> [↑](#footnote-ref-37)
38. <http://www.fs.fed.us/nrs/pubs/ru/ru_fs52.pdf> [↑](#footnote-ref-38)
39. <http://www.nrs.fs.fed.us/pubs/rb/rb_nrs48.pdf> [↑](#footnote-ref-39)
40. <http://www.maine.gov/tools/whatsnew/attach.php?id=392574&an=1> [↑](#footnote-ref-40)
41. <http://www.maine.gov/tools/whatsnew/attach.php?id=125509&an=1> [↑](#footnote-ref-41)
42. <http://www.maine.gov/tools/whatsnew/attach.php?id=661706&an=1> [↑](#footnote-ref-42)
43. <http://www.pressherald.com/2016/02/21/wood-energy-plants-struggle-to-survive-and-save-jobs/> [↑](#footnote-ref-43)
44. <http://www.pressherald.com/2016/02/21/wood-pellet-business-going-up-in-smoke/> [↑](#footnote-ref-44)
45. In 2014, harvest levels in the northern three counties of Maine were 24% lower than 2008 (State Wood Processor Report) or 17% lower (Federal Inventory Analysis). Data provided by Ken Laustsen, MFS. [↑](#footnote-ref-45)
46. <http://www.fs.fed.us/ne/newtown_square/publications/technical_reports/pdfs/2006/342papers/kenefic342-2.pdf> [↑](#footnote-ref-46)
47. <http://www.nrs.fs.fed.us/pubs/rb/rb_nrs48.pdf> Later inventories available on the web do not give statistics for regions. [↑](#footnote-ref-47)
48. <http://www.forestsformainesfuture.org/fresh-from-the-woods-journal/mechanical-harvesting-the-future-is-here.html> [↑](#footnote-ref-48)
49. <http://maineforest.org/wp-content/uploads/2013/09/Maines-forest-economy.pdf> [↑](#footnote-ref-49)
50. <http://www.ncrs.fs.fed.us/fmg/nfmg/fm101/silv/p3_harvest.html> [↑](#footnote-ref-50)
51. <http://www.meepi.org/lif/profiles.htm> [↑](#footnote-ref-51)
52. <http://www-assets.vermontlaw.edu/Assets/iee/IEE_PSD_FinalReport_WoodyBiomass_2015.pdf> [↑](#footnote-ref-52)
53. <http://www.uvm.edu/rsenr/wkeeton/pubpdfs/Buchholz%20et%20al.%202014_GCB%20Bioenergy.pdf> [↑](#footnote-ref-53)
54. <https://books.google.com/books?id=gD14h8SKdeoC&pg=PA286&lpg=PA286&dq=percent+of+tree+nutrients+in+tops+and+branches&source=bl&ots=Rezjku6BZS&sig=dPuADoHQYLkK7PAf6KGJBz9-4Y0&hl=en&sa=X&ved=0ahUKEwiCleOol5HLAhUEFj4KHQwOApoQ6AEISjAG#v=onepage&q=percent%20of%20tree%20nutrients%20in%20tops%20and%20branches&f=false> [↑](#footnote-ref-54)
55. <http://www.fs.fed.us/pnw/pubs/164part2.pdf> [↑](#footnote-ref-55)
56. <http://www-assets.vermontlaw.edu/Assets/iee/IEE_PSD_FinalReport_WoodyBiomass_2015.pdf> [↑](#footnote-ref-56)
57. <http://www.fs.fed.us/r6/nr/wildlife/decaid/pages/Ecosystem-Processes.html> (this source give multiple benefits of downed wood) [↑](#footnote-ref-57)
58. <https://profile.usgs.gov/myscience/upload_folder/ci2014May2318005571597Klockow_SilvaFennica_2014.pdf> [↑](#footnote-ref-58)
59. <http://www.forestguild.org/publications/research/2010/FG_Biomass_Guidelines_NE.pdf> [↑](#footnote-ref-59)
60. <https://forest.umaine.edu/files/2011/07/MAS_Retention_Guidelines08.pdf> [↑](#footnote-ref-60)
61. <http://novascotia.ca/natr/library/forestry/reports/Report88.pdf> [↑](#footnote-ref-61)
62. <https://forest.umaine.edu/files/2011/07/MAS_Retention_Guidelines08.pdf> [↑](#footnote-ref-62)
63. [<http://maineforest.org/wp-content/uploads/2013/09/Maines-forest-economy.pdf>l](http://www.maine.gov/dacf/mfs/policy_management/forest_certification_landowners.html) [↑](#footnote-ref-63)
64. [*http://hamptonaffiliates.com/subcontent.aspx?SecID=149*](http://hamptonaffiliates.com/subcontent.aspx?SecID=149) [↑](#footnote-ref-64)
65. <https://us.fsc.org/en-us/what-we-do/mission-and-vision> [↑](#footnote-ref-65)
66. <http://nsrcforest.org/project/assessing-maine%E2%80%99s-certified-sustainable-timber-harvest> [↑](#footnote-ref-66)
