Biomass Incineration and Climate

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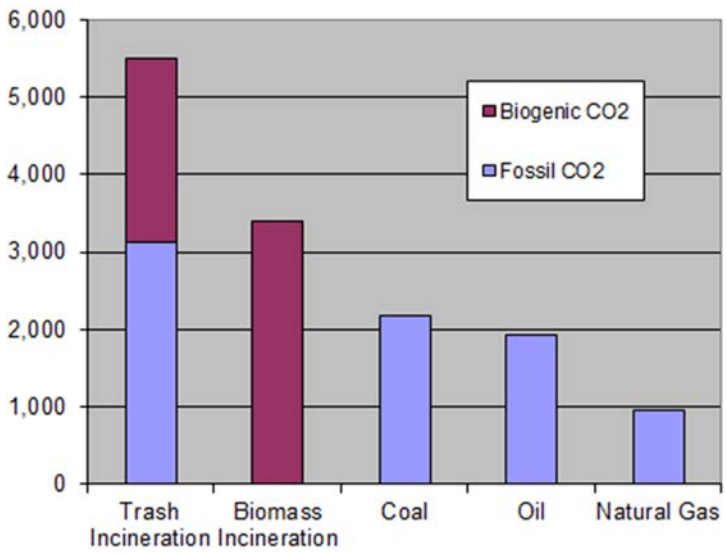
Biomass incineration is worse than coal for the climate. Smokestack emissions of carbon dioxide (CO_2) from biomass is 50% worse than coal per unit of energy produced.[1,2] Beyond the smokestacks, biomass global warming pollution is further increased by emissions from soils in deforested areas, and from the increased need for transportation – since biomass energy requires twice as much fuel than coal (and usually by truck instead of rail).

CO_2 Emissions from U.S. Electric Power Plants
in pounds of carbon pollution per unit of energy produced (lbs/MWh)



Source: U.S. EPA eGRID Database v.9 (2010 data)

Biomass advocates argue that their CO_2 should not be counted at all because biomass is "carbon neutral" because trees and crops regrow, eventually taking the CO_2 back out of the air. Several studies in recent years have debunked this "carbon neutrality" claim, showing that it takes decades for tree-regrowth to bring the emissions down to the level of coal, and centuries to approach carbon neutrality, which is never truly reached. These time frames are far too long for biomass to be a meaningful solution to global warming. Biomass burning aggravates global warming while burning the very forests needed to absorb CO_2.

The government is slowly catching up to the science. In July 2013, the D.C. Court of Appeals ruled that "the atmosphere makes no distinction between carbon dioxide emitted by biogenic and fossil-fuel sources."[3] In September 2013, the U.S. EPA proposed a rule that would regulate CO_2 from any new conventional coal power plants in which, if they co-fired biomass, the biogenic CO_2 would also be counted.[4]

Wood burning releases more CO_2 than coal or other fossil fuels because wood contains far more carbon per unit of energy produced, even if burned at the same combustion efficiency.[5] However, biomass is usually burned with a lower efficiency than fossil fuels.[6] It is more polluting and inefficient in part because wood chips are

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[1] U.S. EPA Emissions & Generation Resource Integrated Database (eGRID) v.9 (2010 data). http://www.epa.gov/egrid/ Analysis by Energy Justice Network outlined at http://www.energyjustice.net/egrid

[2] Mark E. Harmon, Timothy D. Searchinger & William Moomaw. Letter to Washington State Legislature, Feb. 2011, p.2. http://www.energyjustice.net/files/biomass/2011-02-03_WA_Letter.pdf

[3] Center for Biological Diversity v. EPA, 722 F.3d 401, 406 (D.C. Cir. 2013). http://www.cadc.uscourts.gov/internet/opinions.nsf/F523FF1F29C06ECA85257BA6005397B5/$file/11-1101-1446222.pdf

[4] "Standards of Performance for Greenhouse Gas Emissions From New Stationary Sources: Electric Utility Generating Units," U.S. Environmental Protection Agency proposed rule, 1/8/2014, Sec. III.A.2. https://www.federalregister.gov/articles/2014/01/08/2013-28668/standards-of-performance-for-greenhouse-gas-emissions-from-new-stationary-sources-electric-utility#h-42 "The proposed CO_2 emission standards do not apply a different accounting method for biogenic CO_2 emissions for the purpose of determining compliance with the standards. However, the proposed CO_2 emission standards only apply to new fossil fuel-fired EGUs [electric generating units]. Based on the applicability provisions in the proposal, as discussed above, an EGU that primarily fires biomass would not be subject to the CO_2 emission standards. Such units could fire fossil fuels up to 10 percent on a three-year average annual heat input basis (e.g., for start-up and combustion stabilization) without becoming subject to the standards."

[5] Jesse H. Ausubel, "Decarbonization: The Next 100 Years," 50th Anniversary Symposium of the Geology Foundation, Jackson School of Geosciences, U. of Texas, 25 April 2003. http://phe.rockefeller.edu/AustinDecarbonization/ "Wood effectively burns about ten carbon atoms (C) for each hydrogen atom (H). Coal approaches parity with one or two C's per H, depending on the variety. Oils are lighter yet, with, for example, with two H's per C, in kerosene or jet fuel. A molecule of methane, the typical natural gas, is a carbon-trim CH_4." However, the figure on methane is misleading in that methane is a potent global warming gas, so methane that escapes via leaks and isn't burned contributes to global warming effects worse than coal. See http://www.energyjustice.net/naturalgas/ for studies.

