2018

Spatial Informatics Group · Natural Assets Laboratory

Scientific Evidence Does Not Support the Carbon Neutrality of Woody Biomass Energy

A REVIEW OF EXISTING LITERATURE

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SIG-NAL REPORT 2018-01

OCTOBER 31, 2018

Suggested Citation: Gunn, J.S., W. R. Moomaw, and P. Duffy. 2018. Scientific Evidence Does Not Support the Carbon Neutrality of Woody Biomass Energy: A Review of Existing Literature. SIG-NAL Report 2018-01. 10pp. Available Online https://www.sig-nal.org/reports-and-tools

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Summary Conclusions

Based on a comprehensive review of the published scientific literature on forest-derived woody biomass greenhouse gas (GHG) emissions from energy production, we conclude:

- *a priori* assumptions regarding categorical emissions benefits from forest-derived woody biomass energy production are not supported, and an assumption of "carbon neutrality" is fundamentally flawed.
- There is no scientific basis for the presumed carbon neutrality of biomass from managed forests.
- IPCC Guidelines do not automatically consider biomass used for energy as 'carbon neutral,' even if the biomass is thought to be produced sustainably.
- Carbon impacts of forest-derived woody biomass vary and depend on many established factors (including feedstocks, alternate fate, time horizon and age of the trees used for fuel, production methods, and forest management regimes).
- The assessment of potential GHG emissions associated with woody biomass energy must account for these factors.

Introduction

In this paper, we assess whether a policy to treat biogenic CO_2 emissions as carbon neutral, as stated below, has a defensible scientific foundation.

> *"EPA's policy is to treat biogenic CO_2 emissions resulting from the combustion of biomass from managed forests at stationary sources for energy production as carbon neutral." - pg. 75, EPA ...*

Where "managed forest" is defined by the US Environmental Protection Agency (EPA) as "a forest subject to the process of planning and implementing practices for stewardship and use of the forest aimed at fulfilling relevant ecological, economic and social functions of the forest. Also … it specifically comprises lands that are currently managed or those that are afforested, to ensure the use of biomass for energy does not result in the conversion of forested lands to non-forest use." In this report, we assume the term "carbon neutral" to mean there are zero net emissions of greenhouse gases to the atmosphere from energy generation when all life-cycle components (including forest growth elsewhere in the landscape) are considered at the time of energy generation (e.g., from forest wood sources to energy combustion).
Here, we provide a brief summary of key findings from the peer-reviewed published literature, the Intergovernmental Panel on Climate Change Fifth Assessment Report, and material published in the EPA's 2014 Draft Framework for Assessing Biogenic CO2 Emissions from Stationary Sources[1].

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[1] U.S. EPA, Office of Air and Radiation, Framework for Assessing Biogenic CO2 Emissions from Stationary Sources (November, 2014).
https://yosemite.epa.gov/sab/sabproduct.nsf/0/3235DAC747C16FE985257DA90053F252/$File/Framework-for-Assessing-Biogenic-CO2-Emissions+(Nov+2014).pdf

Section I below assesses the validity of an *a priori* assumption of carbon neutrality of woody biomass energy. Section II discusses how carbon emissions impacts vary in timing and extent and depend on many established factors.

I. *a priori* assumptions about the categorical carbon neutrality of forest biomass are not supported in the published literature.

a) Peer-reviewed Literature

Based on a comprehensive review of the published scientific literature on biomass emissions from energy production, we conclude that there is no defensible scientific foundation for EPA's carbon neutrality policy. The vast majority of all published quantitative assessments have concluded that there are net greenhouse gas (GHG) emissions associated with the use of forest-derived woody biomass for electricity production when compared to generating an equivalent amount of energy from fossil sources, even when accounting for subsequent biomass regrowth and avoided fossil emissions.[2]

Two "meta-analyses" (i.e., compiling and summarizing data from multiple studies across a given discipline) have been produced on the topic of GHG emissions from forest-derived woody biomass energy. These two analyses, Buchholz et al. (2016) and Bentsen (2017), summarize the full breadth of quantitative studies conducted over the previous two-plus decades that assess the extent of carbon impacts/benefits incurred by burning biomass to produce energy (not limited to electricity).

