Meta-Issues Related to Carbon Footprint of Biomass Used for Energy Production

Working Paper Prepared for the Oregon Department of Environmental Quality[1]

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1. Introduction

In light of the potential role that biomass could play in certain states under the Clean Power Plan (CPP) but unclear guidance in the CPP on what will constitute "qualifying biomass," Oregon Department of Environmental Quality officials asked The Regulatory Assistance Project (RAP) for a summary of issues to consider in assessing the use of biomass for energy generation and in particular under the CPP.

Discussions of carbon neutrality can become confused, with competing, contradictory, and complex claims. My aim here is to begin with simple practical advice and then follow with a discussion putting the debated views in context. This discussion is based on the use of forest biomass for electricity production, given Oregon's express interest there, but the principles discussed are broad enough to apply to agricultural biomass and other uses of biomass feedstocks, such as for transportation fuel.

First, there are a few situations in which biomass can be considered to be close to carbon-neutral and hence is likely to be considered qualifying biomass under the CPP. These include sawmill waste, forest residual that would otherwise be emitted from burning onsite,[2] afforestation, and certain agricultural crops grown on former agricultural land with low life-cycle energy inputs.

In other situations, mostly those involving harvesting biomass from existing forestland, the answer is more complicated. Harvesting of old-growth timber for energy usage will take a very long time to

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[1] This paper was prepared for the Oregon DEQ and other Oregon agencies to explain why different assumptions on the carbon footprint of biomass yield support different analysis and outcomes in the context of power plant electricity generation. The views and conclusions contained herein are those of RAP and have not been endorsed or adopted by any Oregon agency.

[2] The baseline for harvest residual should reflect local conditions and practices, which can result in not all logging residual being an otherwise "free" source of emissions that otherwise would end up in the atmosphere under baseline conditions. For example, even if logging residual is burned on site, burning can produce black carbon from incomplete combustion of 5–25 percent of the forest residual. The resulting black carbon is stable and resists biological and chemical degradation, so it may well not otherwise end up in the atmosphere. See: Ter-Mikael, M., Colombo, S., & Chen, J. (2015, January). The Burning Questions: Does Forest Bioenergy Reduce Carbon Emissions? A Review of Common Misconceptions about Forest Carbon Accounting. *Journal of Forestry*, p. 65; and; and Forbes et. al. (2006). Formation, transformation and transport of black carbon (charcoal) in terrestrial and aquatic ecosystems. *Sci. Total Environ, 370,* 190-206.

complete a carbon sequestration cycle and will have other detrimental ecological impacts. On the other hand, use of short-lived species such as willow, birch, and poplar, if managed and harvested sustainably, could be closer to carbon-neutral, and makes sense if they displace fossil fuels. I will attempt to make criteria for choices clear, given the complexity of the energy markets and ecological systems considered.

Biomass grows in complex ecological systems involving variable inputs, variations, outputs, and disturbances. Likewise, energy is generated and used in dynamic engineered and market systems with ever-changing fuel and feedstock pricing and supply, and varied production and distribution networks to deliver energy to its ultimate consumers. On national, regional, and global scales, altering ecological and energy systems through regulatory control of certain variables or market influences will alter the outcomes of both systems. This includes the ecological outcomes on the carbon balance, as well as nitrogen balance and disturbance of ecologically significant habitats, to identify a select few of the important outcomes. In turn, the ecological outcomes will affect economic sectors that rely on ecological inputs such as agriculture, forestry, and tourism. Similarly, variation in pricing and supply inputs, the power plants that use them, the availability of supply and demand resources, and the transmission and distribution systems will significantly affect energy system outputs and will in turn alter state, regional, and global economic outcomes of economic sectors that produce and rely on energy.[3]

Given the dynamic and variable reality of ecological and energy systems, the U.S. Environmental Protection Agency (EPA) recognizes that claims of a carbon balance—that is, assertions that a biomass source is carbon-neutral—depend on actual growth, harvest, and consumption cycle conditions, which vary considerably:

> Carbon neutrality cannot be assumed for all biomass energy a priori. There are circumstances in which biomass is grown, harvested and combusted in a carbon neutral fashion but carbon neutrality is not an appropriate a priori assumption: it is a conclusion that should be reached only after considering a particular feedstock's production and consumption cycle. There is considerable heterogeneity in feedstock types, sources and production methods and thus net biogenic carbon emissions will vary considerably.[4]

The EPA cites this Science Advocacy Board review in the 111(d) rule in setting considerations for state use of biomass in state plans and declining to treat all biomass as "carbon-neutral."[5] Although a recent amendment introduced by Senator Susan Collins of Maine to the energy bill pending in the U.S. Senate would mandate that the EPA treat biomass as carbon-neutral under certain circumstances, this paper proceeds to address the scientific basis for analysis of claims of carbon neutrality.

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[3] None of this discussion is intended to adopt a human-oriented view of use value as a singular or sole mode of valuation. The real value of forested ecological systems is likely higher than the total value of all traditional economic use values referenced in this paper.

[4] *See* U.S. EPA. (2014, November). *Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources*. Submitted to the EPA's Scientific Advisory Board for Review, p. ii, citing the peer review by the Biogenic Carbon Emissions Panel of the EPA's Science Advisory Board (SAB Panel).

[5] U.S. EPA. *Final 111(d) Rule: Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units*. 64661-65120, fn. 907, p. 64885.

Whether a system is in balance or not depends in part on the scale and scope of analysis and the baseline assumptions.[6] For carbon balance, the assumed baseline is most often preindustrial atmospheric levels of greenhouse gases (GHG).

In analyzing the balance of any system, an explicit identification of the scale and scope of the analysis and variables in the analysis is helpful because the scale and scoping of the conceptual model or framework can and often does influence the conclusions.

This paper provides identification of issues involved in conceptual-level analysis for further consultation with the Oregon DEQ.

2. Scope and Scale of the Analysis Impacts the Conclusions

By varying scope and scale of analysis, the ecological and energy factors and input may differ, and the outputs of an analysis likely will vary too. Often these frames of reference, such as time scale, spatial scale, and baseline conditions, are inadvertent and not made explicit. This section discusses making those assumptions explicit.

2.1. Temporal Time Frame

As the EPA states, “In terms of science, there is no single correct answer for the choice of timescale for assessments: different timescales allow for evaluation of different questions and contexts.”[7] That said, the choice of timescale of the analysis could drive the conclusions, particularly for carbon balances of ecological systems. For annual energy crop production and use, a shorter period such as one or two years may be appropriate. This is because crops are planted, grown, and harvested within a season and often used within a short time frame.

