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Carbon emissions from burning biomass for energy

Is biomass "Worse than coal"? Yes, if you're interested in reducing carbon dioxide emissions anytime in the next 40 years.

Biomass burning: a major carbon polluter

It's often claimed that biomass is a "low carbon" or "carbon neutral" fuel, meaning that carbon emitted by biomass burning won't contribute to climate change. But in fact, biomass burning power plants emit **150% the CO_2 of coal, and 300 – 400% the CO_2 of natural gas, per unit energy produced.**

These facts are not controversial and are borne out by actual air permit numbers. The air permit for the We Energies biomass facility (link) at the Domtar paper mill in Rothschild, WI, provides an example of how biomass and fossil fuel carbon emissions compare. The mill has proposed to install a new natural gas boiler alongside a new biomass boiler, and presented carbon emission numbers for both. The relevant sections of the permit are shown below.[1] They reveal that the biomass boiler would emit 6 times more carbon (at 3,120 lb/MWh) than the adjacent natural gas turbine (at 510 lb/MWh).

The Domtar plant was required to show its greenhouse gas emissions from biomass by EPA rules. Although the EPA has proposed a three-year deferral of greenhouse gas permitting for "biogenic" emissions under the "tailoring rule" of the Clean Air Act, this waiver will not go into effect until July 2011. Until then, the EPA is requiring facilities with biogenic emissions to report and try to mitigate their greenhouse gas pollution (using Best Available Control Technology, or BACT) if they are also major emitters of other air pollutants. There is no realistic means to reduce CO_2 emissions, however, other than improving plant efficiency.

Burning biomass emits more CO_2 than fossil fuels per megawatt energy generated:

1. Wood inherently emits more carbon per Btu than other fuels
   - Natural gas: 117.8 lb CO_2/mmbtu
   - Bituminous coal: 205.3 lb CO_2/mmbtu
   - Wood: 213 lb CO_2/mmbtu (bone dry)

2. Wood is often wet and dirty, which degrades heating value

   Typical moisture content of wood is 45 – 50%, which means its btu content per pound is about half that of bone dry wood. Before "useful" energy can be derived from burning wood, some of the wood's btu's are required to evaporate all that water.

3. Biomass boilers operate less efficiently than fossil fuel boilers (data from air plant permit reviews and the Energy Information Administration)
   - Utility-scale biomass boiler: 24%
   - Average efficiency US coal fleet: 33%
   - Average gas plant: 43%

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A. Boiler B02 – 350 MMBTU/hour natural gas. This boiler is subject to NSPS (Part 60, Subparts D and Db).

8. Greenhouse Gases
a. Limitations: BACT.
(1) Greenhouse gas emissions may not exceed 190 lb CO_2e per 1,000 pounds of steam produced, or 510 lb CO_2e per MWh of steam produced per month, averaged over any consecutive 12-month period. (s. NR 405.08, Wis. Adm. Code and 10-SDD-058)

Partnership for Policy Integrity
info@pfpi.net

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B. Boiler B01 – Biomass and natural gas fired boiler with a capacity not to exceed 800 MMBTU/hour. The boiler is subject to NSPS (Part 60, Subparts D and Db).

11. Greenhouse Gases
(a) Limitations: BACT. (1) Greenhouse gas emissions may not exceed 3,120 pounds of CO_2e per MWh of gross output, averaged over any consecutive 12-month period. *Gross output* means the gross useful work performed by the steam generated. When the unit is generating only electricity, the gross useful work performed is the gross electrical output from the turbine/generator set. For cogeneration, the gross useful work performed is the gross electrical output plus 75 percent of the useful thermal output measured relative to ISO conditions that is not used to generate additional electrical output (i.e., steam delivered to an industrial process). . **(s. NR 405.08, Wis. Adm. Code)**

If burning biomass emits carbon dioxide, how can it be "carbon neutral"?

CO_2 is CO_2, whether it comes from burning coal or burning trees. So why do some people argue that biomass power generation is "carbon neutral"?

There are two main arguments, the "waste" argument and the "resequestration" argument:

The "waste" argument part 1: "It would have decomposed anyway"
Biomass fuel is often portrayed as being derived from "waste" materials, particularly the tree branches and other material left over after commercial timber harvesting ("forestry residues, slash"), as well as sawdust and chips generated at sawmills ("mill residues"). Because these materials are expected to decay eventually, emitting carbon dioxide in the process, it is argued that burning them to generate energy will emit the same amount of carbon as if they were left to decompose.