Buchholz, T., Hurteau, M.D., Gunn, J., Saah, D., 2016. A global meta-analysis of forest bioenergy greenhouse gas emission accounting studies. GCB Bioenergy 8, 281–289.
https://doi.org/10.1111/gcbb.12245

Buchholz et al. (2016) reviewed outcomes of 66 published forest biomass GHG emissions research studies published between 1991 and 2014, including 59 peer-reviewed studies and seven in the "gray" literature. These studies yielded 149 different scenarios for bioenergy generation that included a range of forest ecosystems, a range of feedstocks (for example, mill wastes, forests residues, thinnings, etc.), benchmark fossil energy sources (e.g. coal, mix, natural gas, oil), or energy conversion efficiency (e.g. electricity, liquid transportation fuel, combined heat and power, heat), and were geographically distributed to most global forest regions.

[2] The timing and degree of net emissions vary widely but depend upon fairly consistent factors. For example, the type of woody feedstock used to make energy matters greatly. Projected emissions from the tops and limbs of harvests that would have otherwise been left in the woods or at the roadside are less than emissions estimated from woody material that market forces dictate could either be used to make paper or energy. The impact to the atmosphere is different depending upon the product pathway. This topic is addressed in more detail in Section II below.

Of these 149 cases, 123 quantified a carbon payback period.[3] Buchholz et al. found that payback periods ranged from zero years to 4,500 years. More than 80 percent of the examined cases found a payback period greater than zero years (101 of 123), illustrating that the majority of studied scenarios produced a carbon debt. In 14 cases where biomass was used to generate electricity, the mean payback period was 1,827 years. The figure below illustrates the variability of carbon payback periods, but also highlights the overwhelming number of cases where the payback period was not zero years.

Bentsen, N.S., 2017. Carbon debt and payback time – Lost in the forest? Renew. Sustain. Energy Rev. 73: 1211-1217. doi:10.1016/j.rser.2017.02.004

The Bentsen (2017) meta-analysis followed a similar approach to Buchholz et al. (2016) and evaluated 245 case studies conducted and published over the past 20 years. Bentsen's results also show that the vast majority of bioenergy cases generate a payback period that is much greater than zero years (see Figure 1 below). Based on Bentsen, the mean payback periods by feedstock were: roundwood (102 years); whole trees (74 years); residues (18 years); stumps (14 years), and mixed feedstocks (~75 years). As discussed in Section II, the reasons for variability are consistent and relevant to a policy discussion on biomass energy emissions.

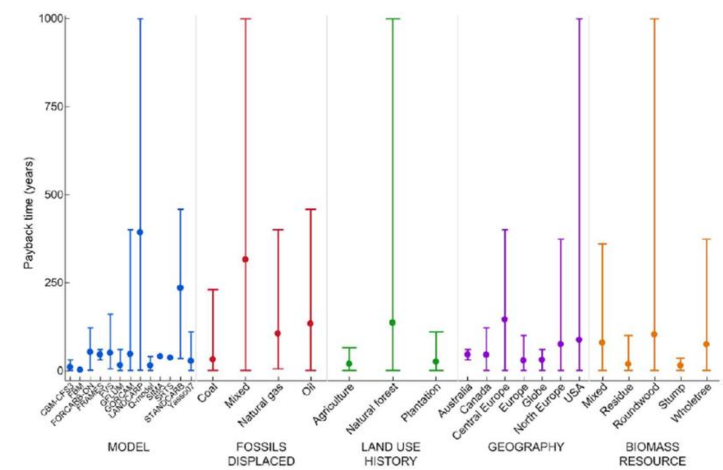

Figure 1. Figure 4 from Bentsen 2017, mean and range of carbon payback times (years) across five influential variables.