On the other hand, using a short time frame for forest biomass when trees grow over many years will directly affect the carbon balance calculation: if the forest biomass is assumed to be removed and burned for energy, it may not have time to grow back in that short time frame. If a biomass removal is assumed with less time than required for that biomass to regrow to the same level of maturity, a balance calculation will show more in the atmosphere and less in the forest. On the other hand, if more time than required for regrowth to harvest maturities is assumed for biomass to regrow and sequester

[6] The concept of balance supposes an ecological system functioning as it should and that system outputs are roughly equal to inputs. A “balanced” global temperature is generally assumed to be comparable to recent centuries or since human civilization began. For a carbon balance in the atmosphere, the assumed baseline is most often preindustrial atmospheric levels of GHGs, for example. The central thesis is that the atmospheric carbon cycle is out of balance owing to human emissions of GHGs and land-use changes. The spatial scope of the carbon system causing climate change is global and the time frame to measure increases in atmospheric carbon is often since the beginning of industrial revolution. The temporal time frame to measure increases in CO_2 as well as global land and water temperatures is often presented on a multi-decade time scale to emphasize recent temperature and CO_2 trends. The concept of balance is similarly often applied to smaller systems, such as forests or water bodies, to examine whether an ecological system is operating in a way that is expected or posited. There are multiple cycles, even for a forest system: a carbon cycle, a nitrogen cycle, and a phosphorus cycle, to mention just a few. As one examines such cycles, it is critical to recognize that whether a system is considered “in balance” may depend in part on the scale and scope of analysis and the baseline assumptions made.

[7] U.S. EPA. (2014, November). *Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources,* p. 34. Submitted to the EPA’s Scientific Advisory Board for review.

carbon from the atmosphere, a balance calculation will show less carbon in the atmosphere and more sequestered in trees.

Legislative and policy-based goals often put deadlines such as 2030, 2050, or 2100 on mandates to reduce emissions by a specific amount (typical legislative or GHG plan goal), limit increases in atmospheric GHGs, or stabilize global temperature increases (COP-15). These dates have important legal meaning but cannot mean that the factors causing climate change and impacts of climate change cease to function on such dates. An analysis with a specific date as a goalpost can nonetheless consider the temporal characteristics of various ecological systems. So rather than consider a planting or harvest starting *sua sponte* in 2016 and ending suddenly in 2050, an analysis can observe that planting and harvest cycles have occurred either consistently or periodically before 2016, and will continue through and after 2050 at either consistent or varied levels of intensity. This is particularly important to recognize when ecological systems have long cycles, and those cycles begin before any specific legal target date and continue to function beyond other specific dates.

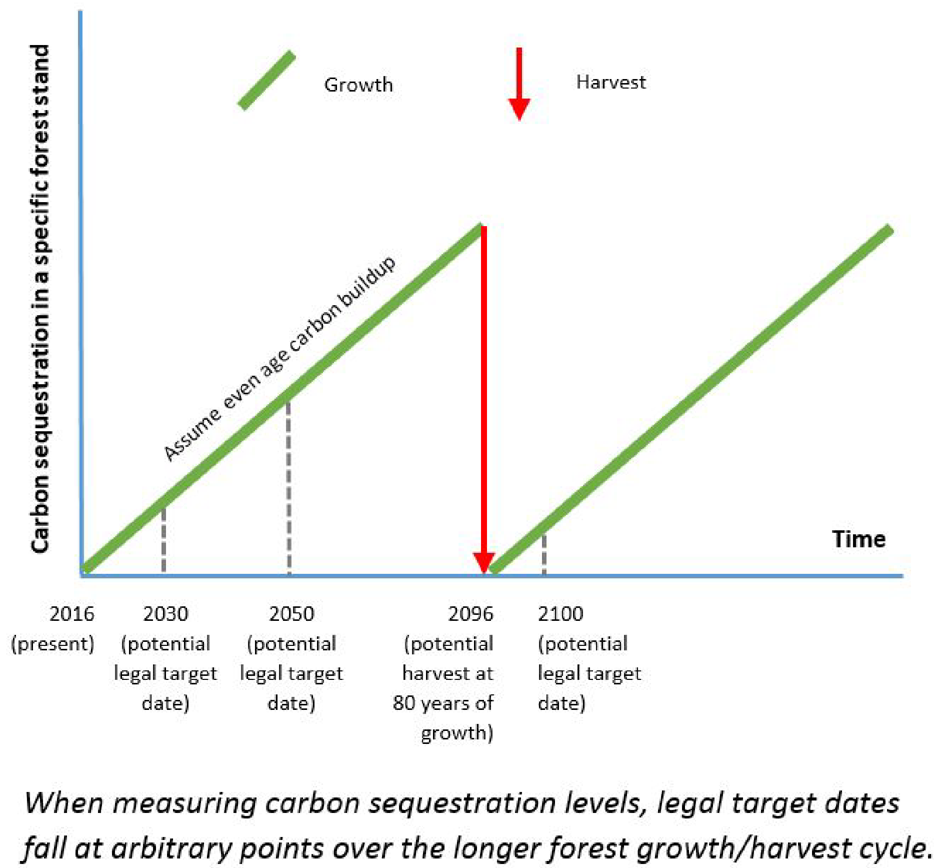

Figure 1. Forest Cycles vs. Regulatory Timelines

2.1.1. Suggestion on Scope of Time Frame

Time frames could be adjusted to reflect empirical reality, so that harvest practices in the state and region for specific types of biomass could be evaluated. These could reflect the typical harvest rotation or age for spruce, pine, and so forth. Time frames could be differentiated by type of land (publicly owned forest or private forest), or by whether the rotation/harvest age is markedly different for different types of forest land management. This may or may not be practical given the data available to state forestry officials.

Any significant policy or market-driven changes to forest management or harvest practices that might significantly alter these assumptions—for example, extending forest rotation periods through offset programs or tax incentives—could be examined in a policy-change case against the base case to assess the changes in carbon sequestration and removals that the practice might affect. To avoid a misleading "snapshot in time," an optimal assessment time frame might allow at least one full growth, harvest, and regrowth "cycle" to occur.

2.2. Selection of the Spatial Scope

Use of a small geographic area, down to a single forest stand, can also yield different conclusions than use of a larger parcel, forest landscape, region, state, multistate, or national area when combined with the temporal scope. For example, one can look at single forest stands in isolation, larger parcels, or the entire forest landscape. The smaller the area of analysis, the greater the gains from sequestration, and the risks for catastrophic loss, appear. For example, a single forest stand can be subject to significant losses (fire, pest infestation) that may be more attenuated over a larger geography.

Altering the spatial scope can make a carbon impact look either severe or manageable. An example is illustrated in Figure 2.[8] A complete harvest of a single acre/hectare of a 40-year-old forest stand appears severe. But a complete harvest of seven different acre/hectare parcels, distributed throughout an area 121 times as large in a large forest landscape, shows a different relative carbon impact. If the management practices are put in place to ensure that the larger forest parcel or landscape continues to sequester carbon for 20 years, the carbon sequestered in the trees on the uncut 114/121 of the forest will exceed the carbon lost from the seven cut parcels representing 7/121 of this forest. Assuming even-age carbon sequestration of Y tons per year per acre/hectare, the 40-year-old stands on seven stands harvested would emit 7 × 40 × Y = 280Y to the atmosphere. But if the entire forest landscape is at risk for harvest and can be protected for 20 years of growth on the remaining 114 stands, that would yield 114 × 20 × Y = 2280Y additional tons sequestered in the 121 uncut stands (plus the seven stands if replanted would have sequestered 7 × 20 × Y = 140Y additional tons). Of course, because of the assumed 40-year stand age and even-age carbon sequestration, what is sequestered on the seven harvested stands also regrows over 20 years to half of what was harvested. So actual sequestration is 2280Y + 140Y, or the sum of growth on the remaining 114 stands and regrowth on the seven harvested stands. Heavier harvest regimes would reduce the carbon sequestration balance. The key to whether the carbon balance is sustainably managed is the remainder of the forest, which can sequester more than what is harvested.