This claim only works if the time element is ignored, and if there is actually enough waste to power the proposed facilities.

It takes years and even decades for trees tops and branches to decompose on the forest floor, and during that process, a portion of that decomposing carbon is incorporated into new soil carbon. In contrast, burning pumps the carbon stored in this wood into the atmosphere instantaneously. There is a difference of many years, and even decades, between the immediate emissions from burning residues, and the slow evolution of carbon from natural decomposition. So one question is, how can a form of energy that dramatically *accelerates* the release of CO_2 into the atmosphere be considered carbon neutral? The answer is that it can't be, unless critical factors like time are ignored.

Another important question is, how much of these "forestry residues" are really available, compared to the amount of fuel required by a growing biomass industry? We explore that question in detail elsewhere; here, it's sufficient to state that forestry residues are extremely limited, relative to fuel demand, and that many facilities already harvest whole trees for fuel.

Waste argument, part 2: the "Methane Myth"
Some people claim that it's better to collect logging residues for biomass fuel, rather than leaving them in the forest, because allowing these materials to decompose naturally can emit not just carbon dioxide (CO_2), but also methane (CH_4). Because methane has a greater global warming potential than carbon dioxide, proponents of biomass power argue it is better from a greenhouse gas perspective to burn this material, and emit the carbon as carbon dioxide, rather than let it decompose in the forest, where some of it may be emitted as methane.

There are notable problems with this argument.

- Methane is not produced in upland areas where well-aerated logging residues are decomposing. Instead, it is chiefly produced in wet, low-oxygen environments like wetland soils. Forest soils contain bacteria that produce methane, but also bacteria that consume methane, so the net emissions are small. (EPA's information on methane puts different sources into perspective).
- Landfills can be sources of methane, but according to a study on landfilled wood, "the resistance of most forest products to anaerobic decomposition in landfills is significant"… and that only about 3% of land-filled wood is emitted as methane or carbon dioxide.
- Notably,biomass proponents never mention something that *is* very likely to be a source of methane emissions: the football field-sized, 30 – 70 foot tall, wet, steaming, and poorly aerated piles of chipped wood fuel at many biomass plants. (One study found temperatures in a wood chip pile rose to 230F less than two months after pile completion; temperatures above 180F are considered to produce a high probability of spontaneous combustion. Off-gassing from relatively dry wood fuels can produce, in addition to CO_2, carbon monoxide, methane, butane, ethylene, and other toxic gases. The buildup of gases in the holds of ships transporting wood pellets has caused accidents and fatalities. Spontaneous combustion in wood chip piles is not uncommon.)

The "resequestration" argument.
The other main argument used to justify the idea that biomass energy is carbon neutral is that re-growing plants recapture, or "resequester" an amount of carbon equivalent to that released to the atmosphere by burning biomass fuels, and therefore net carbon emissions are zero.

When trees are used for fuel, it is obviously not possible for the system to be "carbon neutral" in a timeframe meaningful to addressing climate change. A 50 megawatt biomass power plant burns more than a ton of wood a minute. It takes seconds to burn a tree, and many decades to grow it back.

But proponents have devised deceptive arguments to obscure this logic. Some claim that as long as forests in a region are are growing more wood than is being cut, then carbon emissions from biomass burning are neutralized by this growth. This argument seems to persuade some people, but it is wrong. It sidesteps that fact that growing forests are taking up carbon *now* – and that cutting and burning them for fuel dramatically increases carbon emissions from energy compared to the fossil fuels you're replacing (see a letter about how the Washington State Department of Natural Resources made this very mistake, **here**; and see the Manomet team's takedown of a similar argument. We explain the Manomet study in more detail below).

A similar argument states that as long as forests are growing and sequestering carbon in one place, this makes up for the carbon that's emitted by harvesting and burning trees in another place. But those trees "somewhere else" were already sequestering carbon - and cutting and burning trees over *here* does nothing to increase carbon sequestration over *there*. Not to mention that the trees that you burn over *here* are no longer sequestering any carbon at all, but instead are floating around in the air as CO_2. It makes as much sense to discount biomass carbon emissions using this logic, as it does to discount fossil fuel emissions “because trees are taking up carbon somewhere”.