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[3] The concept of a "payback" of carbon dioxide emissions is generally attributed to Fargione et al. (2008) who calculated a potential carbon "debt" accrued to the atmosphere from switching from fossil fuels to biofuels. Studies use some version of this accounting approach and an articulation of timing to reach parity. That is, the time when carbon in the replacement or post-harvest growing forest *plus* the substitution benefits of using wood instead of a fossil fuel for energy equals the amount that would have been emitted in the fossil fuel energy scenario; *or*, the time when the full amount of emitted carbon is returned to the forest in comparison to a scenario where wood had not been used for energy (Ter-Mikaelian et al., 2015). The latter typically requires a longer period of time to reach parity. The use of parity and payback times has become the norm in studies of biomass energy emissions in the 10 years since Fargione et al. (Bentsen, 2017; Buchholz et al., 2016). Note that the concepts of parity and carbon debt payback are not the same as "zero carbon" emissions in that energy generation that combusts wood as a fuel releases carbon dioxide to the atmosphere at the time of generation.

The significant and compelling conclusion to be drawn from these two comprehensive assessments is that **published research does not support *a priori* assumptions regarding categorical emissions benefits from biomass energy, and an assumption of "carbon neutrality" is fundamentally flawed**.

Several new peer reviewed studies have been published since the two meta-analyses discussed above. The new studies that focus on the production of electricity from woody biomass feedstocks are highlighted below (Table 1). This new work continues to bolster the conclusion that there is no scientific basis for the presumed carbon neutrality of biomass from managed forests. Time frames for payback (or "parity") range from 0 to greater than 100 years for a range of feedstock and forest types, and forest management regimes.

Table 1. Summary of relevant studies published since Buchholz et al. 2016 and Bentsen 2017.

Study	Payback Time Frame	Energy Substituted	Feedstock
(Torssonen et al., 2016)	10 - > 20 years	Coal Electricity	Harvest Residue
(Hanssen et al., 2017)	0-29 years	EU Fossil Grid Electricity	Harvest Residue; Mill Residue; Pulpwood
(Laganière et al., 2017)	0 - > 100 years	Coal, Oil, Natural Gas Electricity	Harvest Residue; Mill Residue; Pulpwood
(Sterman et al., 2018)	44- 104 years	Coal Electricity	Whole trees; Harvest Residues.
(Cintas et al., 2016)	0 (coal) – 45 years (natural gas)	Coal and Natural Gas Electricity	Harvest Residues ("slash")
(Madsen and Bentsen, 2018)	1 year	Coal, Combined Heat and Power	Harvest Residues
(Law et al., 2018)	No payback by 2100	Coal and Natural Gas Electricity	Harvest Residues
(Booth, 2018)	> 50 years	Coal Electricity	Harvest Residue

b) IPCC Emission Estimates of Bioenergy Production Systems

Intergovernmental Panel on Climate Change (IPCC) has warned that, "IPCC Guidelines do not automatically consider biomass used for energy as 'carbon neutral,' even if the biomass is thought to be produced sustainably."[4]

The IPCC's 5th Assessment Report states,

> "The combustion of biomass generates gross GHG (greenhouse gas) emissions roughly equivalent to the combustion of fossil fuels. If bioenergy production is to generate a net reduction in emissions, it must do so by offsetting those emissions through increased net carbon uptake of biota and soils. The appropriate comparison is then between the net biosphere flux in the absence of bioenergy compared to the net biosphere flux in the presence of bioenergy production. Direct and indirect effects need to be considered in

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[4] IPCC Task Force on National Greenhouse Gas Inventories, Frequently Asked Questions, https://www.ipcc-nggip.iges.or.jp/faq/faq.html, Q2-10

calculating these fluxes."[5]

The section then lists six direct sources of GHG emissions associated with bioenergy and one indirect source:

1. GHG emissions associated with biomass production harvest, transport and conversion into secondary energy carriers (wood pellets or liquid or gaseous fuels)
2. Carbon dioxide and other GHGs released during combustion
3. Releases of carbon dioxide associated with land disturbance
4. Short lived GHGs associated with combustion like nitrogen oxides, carbon monoxide, and black carbon
5. Alteration of physical properties that affect surface energy balance including albedo or land reflectivity
6. GHGs from land management and alteration of soil biogeochemistry including emissions of nitrous oxide from fertilizer and methane emissions
7. Indirect effects include emissions associated with induced land use changes elsewhere