[8] Littell, D. (2012, August 14). *Temperate Forest Potential to Mitigate Climate Change*. Presentation to NESCAUM Board of Directors, citing Dovetail Partners, 2012.

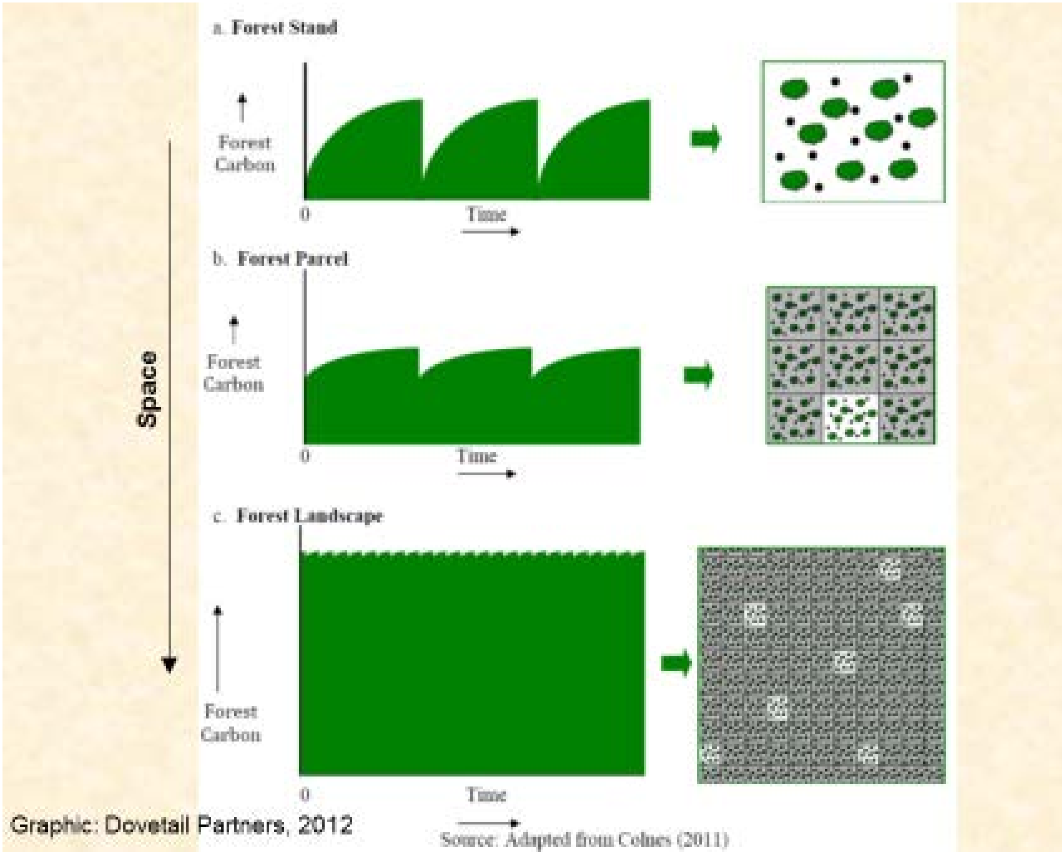

Figure 2. Forest Carbon in a Sustainably Managed Forest at Stand, Parcel, and Landscape Levels

2.2.1. Suggestion on Spatial Scope

If one is concerned with ecological effects on multiple species and media (air emissions, water quality, and water quantity), the spatial scope of analysis is an ecological region. Biomass is only one part of these ecological systems. It may be appropriate to look at larger areas on a state scale, or even multistate regions that encompass multiple ecological regions.

If one is concerned with economic and energy market impacts, one can define regions of analysis based on regional energy markets; biomass markets are usually small because the cost of transportation for biomass (with a low energy density) is often higher than that of fossil fuels. However, regional electricity markets can be largely defined along RTO/ISO or electrical region boundaries. Of course, economic and energy market boundaries are different from ecological regions.

If land is managed or subjected to regulation differently—based, for example, on status as public, private,[9] urban, suburban, or rural—it may make sense to analyze the lifecycle impacts differently for geographies that are in fact managed differently with different landscape impacts. As with economic

[9] The ratio of forest growth to harvest for private forests in the conterminous United States is 1.3, whereas the same ratio for public lands is 5.3. *See* U.S. EPA. (2014, November). *Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources.* Submitted to the EPA's Scientific Advisory Board for Review, fn. 55, p. 38, citing U.S. DOE, 2011.

markets, geographies defined by different legal or regulatory requirements are not likely *a priori* to represent ecological system functions.

2.3 Selection of Starting Point of Analysis (Baseline Conditions)

The baseline condition is critical to consider. If a forest biomass analysis begins with a mature forest in year zero and harvests the entire forest immediately, that will yield a very specific carbon flux (if the carbon is released to the atmosphere). If the same area is assumed to be agricultural land with no biomass in year zero and planted with crops or trees in year one, the carbon flux will look different based on the land use (agricultural or forest) and assumed initial conditions.

The baseline condition is the starting point, but baseline conditions also need to be projected into the future. This projection of a baseline condition is necessary because analysis of changing ecological and economic variables is done to consider practice or policy changes to influence future ecological, energy, and economic outcomes. Measurement of changes among different futures involves a comparison to a baseline case, often identified as a "business-as-usual" (BAU) case.

2.3.1. Suggestion on Baseline Selection

Selecting baselines as close to empirical conditions for the areas, regions, land use, and land ownership types is likely to yield the most accurate results to consider any new practice, policy, or management changes under consideration. The baseline condition will need to be projected into the future as a BAU case. Better data will be available to the extent the BAU case is similar to historic ecological or economic conditions. Where historical data may not be a good predictor of the future, economic BAU assumptions can use official U.S. agency projections such as those of the Energy Information Administration (EIA), U.S. Department of Energy (DOE), and the EPA.

2.3.2. Alteration of Baseline: Improved Forest Management

Changing the baseline to a policy case can be used to assess the impact of more sustainable management of forests, for example. If one finds that current forest practices result in overcutting of the wrong species and as a result have a net carbon loss effect, it makes sense to look at policy changes to increase net carbon sequestration. So the current baseline is a net carbon loss. Then, for example, one can assume that Forest Stewardship Council management standards are implemented, the level of cutting drops, and the management regime favors large-diameter-saw timber (and results in more carbon being sequestered over time). In this case, two things will happen: first, biomass may become carbon-neutral or carbon-positive, even accounting for losses from harvests, in a reasonable period, and second, there will be a policy-driven reduction in forest-based carbon releases.

2.4. Illustration of Spatial and Temporal Scope Assumptions

Figure 3 illustrates how carbon sequestered in forest biomass can look different based on the spatial scope analyzed over time. It also shows how forest biomass varies over time and how starting conditions matter.