67. <http://www.nrs.fs.fed.us/pubs/rb/rb_nrs48.pdf> Later inventories available on the web do not give statistics for regions. Also, there was a Great Recession starting in 2008 that led to less cutting because of market forces, rather than landowner restraint. Average cut per year for 2008-2010 was nearly 14% lower than for 2005-2007 (see <http://www.maine.gov/dacf/mfs/publications/annual_reports.html> processor reports). [↑](#footnote-ref-67)
68. The 2014 figures for the northern counties show continued overcutting of red spruce and sugar maple. Data from Ken Laustsen of MFS. [↑](#footnote-ref-68)
69. The 2014 figures for northern counties show area of seedlings/saplings still at 37% but a slight decrease in sawtimber and an increase in poletimber (5-9 inch diameters). Data from Ken Laustsen, MFS. [↑](#footnote-ref-69)
70. In 2014, overcutting of hardwood continued, but lessened. Due to growth of small diameter fir and white spruce, spruce-fir growth was greater than cut. Data from Ken Laustsen, MFS. [↑](#footnote-ref-70)
71. <http://www.dovetailinc.org/report_pdfs/2008/dovetailconcrete0808a.pdf>, [↑](#footnote-ref-71)
72. <http://www.treehugger.com/green-architecture/new-study-confirms-switching-wood-construction-concrete-or-steel-reduces-co2-emissions.html> [↑](#footnote-ref-72)
73. <http://www.greenbuildingadvisor.com/blogs/dept/musings/all-about-embodied-energy> [↑](#footnote-ref-73)
74. <http://www.nrcm.org/wp-content/uploads/2013/10/TWS_US-Forest-Carbon-and-Climate-Change_2007.pdf>

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75. <http://www.synapse-energy.com/sites/default/files/SynapseReport.2012-06.0.Biomass-CO2-Report.11-056.pdf> [↑](#footnote-ref-75)
76. <http://www.rwe.com/web/cms/en/1714906/rwe-npower/about-us/our-businesses/power-generation/tilbury/sustainability/> [↑](#footnote-ref-76)
77. <https://www.eia.gov/state/analysis.cfm?sid=ME> [↑](#footnote-ref-77)
78. <http://cta.ornl.gov/bedb/biopower/Biopower_Overview.pdf> [↑](#footnote-ref-78)
79. <http://www.woodenergy.ie/woodasafuel/listandvaluesofwoodfuelparameters-part3/> [↑](#footnote-ref-79)
80. <http://chemed.chem.purdue.edu/genchem/topicreview/bp/1organic/coal.html> [↑](#footnote-ref-80)
81. <http://www.synapse-energy.com/sites/default/files/SynapseReport.2012-06.0.Biomass-CO2-Report.11-056.pdf> [↑](#footnote-ref-81)
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83. <http://www.uvm.edu/rsenr/wkeeton/pubpdfs/Buchholz%20et%20al.%202014_GCB%20Bioenergy.pdf> [↑](#footnote-ref-83)
84. <http://docserver.ingentaconnect.com/deliver/connect/saf/00221201/v113n1/s9.html?expires=1458740407&id=86459719&titleid=3830&accname=Guest+User&checksum=A0D5218787F46470D5B3FC8620138E0B> [↑](#footnote-ref-84)
85. <http://www.uvm.edu/rsenr/wkeeton/pubpdfs/Mika%20and%20Keeton%202014.%20%20Net%20carbon%20fluxes%20from%20bioenergy%20harvests_GCB%20Bioenergy.pdf> [↑](#footnote-ref-85)
86. <http://www1.eere.energy.gov/manufacturing/pdfs/energy_use_and_loss_and_emissions.pdf> [↑](#footnote-ref-86)
87. <http://www.twosidesna.org/download/The-carbon-footprint-of-paper-is-not-as-high-as-you-think.pdf> [↑](#footnote-ref-87)
88. <http://www.ghgprotocol.org/files/ghgp/tools/Pulp_and_Paper_Guidance.pdf> [↑](#footnote-ref-88)
89. <http://www.twosidesna.org/download/The-carbon-footprint-of-paper-is-not-as-high-as-you-think.pdf> [↑](#footnote-ref-89)
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95. <http://www.statista.com/statistics/270314/production-of-paper-and-cardboard-in-selected-countries/> [↑](#footnote-ref-95)
96. <http://urbansustainability.snre.umich.edu/wp-content/uploads/2014/08/2009_Vos-and-Newell_A-Comparative-Analysis-of-Carbon-Dioxide-Emissions-in-Coated-Paper-Production.pdf> [↑](#footnote-ref-96)
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101. <http://apps1.eere.energy.gov/states/electricity_generation.cfm/state=ME> [↑](#footnote-ref-101)
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