The assessment then addresses whether "… the CO_2 (carbon dioxide) emitted from biomass combustion is climate neutral because the carbon that was previously sequestered from the atmosphere (before combustion) will be re-sequestered if the growing stock is managed sustainably. The assessment finds that "[t]he shortcomings of this assumption have been extensively discussed in environmental impact studies and emission accounting mechanisms"[6] and states that "the neutrality perception is linked to a misunderstanding of the guidelines for GHG inventories."[7]

The assessment cites references that demonstrate that if forests are allowed to continue to grow rather than being cut and burned, "forest bioenergy systems have higher cumulative carbon dioxide emissions than a fossil reference system (for a time period ranging from a few decades to several centuries)."

II. Carbon impacts of forest-derived woody biomass vary and depend on many established factors (including feedstocks, alternate fate, time horizon, age of harvested forest, production methods, and forest management regimes).

a) Peer-Reviewed Literature

Instead of supporting *a priori* assumptions of carbon neutrality, the established findings in the studies summarized above firmly recognize that carbon emissions impacts from biomass energy

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[5] Working Group 3 (2013), first paragraph of section 11.13.4

[6] Fifth Assessment Report, IPCC, Agriculture, Forestry and Other Land Use (AFOLU) (IPCC AR5) http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter11.pdf pg 879

[7] Fifth Assessment Report, IPCC, Agriculture, Forestry and Other Land Use (AFOLU) http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter11.pdf pg 879, footnote 14

vary in extent and depend on many established factors including biomass feedstock type, geographic regions, timeframes, production methods, forest management regimes, energy type (and displaced energy source), and alternative fates, among others. Further, the climate impacts of biogenic carbon dioxide are identical to geologic (i.e., fossil) carbon dioxide, so it is imperative to understand the relative contribution of emissions from both sources to the atmospheric carbon pool and to assess the atmospheric residence time.

Consistent with the common biomass energy accounting principles, Walker et al. (2013) proposed that to understand GHG emissions associated with biomass energy generation we need to know something about the woody feedstock being used (e.g., harvest residues or pulpwood), the form of biomass energy being generated (e.g., heat or electricity), the fossil fuel being displaced (e.g., coal or natural gas), and finally, how forests are managed[8] or harvested to produce the desired feedstock. In addition, understanding the alternative potential fates of the feedstock is also critical. This framework plays out in the conclusions of both Buchholz et al. (2016) and Bentsen (2017) when categorizing the observed differences in carbon payback periods in published literature. Bentsen concludes that the use of harvest residues (the tops and limbs produced as a result of harvesting wood for other products) for energy generation results in shorter times until atmospheric carbon is removed by regrowth (mean = 18 years) than the use of roundwood and whole trees (102 and 74 years respectively). This is important to note and highlights the need for broadly-accepted definitions of forest-derived woody biomass feedstocks, such as “residues” and “whole trees.”

Forest ecosystems with typically long time frames between natural disturbance events (such as fires in parts of the Pacific Northwest) also tend to have longer payback periods. Studies of short-rotation plantation systems had mixed results in Buchholz et al., but tended to have shorter payback periods than natural forest systems in Bentsen’s analysis. In studies where an increase in harvest is required to meet biomass demands (e.g., Holtsmark 2012; Walker et al. 2013), the time to emissions parity with the fossil fuel alternative can be long or never occur. Additionally, studies that attribute land-use decisions where additional land becomes forested typically show short-term emissions in excess of the fossil fuel baseline. However, those benefits can be negated when “leakage” in the form of displaced production of existing forest products (e.g., paper) is accounted for (Galik et al. 2016). Benefits also rely on assumptions