By looking at a single forest stand that has most biomass removed, the variation of forest biomass is dramatic. However, if that single stand is put in a larger parcel and assumed to be the only stand that is removed from an area nine times as large, then the impacts on forest carbon are less dramatic. Using the example in Figure 3, a harvest of a 40-year-old stand results in the loss of Y times 40 years, or 40Y carbon. It would take 40 years to regrow the single stand and thus 40 years to re-sequester a single stand, but if all nine stands in the single parcel are managed to sustain only the single harvest, then the carbon lost in the harvest is more than regained in less than five years (nine stands times five years times Y = 45Y). The same result can occur through sustainable management regimes that result in thinning and selective harvest over time of one-ninth of the forest biomass using the same example. However, the net result could be more sustainable forest management than a series of selective clear-cuts. We note that this analysis uses a simplified assumption that all harvested forest biomass is used for energy production, which is virtually never the case. Wood is generally harvested for timber value as well as pulp and paper—those uses with the highest market value. Forest biomass used for energy production is the byproduct or waste of the harvest or processing of wood for timber, pulp, and paper. Thus, forest biomass used for energy production in the United States is generally primary and secondary byproduct of mills and forest residual from harvests.

And at a yet higher level of spatial analysis, if the loss of forest carbon is analyzed over a forest landscape (with low harvest rates shown in Figure 3), the relative change in forest carbon will be marginal. If the harvest rate across a forest landscape is higher than assumed in this graphic—or if there are natural losses from forest fires and pest infestations—the forest biomass impacts shown in the graphic illustrations would look different, so this type of graphic illustration needs to be adjusted based on empirical conditions in specific regions and forests.

3. Harvesting, Transportation, and Processing

Under the CPP, there is no requirement for full life-cycle carbon footprint analysis. So natural gas-fired combined cycle power plants are not required to perform a “wellhead-to-wires” accounting of carbon dioxide (CO_2) equivalents of methane releases from wells, collection piping, storage, transportation, processing, interstate pipeline, and local gas distribution system losses prior to the gas being fired. For that reason, accounting for the life cycle of biomass is not an apples-to-apples comparison.

That said, there is a principled view that all sources of energy should be evaluated under full life-cycle analysis. So, for example, in examining the life-cycle carbon footprint of a hydroelectric project, the analysis includes accounting for the concrete, steel, and lost forest sequestration from hydroelectric dam development and forest losses from impoundments, as well as lost soil carbon over time in impounded areas. Every form of energy generation has a life-cycle carbon footprint. With the strong caveat that biomass should not be singled out for life-cycle analysis, these losses are often cited in the literature and thus are covered here.

If considering full life-cycle impacts, biomass has life-cycle losses from harvesting, transportation, and processing for energy production. The energy losses and consequential emissions generated can include harvest, chipping, transportation, storage, heat and pressure in drying, pellet formation, shredding, and torrefaction, the process of converting biomass into a coal-like material. These losses are a part of each specific energy generation and are unavoidable, because these activities cannot be reduced to zero. The effectiveness of substituting woody biomass for fossil fuels is highly dependent on factors affecting bioenergy conversion efficiency, including the emissions from harvesting, transporting, and firing of the biomass.[10]

Notably, other fuels such as coal and natural gas are not required to conduct life-cycle analysis, so a much more stringent level of emissions analysis would be applied for biomass alone. An apples-to-apples comparison could use the GHG (and other pollutant) emissions from mining, processing, and transporting of coal and the fugitive methane emissions from extracting, collecting, processing, transporting, storing, and distributing natural gas. This would produce an accurate life-cycle analysis comparison of biomass to coal and natural gas for generating electricity.

Transportation is often the largest of these life-cycle loss factors. Transportation emissions often include truck transportation from harvest to processing or storage facilities, and then perhaps more transportation beyond that. If biomass is harvested and transported within a local geography to where the biomass is converted to energy, such as a 25- to 40-mile radius of a biomass plant, the total losses can be less than ten percent, according to some studies. If the distance of transportation is more or the processing is more energy-intensive (e.g., torrefaction), then losses—increasing life-cycle carbon emissions—can increase.

4. Efficiency of the Energy Use in Cogeneration

Although not an issue within the forest-energy-emissions-uptake cycle, how the energy is used makes a difference for overall efficiency. This is true of any generation source, not just biomass. The carbon-neutral nature of the feedstock is a distinct issue from more efficient use in cogeneration. This issue is covered here because it has received some treatment as a prerequisite for use of biomass in some studies. The low energy density of wood, combined with its higher moisture content, can yield lower efficiency in some boilers' designs. That said, requiring efficiencies that can be achieved through combined heat and power (CHP) applications only for biomass boilers seems to be somewhat arbitrary, as CHP improves the conversion efficiency of combustion generation whenever a thermal load can also be used, such as for an industrial or district heat application.

That said, in any boiler, the efficiency of capturing the energy produced by combustion—conversion to thermal energy by combustion and then electrical energy—often involves huge losses of thermal energy that is not used to generate electricity. The effective efficiency of a specific boiler configuration and end uses in converting the biomass to useful energy can vary substantially based on whether it is an older stand-alone boiler or a CHP unit.

A 1980s vintage stand-alone biomass boiler can convert heat energy from biomass combustion to electricity at an effective rate of 20 percent. The rest of the energy created by combustion is lost to the atmosphere or to cooling water. If this otherwise wasted thermal energy from the combustion process can be utilized in thermal or industrial uses, the efficiency of energy usage can be increased to 65 to 75 percent with current engineering and design for advanced CHP boilers. In CHP boiler/generator configurations, any form of combustion can generate almost three times the useful energy.

[10] Mitchell, S., Harmon, M., & O'Connell, K. (2012). Carbon Debt and Carbon Sequestration Parity in Forest Bioenergy Production. *GCB Bioenergy.* Blackwell Publishing Ltd.doi: 10.1111/j.1757-1707.2012.01173.x.

Thus, advanced CHP boiler and generator configurations can more than triple the effective use of energy from biomass combustion. These thermal applications can displace fossil fuel emissions as addressed below. This is true, however, of all CHP applications for any fuel source. There is nothing particular or unique about biomass plants that makes cogeneration a necessity, and there is no reason to impose a CHP efficiency standard onto biomass combustion in particular. From an efficiency point of view, one should always do cogeneration where and when one can use both the thermal load and the electricity.

5. Displaced Emissions/Substitution of Fuels

Electricity generation is "dispatched" on the margin, meaning that generators are dispatched from lowest-cost to higher-cost units. This is particularly the case in restructured markets, although vertically integrated utilities endeavor to dispatch their lowest cost units first as well. Thus, in the short run, one type of electricity generation displaces another on an economic basis.

A fuel can be less expensive for electricity generation because it is free (solar, hydro, or wind), because its market price is lower (recently natural gas has been less expensive), because it is subsidized to reduce its effective price through varied tariff, grant, or tax programs.[11] If short-term markets produce different economics than would apply if externalities such as pollution and climate change were factored into pricing, incentives can be put in place to encourage the use of more efficient long-term renewables and correct for the short-term inefficiencies.

Where biomass can be used to substitute for a traditional fossil fuel, there is significant potential to reduce overall energy system carbon emissions through the substitution effect over long time periods of 50 to 100 years (see Section 2.1). The biomass energy's total emissions (over the selected time frame) must be less than alternative fossil fuels for biomass to reduce GHG emissions. A policy measure used in some states to encourage this substitution is qualification of biomass for treatment as a renewable resource under a renewable portfolio standard or other incentive program.