Over long enough time periods, forests cut for biomass fuel can ultimately regrow and recapture the carbon released by burning. But the inescapable conclusion of doing carbon accounting correctly is that burning biomass instead of fossil fuels always represents an extra burst in carbon emissions over some multi-year or multi-decadal period, and in some cases more than a century. It can’t be any other way. When you cut a forest for fuel, you’re *increasing* carbon emissions produced per unit energy by switching to wood, and at the same time, *decreasing* the total amount of forest available to take carbon out of the air and sequester it into growing trees (think of the forest as a scaffolding, upon which more carbon is hung each year. A forest cut for biomass doesn’t have the “infrastructure” to accumulate carbon quickly).

Industry data show that the overwhelming majority of biomass burners are now and will continue to be fueled by wood. Net carbon emissions from burning trees are enormous in part because trees are such long-lived organisms, so it takes decades to centuries to re-grow them after they’re burned.

But what about using crops for fuel, or other plants that have a shorter lifecycle than trees? Plants with a yearly lifecycle – like the perennial grass switchgrass – have lower net carbon emissions over time, because net carbon emitted by harvesting and burning can be re-grown in a shorter period. However, it is important to make sure that using energy crops as fuel doesn’t cause an increase in carbon emissions somewhere else. For instance, cutting down forests and planting switchgrass would represent a massive loss of carbon to the atmosphere from harvesting the trees, as well as the decomposition of roots and soil carbon following harvest. This pulse of carbon would outweigh any benefit of replacing fossil fuels with energy crops for a long time.

And, to replace even a small percentage of fossil fuels with switchgrass or a similar energy crop would take a huge amount of land. Supplying a single 50 MW biomass plant with switchgrass would require harvesting around 65,000 acres a year (assuming 7 tons of switchgrass harvested per acre). To replace any significant amount of the approximately 969,440 MW of fossil-fueled capacity in the U.S. (2009 data), would require tens of millions of acres of land that are currently growing food or feed, not to mention the 30 million acres of corn that are currently devoted to ethanol production, with notable impacts on commodity prices worldwide.

Science-based accounting for biomass energy carbon emissions: the Manomet Study

When citizen scientists and activists discovered that two to four utility-scale biomass electricity generating plants were planned in Massachusetts, they organized. Some basic math quickly revealed that the hundreds of thousands of tons of wood required to fuel these plants would far exceed not only the amount of “forestry residues” generated in the state, but also the state’s total annual commercial sawtimber harvest. Clearly, these plants would be big carbon polluters, but as “renewable energy” they would not have to report or count their emissions under state regulations, which treat all renwables as carbon neutral.

Responding to citizen activism, the state issued a request for proposals for a group to study the forest cutting impacts and net carbon emissions from biomass power. The group that was awarded the contract was headed by the Manomet Study for Conservation Sciences, and included representatives from the Biomass Energy Resource Center, the Forest Guild, and others. Several of the group’s members were already on the record claiming that burning biomass was carbon neutral.

Nonetheless, when the final “Biomass Sustainability and Carbon Policy Study” (aka the “Manomet Report”) was issued, the results surprised even the researchers. The study concluded that net carbon emissions from burning biomass in utility-scale facilities emitted more carbon than even coal, and that it would take decades to pay off the “carbon debt” created by harvesting forests for fuel. Small burners (i.e. thermal and combined-heat-and-power facilities) with higher efficiencies were found to have shorter payoff periods for their carbon debt, but even their emissions exceeded those from fossil fuels for several years.

The study assumed that the carbon debt from "logging residues" used for fuel – that is, the wood left over from sawtimber harvesting, which would decompose and emit carbon anyway – was basically paid off within a few years. But because there is relatively little of this material available in Massachusetts, the main fuel supply for biomass facilities would have to be trees that would not otherwise have been cut. And "trees that would not otherwise have been cut" turned out to have a really large carbon footprint when harvested and burned for fuel.

Upon release of the Manomet Study, the State issued a directive that new rules should be drafted to restrict the eligibility of biomass power for renewable energy credits to those facilities that could demonstrate lifecycle emissions no more than 50% those of a natural gas plant, over a 20 year period. New restrictions were also proposed that restricted the amount of wood that could be taken from a logging site and used for fuel. As of March, 2011, the final version of the rules has not been released, but as drafted, the regulations stood as the sole example of a science-based policy on biomass power anywhere in the U.S, or the world.

The Manomet Study approach to carbon accounting, or, "Carbon accounting ain't for sissies".