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[8] It has been long known that older forests sequester more carbon than younger ones (Harmon et al., 1990). More recently, a study of all types of forests found that one-half of living biomass (and carbon) was in the largest one percent diameter trees regardless of forest type or location (Lutz et al., 2018). Intensively-managed forests keep the mean age of trees in the range of decades to centuries well below their natural lifespan (Gunn et al., 2014; Gunn and Buchholz, 2018). Hence, forest management that includes removals of bioenergy feedstocks not only releases CO_2 soon after harvest into the atmosphere, but changes forest structure and age class distribution with long-term implications for carbon storage on the landscape.

about future landowner behavior changes that result in non-forest land being converted to establish tree plantations.

Birdsey et al. (2018) also recently summarized the range of outcomes from specific case studies for woody biomass electricity generation in the southeast US. The results are affected by the type of woody feedstock used, accounting practices, and how forests are managed (Birdsey et al., 2018). As Searchinger et al. (2018) and many others have frequently pointed out, electricity generated from wood combustion releases substantially more CO_2 (per kilowatt hour) than coal or natural gas because of the inefficient conversion of heat to electricity.

b) EPA 2014 Biogenic Assessment Factor (BAF) Case Studies (Appendix M)

The EPA Scientific Advisory Board (SAB) was asked by the EPA to provide a peer review of its Framework for assessing the biogenic emissions from stationary sources that burn biomass. The EPA's Framework was developed to generate the "Biogenic Assessment Factor" (BAF), which is a factor that weights the stack emissions to account for the biological carbon cycle effects associated with their growth, harvest, and processing. According to the SAB (2012), "[t]he BAF is an accounting term developed in the Framework to denote the offset to total emissions (mathematical adjustment) that reflects a biogenic feedstock's net carbon emissions after taking into account its sequestration of carbon, in biomass or soil, or emissions that might have occurred with an alternate fate had it not been used for fuel."[9]

The EPA's Framework for Assessing Biogenic CO2 Emissions from Stationary Sources presents two relevant case studies. The cases studied feature softwood roundwood (i.e., the merchantable trunk of a tree that may have other market uses, such as for pulp-making) as a biomass energy feedstock in the southeast US and residues from logging/harvesting (i.e., tops and limbs not typically merchantable for other products) in the Pacific Northwest (Fig. 2). These case studies illustrate a temporal component to potential emissions associated with generating electricity from woody biomass compared to the same energy derived from fossil fuels: the BAF begins > 0 (indicating net emissions of biomass energy greater than the baseline) and declines to < 0 (indicating net emissions of biomass energy less than the baseline) over time. For the southeast US roundwood case study (where round wood is used as the feedstock), this transition to < 0 happens at around year 40. When logging residues are the feedstock, the transition happens sooner (20-25 years). Both results are consistent with the summary findings of the two meta-analyses described above.

[9] SAB Review of EPA's Accounting Framework for Biogenic CO2 Emissions from Stationary Sources (September 2011), (September 28, 2012)