6. Sequestration in Wood Products

Traditional wood products such as lumber, other building materials, or furniture provide both a higher market value for merchantable wood and a higher carbon reduction value than using wood for bioenergy. Traditional carbon is sequestered in these products, and they have the potential to substitute for other products with higher life-cycle emissions such as steel and concrete. The retention of carbon in traditional wood products can be characterized by product half-life: the time in which half of the product can be expected to become waste. The half-life of construction lumber is estimated at 67 to 100

[11] For any of these reasons, if biomass energy displaces coal, oil, or gas generators, the relative difference in emissions per megawatt-hour can be calculated. To get a precise measure of the relationship between different fuels (and renewables), one needs good data on what economists call the cross-elasticities of market demands of different fuels. Because the energy markets are constantly in flux and can be regional in nature, these cross-elasticities are very difficult for policymakers to access and keep current (or anyone other than energy market players who make money in selling and buying various fuels, futures, and energy).

years.[12] New construction techniques and advanced wood composite structural timber and materials can replace much more energy-intensive steel and concrete, reducing emissions from upstream manufacturing of building materials.[13]

Advanced wood composites are becoming more familiar to architects and building professionals, and their use is increasingly reflected in building codes. This means that sequestration of forest carbon in wood construction products, in combination with landscape sequestration and the sustainable use of wood for energy, has the potential to sequester more carbon than unharvested forests do.[14] Although only energy used to generate electricity from qualifying biomass is relevant for the purposes of the CPP, the carbon sequestration potential of a wood products strategy has substantial potential beyond electricity in the building sector. Steel and concrete materials could be displaced by wood-based building materials with much lower carbon life-cycle emissions profiles.

Some studies suggest that more than 10 percent—or even as much as 30 percent—of fossil fuel emissions could be avoided with a combination of carbon sequestered in wood products, emissions avoidance, and fossil-fuel-displaced energy emissions.[15] Gains in atmospheric carbon reductions are even greater in forest areas where fire risk and fire management are major concerns. In such forests, even greater carbon emissions savings can be achieved through selective harvesting to reduce fire danger in combination with a wood product sequestration and fossil fuel displacement strategy.[16]

The carbon-reduction strategy described in this section is dependent on harvesting being undertaken sustainably, as described elsewhere in this paper.

7. Criteria to Maintain Forests as Healthy Ecosystems: Land Use Change and Sustainable Management

Part of the assertion of biomass carbon neutrality is that carbon is sequestered in live biomass (crops, trees) and soil carbon in a circular cycle: it is sequestered and it is released in successive cycles. If the forest land base is maintained and the amount of biomass (trees, vegetation, and soil carbon) in the forest is maintained or increases, the case for "carbon neutrality" posits the carbon cycle as a basic circular cycle from combustion and thus carbon emissions to uptake of atmospheric carbon into tree and other forest biomass (through photosynthesis). In simple terms, the theory is that carbon that goes into the atmosphere from the burning of biomass is taken back out of the atmosphere by biomass regrowth.

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[12] Ter-Mikael, M., *supra* fn. 1, at 63, citing Skog, K. E., & Nicholson, G. A. (2000). *Carbon Sequestration in Wood and Paper Products*. pp. 79-88, in *The Impact of Climate Change on America's Forests: A Technical Document Supporting the 2000 USDA Forest Service RAP assessment.* Joyce, L. A., & Birdsey, R. (eds).

[13] Oliver, C.D., Nassar, N., Lippke, B., & McCarter, J. (2014). Carbon, Fossil Fuel, and Biodiversity Mitigation With Wood and Forests. *Journal of Sustainable Forestry*, 33:248-275.

[14] Oliver, C.D. *supra* fn 12; Matthews, R., Mortimer, N., Mackie, E., Hatto, C., Evans, A., Mwabonje, O., Randle, R., Rolls, W., Sayce, M., & Tubby, I. Forest Research, The Research Agency of the Forestry Commission. *Carbon Impacts of Using Biomass in Bioenergy and Other Sectors: Forests*. DECC project TRN 242/08/2011, Final Report URN 12D/085.

[15] Oliver, C.D. *supra* fn 12, pp. 264, 268-70.

[16] Oliver, C.D. *supra* fn 12, p. 265.

The carbon cycle theory cannot legitimately show full "carbon neutrality" because there are always some life-cycle system losses of carbon emissions necessary to maintain the carbon cycle, as described in Section 2. Indeed, even renewable generation such as hydro, wind, and solar have life-cycle emissions from embedded energy material inputs, manufacturing and construction, and landscape emissions losses. The carbon cycle theory also fails if the carbon stored in the forest declines owing to, among other factors, (*1*) loss of forest land base, or (*2*) higher harvesting rates and other forest biomass losses that the forest cannot sustain.

On the loss of forest land base, if land is converted to different uses (see Figure 3),[17] such as cleared for agriculture, developed, or even if it burns and never recovers, there is a very possible permanent loss of forest carbon sequestration. For this reason, changes in land use need to be considered.

Figure 3. Forest and Agricultural Land is Being Lost to Conversion

Conversion of forests to any other land use can reduce the legitimacy of claims that a carbon cycle is balanced. Besides the loss of forest biomass that directly sequesters carbon, there is often a loss of carbon soil on such lands over time. If conversion rates are not well documented already, then local, regional, state, and multistate land-use or land-cover can be assessed based on LIDAR or satellite remote sensing data. Although remote sensing data are increasingly available and accessible, it remains necessary to ground-truth data with actual forestry measurements of tree growth (diameter, species, height, tree count, and so on). New Zealand, for example, has a sophisticated and well-developed carbon measurement program as one of the base elements of its emissions trading program.

If the trees are harvested at a rate that is not sustainable, then the carbon cycle also fails. This is because the carbon sequestered in the forests will decrease, and thus atmospheric carbon will increase, even within the carbon cycle theory. For this reason, most programs that allow for carbon cycle claims or forestry carbon offsets often require that forests are managed and biomass is harvested subject to sustainable management and harvest standards, such as the Forest Stewardship Council (FSC),

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[17] Littell, D. *Adapting Environmental Protection to 21st Century Climate Challenges*. Keynote Presentation, Chewonki Foundation, Sustainable Energy Conference, May 8, 2010.

Sustainable Forestry Initiative (SFI), or American Tree Farm (ATF). There are also stronger examples for applying these sustainable management standards to ensure no net loss of forest biomass.[18] These sustainability standards do not address carbon specifically, and in general they vary in rigor, from FSC to SFI to ATF.