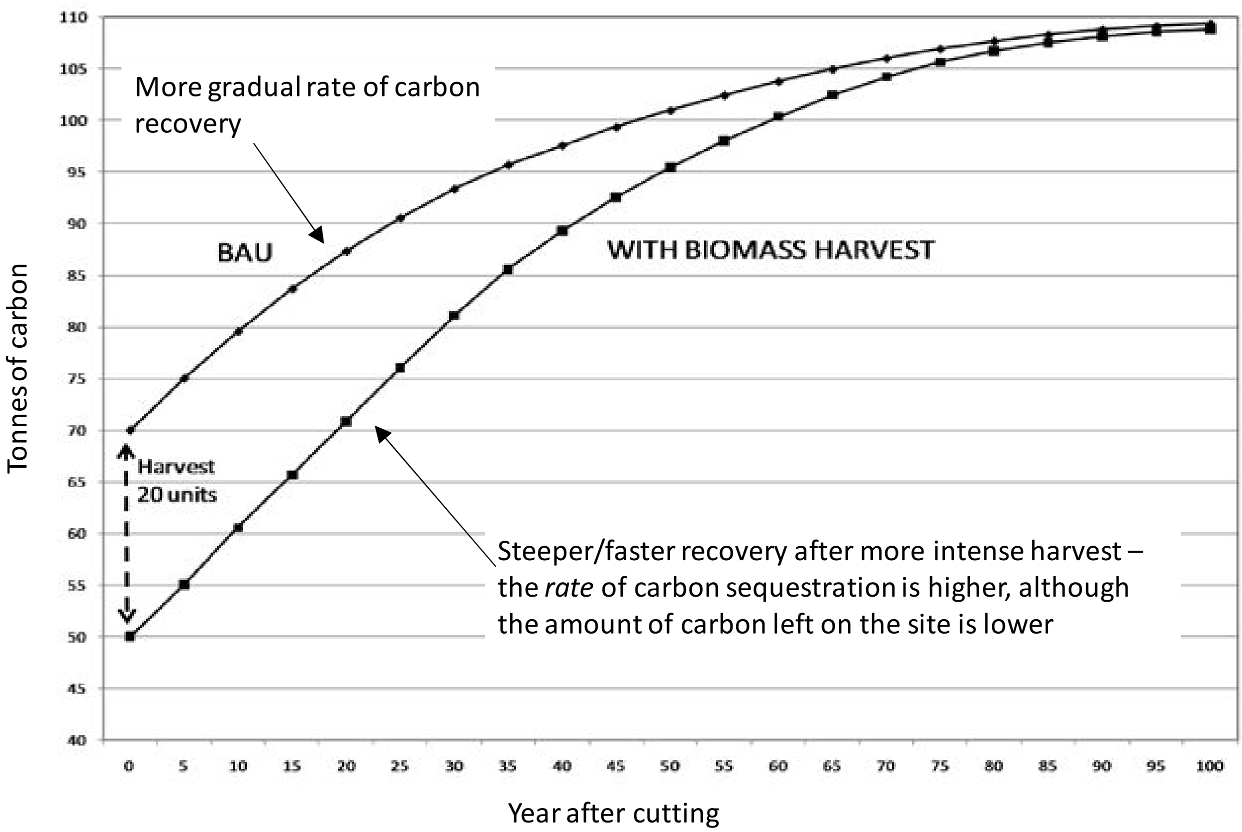
The Manomet team used a computer model of forest growth, the Forest Vegetation Simulator (FVS) to estimate net carbon emissions from biomass power. The FVS uses data collected on forest biomass and growth from the region of interest (in this case, Massachusetts forests) to run the simulations of forest regrowth after harvest.

The strength of the Manomet approach is that it acknowledges that forests *already* represent significant "sinks" for our emissions of carbon dioxide – that is, they convert atmospheric carbon dioxide into wood that takes the carbon out of circulation and thus reduces global warming potential. Forests do this whether the carbon is emitted by burning fossil fuels, or biomass.
The Manomet modeling approach compares carbon release and forest carbon sequestration under two basic scenarios:

1. The "business as usual" (BAU) scenario, where energy is generated from fossil fuels, and forests are cut for commercial timber, but not biomass fuel. Under the BAU scenario, the standing carbon in the forest is reduced down to 70 tonnes/hectare by commercial timber harvesting.

2. Under the "biomass" scenario, forests are still harvested for commercial timber down to 70 tonnes of standing carbon per hectare, but then a further 20 tonnes of forest carbon is harvested for biomass fuel, reducing the standing carbon to 50 tonnes/hectare (these assumptions and scenarios are particular to the model but do not turn out to be very important for the results, because the results largely depend on the magnitude of the *difference* between the two harvest intensities, and not the absolute magnitudes of the harvest intensities themselves).