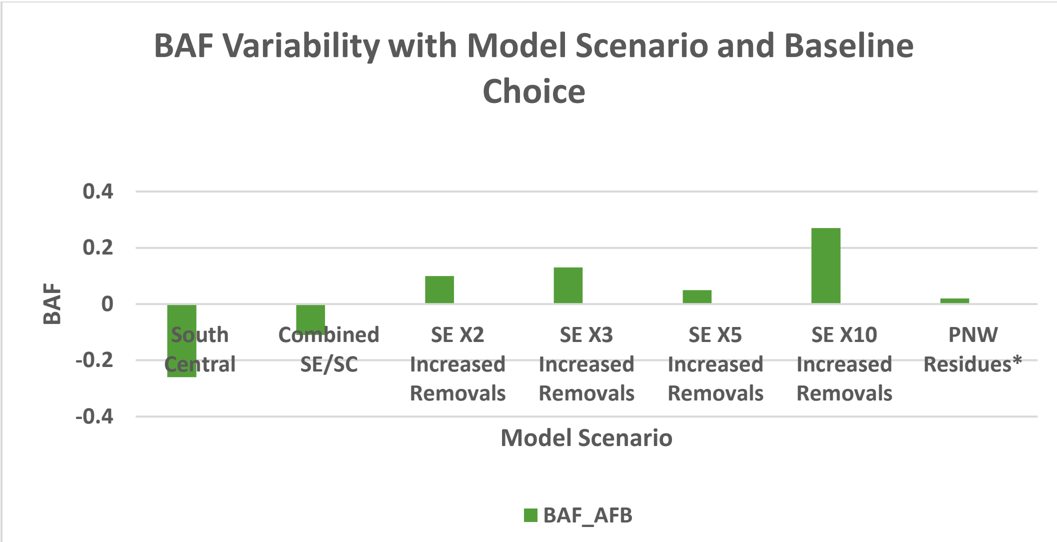

Figure 2. EPA Biogenic Assessment Factors (BAF) for EPA Scenarios (southeast roundwood, PNW harvest residues). AFB = Anticipated Future Baseline. Data from table M-2 in EPA 2014.

The EPA (2014) sums up this dynamic well in Appendix B:

> *"In general, accounting for temporal effects will be most significant when considering future potential fluxes related to long rotation feedstocks (e.g., roundwood), activities that affect the equilibrium storage in soil carbon pools, decay rates, or in cases of significant land use change, where biogenic feedstock production has implications for long-term emissions changes in terrestrial carbon stocks."*

Published case studies continue to emphasize the statement above and support the conclusion that the assessment of potential GHG emissions associated with woody biomass energy must account for all of these factors.

Conclusion

Declaring bioenergy to be carbon neutral will not change the fact that the "combustion of biomass generates gross GHG emissions roughly equivalent to fossil fuels" (IPCC AR5). The critical concern is concentrations of GHGs in the atmosphere. Neither the declaration of carbon neutrality, nor the guarantee of a sustainably-managed forest can assure that the amount of carbon dioxide in the atmosphere will avoid "dangerous anthropogenic interference with the climate system."[10] Accounting for the contribution of forest-derived woody biomass energy GHG emissions to the atmosphere is clearly a complex endeavor and methods are evolving rapidly in the scientific literature. Indeed, it has more recently been demonstrated that there is a need for full lifecycle assessments and systems dynamics accounting. Such an accounting framework tracks all of the carbon at all times throughout the entire cycle of harvesting, fuel

[10] UN Framework Convention on Climate Change Article 2, 1992. https://unfccc.int/resource/docs/convkp/conveng.pdf

production and transportation and combustion of the wood. This provides a time-evolving accounting system not only for carbon, but for other GHGs associated with forest-derived biomass energy such as N_2O from fertilizing reforestation and especially plantations, and any methane emissions associated with the storage of wood pellets or wood chips (e.g., Sterman et al., 2018). This system also does away with the need for specific time frames or even the use of arbitrary time dependent global warming potentials.

Published studies to date provide a great deal of insight on the potential risks and benefits of using wood for energy. Based on our comprehensive review of the published scientific literature on forest-derived woody biomass greenhouse gas (GHG) emissions from energy production, we conclude:

1) *a priori* assumptions regarding categorical emissions benefits from forest-derived woody biomass energy production are not supported, and an assumption of "carbon neutrality" is fundamentally flawed.;
2) There is no scientific basis for the presumed carbon neutrality of biomass from managed forests.
3) IPCC Guidelines do not automatically consider biomass used for energy as 'carbon neutral,' even if the biomass is thought to be produced sustainably.
4) Carbon impacts of forest-derived woody biomass vary and depend on many established factors (including feedstocks, alternate fate, time horizon, production methods, and forest management regimes).
5) The assessment of potential GHG emissions associated with woody biomass energy must account for these factors.

Acknowledgements

Natural Resources Defense Council (NRDC) provided funding to Spatial Informatics Group – Natural Assets Laboratory (SIG-NAL) to support the work of John Gunn in coordinating this research and writing this report. The other co-authors did not receive funding from NRDC.

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