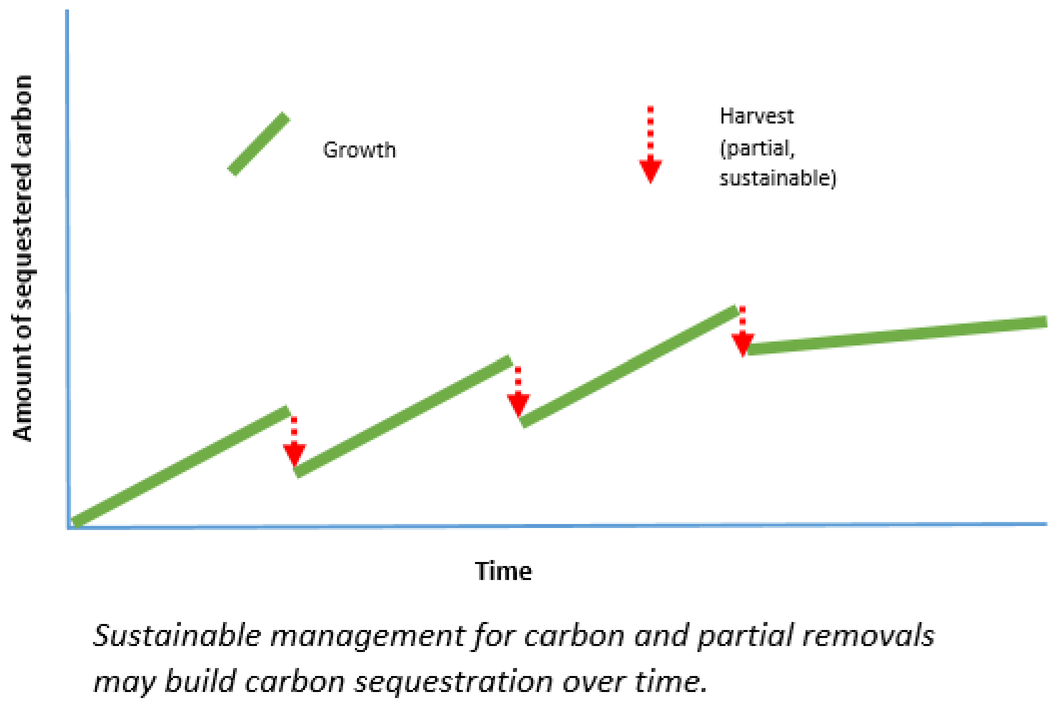


Figure 4. Potential Carbon Sequestration in Working Forest Project[19]

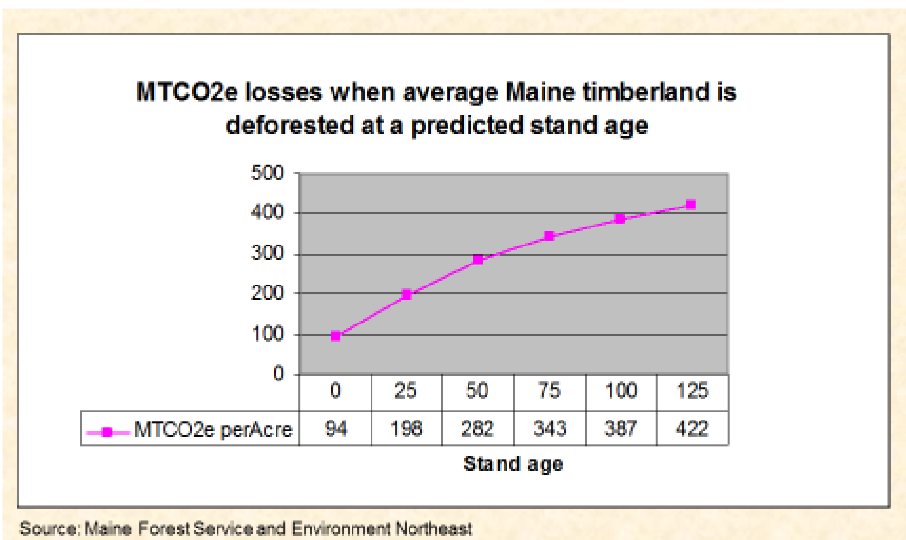
[18] New York's criteria for sustainably harvested biomass requires:
(1) Certification Criterion: In order to demonstrate to the Department that a given fuel source satisfies the Certification Criterion, the [biomass unit] must provide sufficient documentation to the Department. The documentation should demonstrate that the biomass is obtained from land that has:
(a) a United States Department of Agriculture (USDA) Forest Service Forest Stewardship Plan in place, and a harvest plan. The harvest plan must be approved by a forester [1] prior to harvest, and be based upon the New York State Renewable Portfolio Standard (RPS) approved template [2] and recommended Best Management Practices (BMPs); or
(b) been issued a Certificate of Approval pursuant to Section 480-A of the Real Property Tax Law (RPTL); or
(c) been certified by a Department-approved non-governmental forest certification body, such as Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI), or American Tree Farm (ATF).
2) Carbon Re-sequestration Criterion: The Carbon Re-sequestration Criterion may be demonstrated via a legally binding permanent conservation easement, or some other Department-approved land-use instrument, that documents that forest-based, woody biomass and unadulterated wood and wood residues are from forest land that will be maintained in a forested state for:
(a) A time period, as supported by a demonstration to the Department, that is sufficient to re-sequester the CO_2 that was released through the combustion of the biomass. For purposes of making this demonstration to the Department, the [biomass emitting unit] may take into account forest lands that are not specifically included in the harvest of the biomass, provided such lands meet the Certification Criterion; or
(b) 100 years, with no additional demonstration to the Department. *See* http://www.dec.ny.gov/energy/65141.html.

[19] California Air Resources Board, Compliance Offset Protocol, U.S. Forest Projects, adopted June 15, 2015, p. 24. Retrieved from http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/forestprotocol2015.pdf; DuBoisson, M. (2010, June). *Overview of Climate Action Reserve Protocols*. Minnesota Forest Offsets Workshop. Retrieved from http://www.dovetailinc.org/workshop_materials/climate_action_reserve_protocol.pdf

Ideally the existing sustainable forest standards would be modified to include and address carbon management. That said, measuring forest carbon precisely is resource-intensive. The California Air Resources Board has approved carbon offset project criteria specifically for U.S. forest projects, and those standards contain approved growth and yield models.[20] There are other carbon offset projects and standards accessible from other jurisdictions. Compliance with these forestry offsets criteria is resource-intensive, but does bring in enough additional revenue for landowners already inclined to support sustainable forestry to more than compensate for the carbon offset management costs.

On private lands, additional tax incentives intended to keep private land in forestry and land-use restrictions can also provide both incentives for and limitations on conversion of private forestland to non-forest uses. The same is true of maintaining agricultural land, which can be used for energy crops capable of supporting energy substitution. When combined with increased carbon offsets revenue and sales from harvest of certified timber and biomass, the positive vision is a set of incentives through enhanced revenue sources from multiple sources and limitations that support long-term forestry and agricultural uses—serving carbon sequestration, conservation, and broader sustainability goals.

From an ecological perspective, there is a strong case to be made to protect the few remaining old growth stands and forests based on biological and biotic diversity considerations as well as unique ecological values these forests represent. Whether certain old growth is put off limits or not, it is indisputably the case that the age and species harvested severely impacts the forest carbon sequestration losses and imposes substantial additional ecological costs. An illustrative example of carbon losses from stands of different ages developed by the Maine Forest Service and an NGO is shown in Figure 5 to illustrate this point.[21]



Stand age	0	25	50	75	100	125
MTCO2e perAcre	94	198	282	343	387	422

Figure 5. Forest Age Matters

[20] California Air Resources Board, Compliance Offset Protocol, U.S. Forest Offset Projects. Retrieved from http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/usforestprojects_2014.htm

[21] Littell, D. (2009, December 14). Forestry Potential in Temperate Climates to Mitigate Climate Change. COP-15 Side-Event Panel Presentation, citing the Maine Forest Service and Environment Northeast (now the Acadia Center).

8. Indirect Land Use Change and Indirect Market Forces

Land use impacts and conversion are not always direct. Even as carbon stocks increase on certain holdings, it is possible that increasing demand for biomass could move harvest activities to other land, forests, regions, and states. That could in fact increase overall emissions if it results in higher transportation-related emissions to move biomass to point of use (see Section 2). It could also lead to net carbon losses from forests that are remote from specific regulatory jurisdictions.