Manomet's graphic (from page 98 of the report) shows the regrowth of forest plots cut under the BAU scenario and the biomass scenario. We reproduce it and annotate it below. Notice that the model estimates a higher rate of regrowth (steeper curve) under the heavier harvest of the biomass scenario. This occurs because the model simulates greater penetration of light and greater water and nutrient availability in the more heavily cut forest, which allows the trees remaining on the site and the new trees geminating after harvest to grow faster. The graphic shows how initially, there is a difference of 20 tonnes of carbon between the two scenarios. After a couple of decades of regrowth, the faster rate of carbon sequestration on the more heavily harvested plot starts to narrow the gap between the two curves.



The next step is to add the emissions from energy generation into the model. Manomet estimated the amount of energy that could be generated from the 20 tonnes of biomass per hectare removed in the biomass scenario, then calculated what the carbon emissions would be if the same amount of energy were generated using fossil fuels in the BAU scenario (fossil fuel carbon emissions are a weighted average from power generators in Massachusetts, so are not representative of a 100% coal or a 100% gas scenario, but lie somewhere in-between). For this scenario, Manomet concludes that generating a given amount of energy using biomass would emit 20 tonnes of carbon, and generating the same amount of energy from fossil fuels would emit only 11 tonnes of carbon.

Biomass as fuel emits more carbon per unit energy than using fossil fuels. This creates a "carbon debt", the carbon emitted to the atmosphere that was formerly held in trees or other plants that must be paid back. When trees are harvested and burned as fuel, repaying the debt requires a higher rate of carbon sequestration than in the BAU scenario, where forests were cut for commercial timber but not fuel. If the growth rates were the same, the initial difference of 20 tonnes of carbon following harvest would persist indefinitely.

The growth curves above shows how this carbon debt is repaid. For the carbon held in the biomass scenario to catch up to the BAU scenario requires accelerated growth, and indeed, the FVS model simulates a higher growth rate in the forests cut heavily for both commercial timber and biomass fuel, compared to the forests that are cut just for commercial timber. The higher growth rate allows carbon to accumulate faster in the biomass scenario, eventually closing the gap and catching up to the carbon accumulated in the BAU scenario.

This outcome is heavily dependent on the FVS model assumption of a higher growth rate in the forest cut more heavily for fuel. If this turns out to be not true for any reason – for instance, if cutting forests for biomass actually lets in *too much* sun, overheating and drying the site and interfering with seedling regeneration, then resequestration of the extra carbon emitted by burning biomass may be postponed indefinitely. The model's conclusions will not be sustainted unless the growth rate on the more heavily cut biomass plot eventually exceed the growth rate on the BAU plot.

Further, for these conclusions to hold it is also essential that the forest plot not be cut again, prior to the full resequestration of carbon. To achieve that goal following harvesting for biomass, forests have to be left alone for decades.

For a review of these and other assumptions that likely mean that the Manomet Study painted *too rosy* a picture of the carbon impacts of biomass energy, click here.

Manomet's modeling – a closer look

Getting deeper into the modeling behind the Manomet study requires defining some terms. We try here to present the Manomet approach from a couple of different angles.

First, we look back at the previous graphic, and see that immediately following harvest, there is more standing carbon in the BAU system than the biomass system:

- C_{BAU}: Standing carbon per hectare in the BAU forest, which has been cut for sawtimber = 70 tonnes
- C_{BIO} : Standing carbon in the forest cut for biomass fuel and sawtimber = 50 tonnes

Following harvest, 20 additional tonnes of carbon have been removed as fuel from the biomass system. This is subtracted from the standing carbon (as shown in the term above) and shows up as energy emissions:

- E_{BIO} : Emissions from biomass fuel = -20 tonnes (expressed as a negative number to represent carbon that's been taken out of "solid" form and entered the atmosphere as CO_2.)

In the BAU system, energy was produced by burning fossil fuels instead of biomass, which emitted 11 tonnes of carbon:

- E_F : Emissions from fossil fuels = -11 tonnes

Below are the first 75 years of data that describe the carbon recovery (in tonnes) of single plots harvested under the BAU and biomass scenarios from the graphic above (these values are estimated off Manomet's graphics, so may not match the data used in the model precisely).

year	C_{BAU}	C_{BIO}	$E_F + C_{BAU}$
0	70	50	59
5	75	55	64
10	79.75	60.5	68.75
15	83.75	65.75	72.75
20	87.5	71	76.5
25	90.5	76.25	79.5
30	93.4	81.4	82.4
32	94.25	82.75	83.25
35	95.5	85.5	84.5
40	97.5	89.5	86.5
45	99.4	92.5	88.4
50	101	95.4	90
55	102.5	98	91.5
60	103.75	100.4	92.75
65	105	102.5	94
70	106	104.4	95
75	107	105.5	96

Remembering that in the BAU scenario, energy emissions from fossil fuel combustion were 11 tonnes of carbon, and in the biomass system were 20 tonnes from the material harvested and burned for fuel, we can see that the BAU system as a whole contains 9 tonnes more standing carbon than the biomass system.

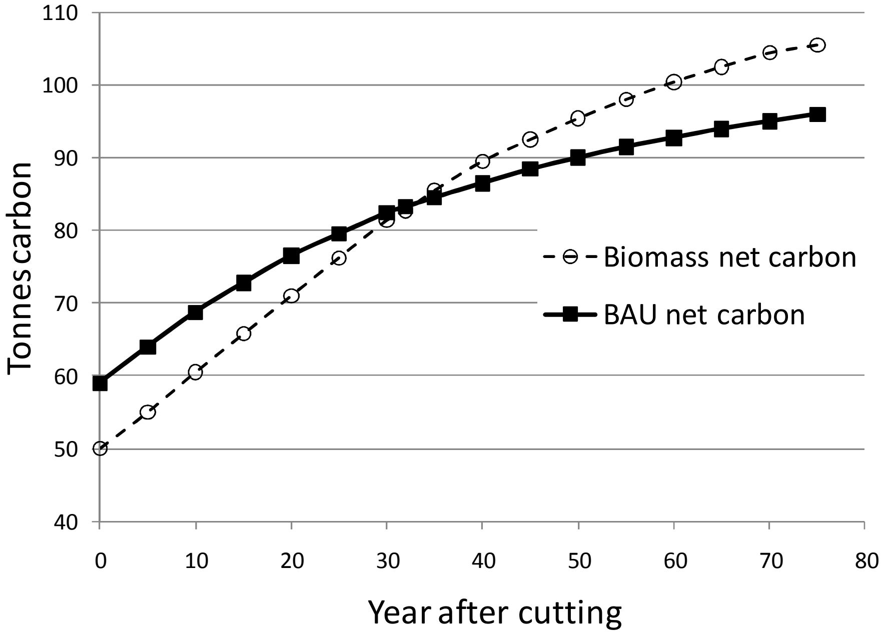
The question thus is, How many years will it take until the gap is closed and $E_F + C_{BAU} = C_{BIO}$?

Five years after harvest:
BAU system: $E_F + C_{BAU} = -11 + 75 = 64$
Biomass system: $C_{BIO} = 55$
So there are still 9 tonnes more carbon held in the BAU system than the biomass system.

At year 25, the growth rate for the biomass scenario is higher than for the BAU scenario, so the gap is narrowing and there is now only 3.25 tonnes more carbon held in the BAU system:
BAU system: $E_F + C_{BAU} = -11 + 90.5 = 79.5$
Biomass system: $C_{BIO} = 76.25$