A second concern for policymakers considering changes to incentives, standards, or rules is that restrictions put on forest management or harvests (such as sustainable harvest and management requirements) might reduce harvests from specific lands but indirectly result in higher harvests from such other lands through indirect market forces.

Thus policies, practices, or market forces that increase demand for or price of timber, pulp, or energy-related biomass can result in heavier harvesting in other areas, regions, or even other nations outside the policymaker's immediate considerations. For example, European demand for biomass as a substitute for coal and for dedicated biomass boilers is now recognized to be driving significant harvests from forests in the southeastern United States. Traditional use harvesting in southeastern forest is displaced or harvests move elsewhere. Increased U.S. harvests that satisfy the enhanced European demand for biomass energy is an example of the market forces manifest in the United States caused by policies put in place in EU countries.

Although the example of EU policies driving export to Europe of U.S. biomass is well known and very visible given harvests of large areas, transportation, and port activity in the United States and Europe, other market forces can operate in ways that are not so clear, particularly with the fluctuations in U.S. energy markets. Indirect land use and indirect market forces can be difficult to quantify and track.[22]

9. Broader Ecological and Sustainability Concerns

Forests are important ecosystems that are under significant pressure from conversion and losses owing to human activities as well as the effects of climate change. These stressors enhance natural forest stressors such as pest infestations and forest fire. In sum, forests represent many functions and values threatened by current development, climate, and ecological trends.

Most of the discussion in this paper focuses on economic use values: use of trees for timber, pulpwood, and biomass energy. Even expanding this list to include carbon sequestration and recreational use of forests as ecosystem services is narrowly defined around a set of traditional use values that have been well recognized for more than a century. Other ecological services beyond timber, pulp, wood for energy, recreational, and aesthetic benefits that humans receive from forests, such as provision of clean water, clean air, carbon, nitrogen, phosphorous sequestration (or balancing services), and habitat for many species, has mostly unquantifiable value that may well be higher than the traditional use values.

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[22] *See* U.S. EPA. (2014, November). *Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources*. Submitted to the EPA's Scientific Advisory Board for Review, p. 19. ("One form of leakage—indirect land use change attributable to production of biogenic feedstock—can be challenging to quantify, because it often involves a number of complex socioeconomic dynamics (e.g., trade, market interactions) as well as biophysical impacts that occur outside of the biogenic feedstock production site and for which data may or may not be available. However, indirect land use change can result in significant emissions if it occurs at a large scale and involves conversion of land with relatively large preexisting carbon stocks.)

Some of these ecosystem services are valued only in their decline, such as pollination services from bees and bats as those species suffer from habitat loss, among other stressors. In many parts of the world, forests sustain indigenous people. At noted in footnote 1, this analysis focuses only on economic and use valuation but does not mean to suggest those are the most important valuation methodologies.

Similarly, a narrow focus on the energy and carbon sequestration values and services occurs in the immediate context of the CPP. However, this focus on the CPP and climate mitigation strategies ought not neglect to recognize the broader ecological values that forests provide, as well as the immediate context of worldwide forest losses and degradation due to development and energy production.

10. Conceptual Applications

A few simple conceptual examples were requested to illustrate how varying these assumptions affects the conclusions reached in particular studies. These are short examples drawn from existing analysis to show how varying the assumptions discussed previously can yield different carbon emissions profiles.

10.1. Massachusetts Manomet Study

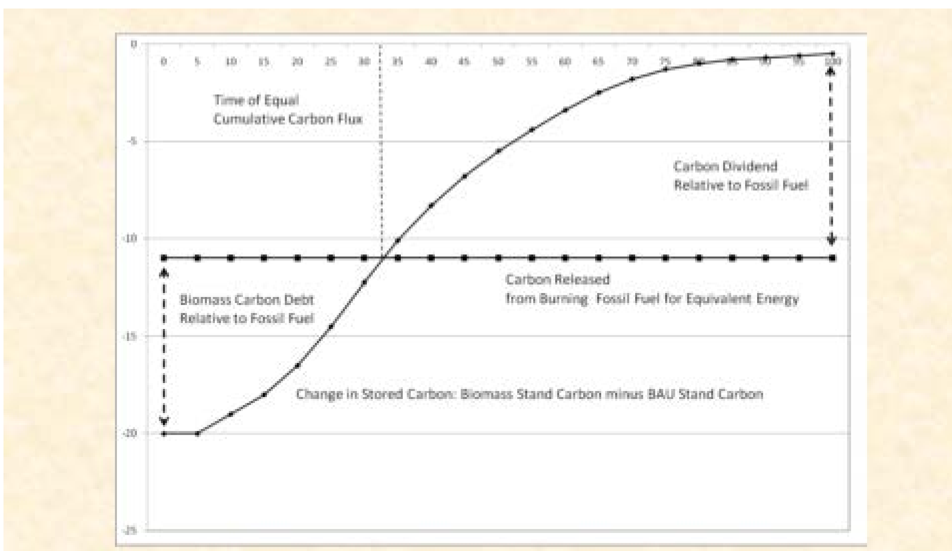

Figure 6. Debt Then Dividend Concept

Manomet Inc., an NGO based in Massachusetts, performed a study under contract with the Massachusetts Department of Energy Resources released in 2010. This study has been well publicized and reached the conclusion, in some views, that burning biomass is “worse than burning coal.”

The study made assumptions on the criteria identified in section 1 consistently in a direction that decreases the measure of carbon neutrality: a baseline of a mature forest stand was assumed (starting point is high forest carbon), with a heavy harvest on a single parcel (narrow spatial scale) initially showing an immediate carbon loss, and the time frame was constrained to 2050. Thus in year zero, the heavy and assumed complete harvest created a “carbon debt” of 100 percent necessary to pay back to get back to zero atmospheric carbon impacts according to the debt-payback analogy made in the study. The narrow geography made the debt look significant and with no reference to continuing sequestration on other adjoining stands or forest lands. Narrow spatial scope with an initial baseline of a full harvest therefore created an initial “carbon debt.” Lastly, the time frame adopted for the analysis did not allow time for the harvested trees to regrow, so a temporally narrow time frame also limited the ability of the carbon debt to be repaid. In short, given the meta-assumptions of the Manomet study, it is not surprising that it reached a result showing large losses of forest carbon sequestered in that single theoretical stand. Ultimately, if more time than the 2050 end date of the study was assumed, then Figure 6[23] shows most or all of what the Manomet study describes as a “carbon debt” would be repaid, even for that narrow stand over time.

Note the forest stand rotation assumed appears to be roughly 60 to 100 years for the forest biomass to regrow to its former carbon level just before the initial year zero harvest. This diagram embeds an analysis of carbon generated from fossil fuels and concludes that it would take 32 years for the biomass-generated energy to have the same carbon footprint as the hypothetical fossil unit and roughly 100 years for the biomass energy to balance emissions and carbon uptake—so 100 years for the carbon cycle to catch up.