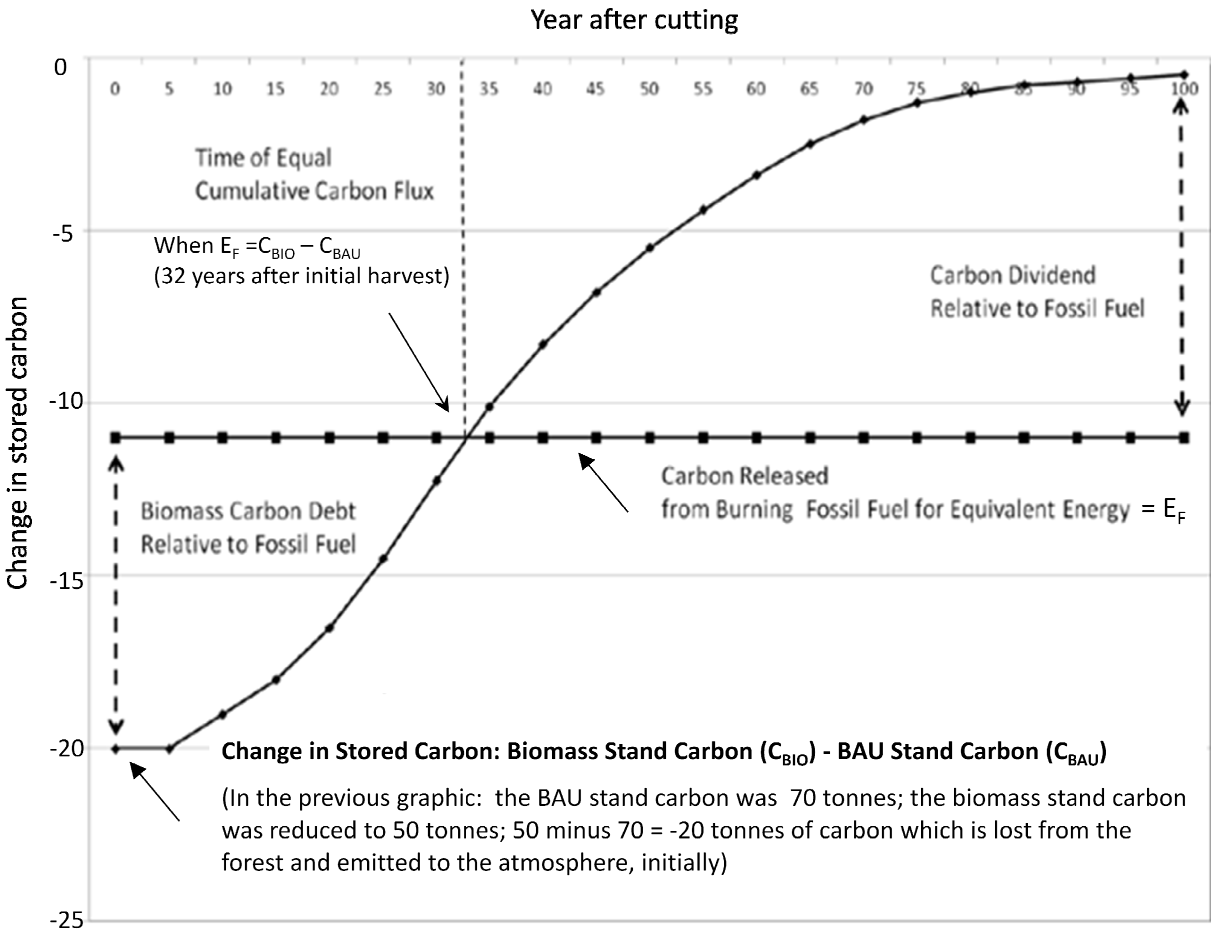
The Manomet model estimates that the gap closes completely at year 32. That is when net carbon held in the two terrestrial systems is equivalent, and net emissions from biomass power equal net carbon emissions from fossil fueled power.

Graphically, Net Carbon looks like this:



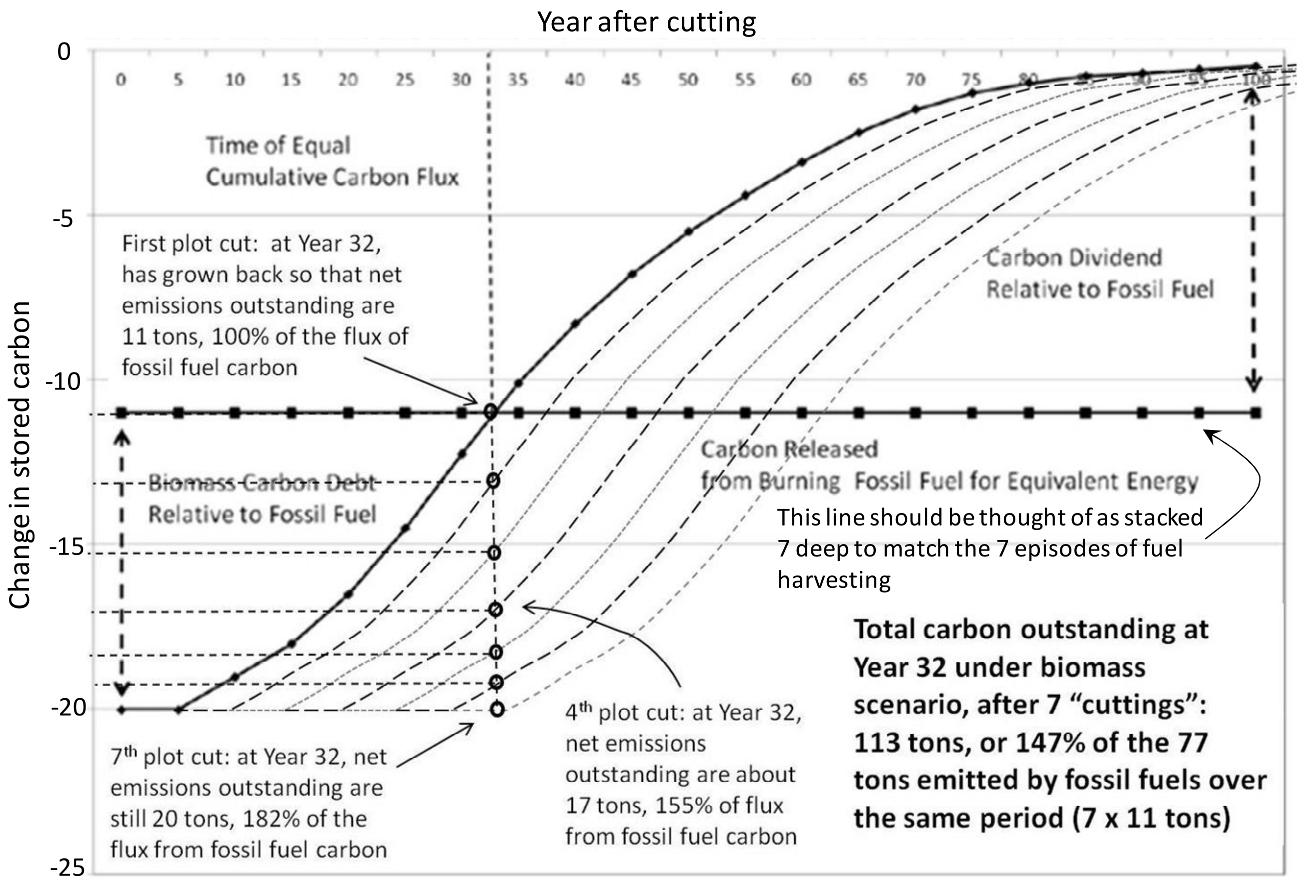
Manomet demonstrates the relationship between the two systems in a way that can be a little difficult to explain. One way to think about it is by rearranging the initial equation. Instead of asking as we did above, At what year does $E_F + C_{BAU} = C_{BIO}$, we rearrange the equation and instead ask, At what year does $E_F = C_{BIO} - C_{BAU}$?

When this is graphed against time, it looks like the following, which appears in the Manomet report on page 98:



The two previous graphics both show that following a single year's worth of fuel harvesting, it takes 32 years to repay the carbon debt and sequester enough carbon so that net emissions from biomass are the *same* as if the energy had been produced from burning fossil fuels. It is especially important to remember that up to this point, we have only been talking about the net carbon emissions through time and the carbon recovery occurring on the plots cut in a single year that have been cut once to yield biomass fuel.

Biomass plants are big investments, and no one builds one to operate for just a single year. To see what a facility's total carbon footprint looks like through time, we replicated the single plot graph to show multiple years of fuel harvesting (as with the former graphics, we have added to and adapted Manomet's charts). The horizontal line describing emissions from fossil fuels should be assumed to be duplicated as well – think of lines stacked on top of each other - since each year's use of biomass for fuel is compared against a year's use of fossil fuels in the BAU scenario.



As in the earlier graphic, net carbon emissions from the initial harvest of biomass achieve 100% parity with fossil fuel emissions at year 32 since the beginning of facility operation. However, at year 32, carbon from the next round of harvesting hasn't achieved 100% parity – it still has a carbon debt of about -13 tonnes. The third round of harvesting has a carbon debt slightly south of -15 tonnes at year 32 since the beginning of operation, and by the fourth round of cutting, the carbon outstanding is -17 tons. Summed over the 7 harvests shown here, the total biomass emissions are still greater than the total fossil fuel emissions, which are 77 tons (11 tons, replicated 7 times).

This is just an example – for visual clarity, the "harvests" have been staggered every five years, instead of occurring every year as they would for a biomass facility in continuous operation – but for this scenario, after 7 rounds of harvests, the net emissions under the biomass scenario are still 147% those in the BAU scenario.

The bottom line: unlike other renewable energy technologies like wind and solar, biomass is a perpetual emitter, meaning that every year's fuel supply requires creating a new "carbon debt".

[1] The biomass boiler can also burn gas but the emission figures are for biomass, only. Greenhouse gas emissions are expressed as CO_2 equivalents per unit output – i.e., per megawatt-hour – as opposed to being on a per unit heat input basis, as is typical for conventional pollutants. This allows the differences in the boiler efficiencies to be reflected in the final output numbers.