10.2. Biomass Industry Analysis

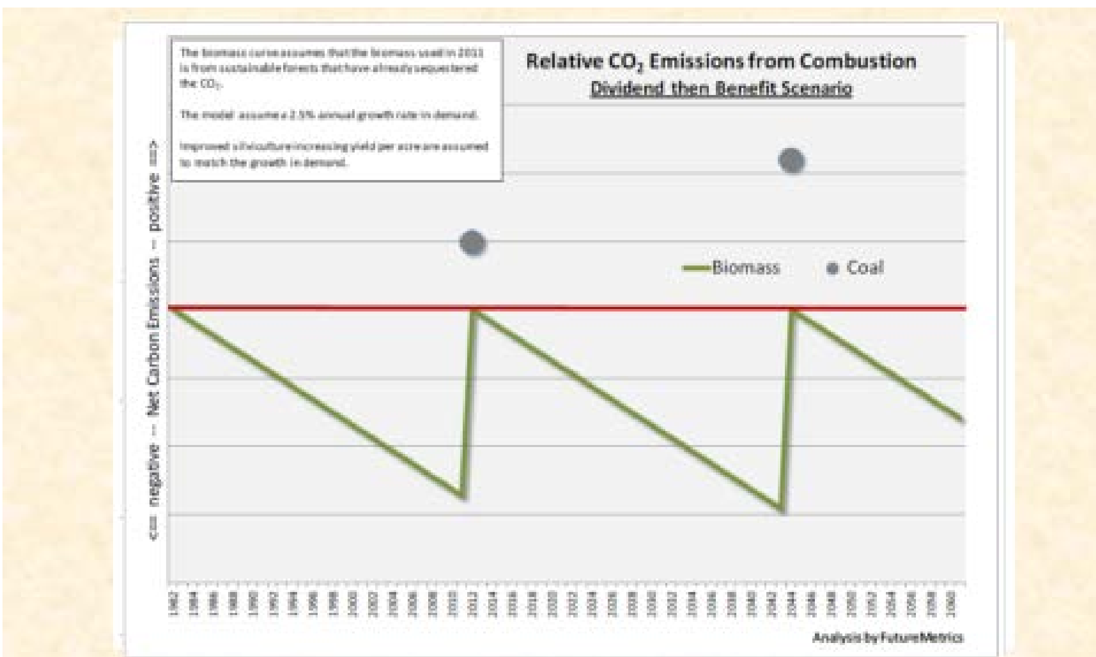

Figure 7. Debt Then Dividend vs. Dividend Then Benefit

Figure 7, produced in 2011,[24] makes a different set of assumptions on issues identified in Section 1 and 2. This graphic on its face is not specific on whether it is analyzing a stand, parcel, or forest landscape. As

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[23] Littell, D. (2012, August 14). Temperate Forest Potential to Mitigate Climate Change. Presentation to NESCAUM Board of Directors, citing Manomet, 2010.

[24] Littell, D. (2012, August 14). Temperate Forest Potential to Mitigate Climate Change. Presentation to NESCAUM Board of Directors, citing Manomet, 2010 and Strauss, 2011.

opposed to an initial harvest assumed by the Manomet study, this analysis assumes an initial period of carbon sequestration. Therefore, the baseline condition and starting point are different. And those different assumptions on baseline and starting point yield an initial carbon sequestration "dividend" rather than "debt" shown by Manomet. These are merely assumptions that show markedly how one study starts out with assumptions that make biomass look good, creating a carbon "dividend," and another study starts out not so good in terms of carbon emissions, creating a carbon "debt."

Likewise, Strauss assumes that biomass is assumed to be harvested from a sustainably managed forest, and there is an assumption that there are no life-cycle carbon losses from harvest, processing, transportation, handling, and harvest. The time assumed by Strauss allows for multiple biomass regrowth and harvest cycles, and always a positive carbon "dividend" rather than any debt. The gray dots show emissions from a coal-fired power plant increasing overall emissions. The presentation in the graphic is different than that used by Manomet, which factors in emissions from a fossil fuel unit as a horizontal line, rather than showing separately, as does Strauss, above the horizontal axis over time (the graphics are not comparable).

The time frame in Strauss's analysis is sufficient to allow 2.5 growth cycles and two harvests. Rotation appears to be about 34 to 35 years. Therefore, the species and forest appear to grow more quickly (a southern forest, perhaps) than the stand analyzed in the Manomet study that was supposed to be in Massachusetts. Tree growth will vary by species, soil, latitude, moisture, and numerous other conditions, and can be empirically determined based on forest characteristics. The rotation time for forest harvest is a silviculture determination based on economic as well as tree growth considerations, but generally both the period needed for tree growth to maturity for harvest and rotation periods get longer as one moves from south to north.

1010.3. Carbon Footprint Analysis

The type of analysis performed above can be compounded with additional analysis and assumptions to show a comparison to other fuels. Arguably, there are so many hidden assumptions in such an analysis that it is very hard to separate good from bad studies. Figure 8[25] is from a 2011 study published in the *Journal of Forestry*. It shows a comparison of carbon emissions from bituminous coal to natural gas, biomass, and then biomass netted to consider the carbon uptake.

[25] Littell, D. (2012, August 14). Temperate Forest Potential to Mitigate Climate Change. Presentation to NESCAUM Board of Directors, citing *Journal of Forestry*, 2011.

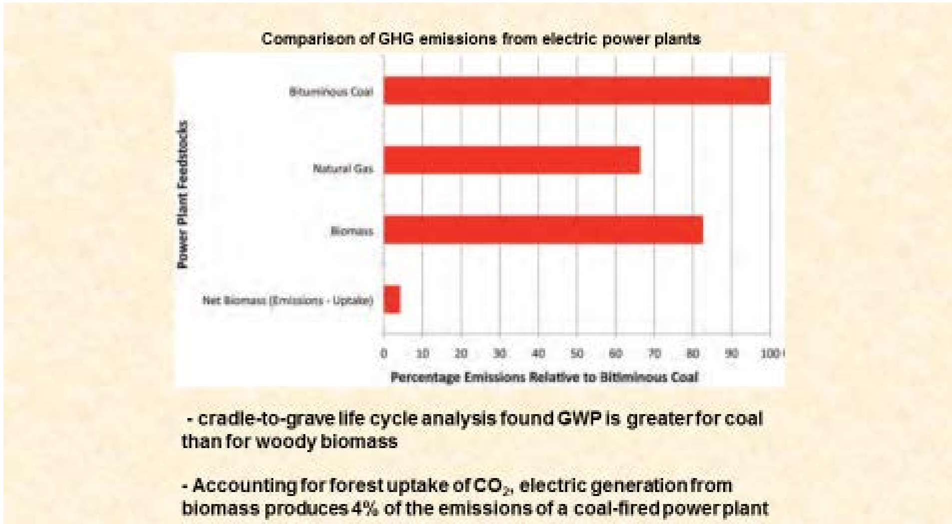

Figure 8. Biomass GHG Emissions vs. Fossil Fuel Sources

What is notable here is the attempt to show both total emissions to produce the same energy output and then the adjustment to net out biomass emissions. There is a conclusion that biomass emissions in total (emissions out of the biomass generator stack) are higher than natural gas, and then an application of the forest carbon uptake to create a net biomass emissions profile. It is also notable that there is a recognition that there are life-cycle emissions losses for biomass (because there are still net emissions after carbon uptake is netted out). With carbon uptake accounted for in this study, biomass therefore constitutes roughly four percent of the emissions of a coal unit.