[6] Haberl, et. al., "Correcting a fundamental error in greenhouse gas accounting related to bioenergy," Energy Policy, 45 (2012) 18–23, p.19. http://www.sciencedirect.com/science/article/pii/S0301421512001681

about 45-50% water by weight.[7] Before "useful energy" can be generated, the water must be heated and driven off, which consumes energy and degrades facility efficiency.[8]

Burning forests for energy is a double-whammy for global warming. U.S. forest growth annually pulls enough CO_2 out of the atmosphere to counteract about 14% of the CO_2 emissions from each year of power generation.[9] Cutting and burning these trees releases their stored carbon while crippling the ability of forests to serve as a carbon sink.

Busting the "carbon-neutrality" myth:

The carbon-neutrality myth and alleged carbon emissions benefits of biomass depend on many faulty assumptions, including:

1. That fossil fuels are displaced when biomass is burned
2. That CO_2 emitted from biomass burning is instantly sucked up by newly growing plants (additional ones that would not have been growing, anyway) and that these plants are left to grow until a point of "carbon neutrality" is reached
3. That rotting biomass releases as much or more global warming pollution than burning would
4. That any "terrestrial" (non-fossil fuel) carbon adds to climate change regardless of whether it's in the air, or sequestered in plant matter or soils
5. That there are no CO2 emissions from logging or transportation
6. That there are not significant carbon emissions from soils after logging

Are fossil fuels actually displaced when biomass is burned?

Displacement sometimes occurs but, more typically, biomass competes within the realm of renewable energy subsidies and mandates, primarily competing with (emission-free) wind and solar. Even if fossil fuels were displaced, they're being displaced by an inefficient and dirty fuel that is worse than fossil fuels for the climate.

37 states plus DC have some sort of renewable electricity mandate, usually known as Renewable Portfolio Standard (RPS) laws, which require increasing amounts of "renewable" energy in the mix of companies selling electricity. These mandates usually are split into two classes, or tiers, where biomass and landfill gas burning typically compete with wind and solar in the top tier, where credits are worth more. Trash incineration usually competes in a second tier with hydroelectric and other dirtier, cheaper and/or pre-existing sources.

Within this top tier, biomass is sucking up a large portion of the credits used to meet these mandates – credits that otherwise would go to wind power. In Massachusetts in 2011, 48% of the energy used to comply with their Class I requirements (where biomass competes with wind and solar) came from combustion technologies (mainly landfill gas burning and biomass incineration), equal to the portion coming from wind and solar.[10] The figures are nearly identical in Pennsylvania in 2012, with 48% of their Tier I requirements coming from combustion sources, mainly landfill gas and biomass.[11] In DC, 93% of their Tier I mandate in 2011 came from biomass and landfill gas, gradually falling from 100% in the first two years of their program.[12]

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[7] "TechLine – Wood Biomass for Energy," Forest Products Laboratory, April 2004, p.1. http://www.fs.fed.us/sustainableoperations/greenteam-toolkit/documents/WoodBiomassForEnergy.pdf

[8] Mary S. Booth & Josh Schlossberg, "Comments on the Vermont Comprehensive Energy Plan," Partnership for Policy Integrity, July 13, 2011, p.2. http://www.pfpi.net/wp-content/uploads/2011/07/PFPI-Comments-on-Vermont-Comprehensive-Energy-Plan.pdf

[9] Mary Booth & Richard Wiles, "Clearcut Disaster: Carbon Loophole Threatens U.S. Forests," Environmental Working Group, June 2010, p.11. http://static.ewg.org/pdf/EWG-clearcut-disaster.pdf Carbon dioxide sequestered into new forest growth was estimated by calculating the growth increment of forests between 2002 and 2007, using Forest Service data.

[10] "Massachusetts RPS & APS Annual Compliance Report for 2011," Department of Energy Resources Executive Office of Energy & Environmental Affairs Commonwealth of Massachusetts, April 9, 2013, p.14. http://www.mass.gov/eea/docs/doer/rps-aps/rps-aps-2011-annual-compliance-report.pdf

[11] "2012 Annual Report -- Alternative Energy Portfolio Standards Act of 2004," PA Public Utility Commission, October 2013, p.29. http://paaeps.com/credit/getFilenouser.do?file=AEPSReport_12.pdf&docdir=true

[12] "2013 Report on the Renewable Energy Portfolio Standard," Public Service Commission of the District of Columbia, April 1, 2013. "Renewable Energy Credits Submitted tor 2011 Compliance" chart, p.13. http://www.dcpsc.org/pdf_files/reports/renewable_2013.pdf Previous years available in the annual reports at: http://www.dcpsc.org/Electric/Renewable.asp

Biomass CO_2 emissions are not instantly sucked up by newly-growing plants

Counting CO_2 captured when trees regrow is double-counting. The CO_2 absorbed by trees is often double-counted by biomass proponents, since it should only count if *extra* tree growth occurs beyond that which would have happened anyway (without biomass burning). Climate models already account for tree growth as part of the status quo. Carbon neutrality assumes that biomass grown is in addition to what would have grown anyway, which is almost never true.[13,14] One cannot legitimately take credit for forest growth elsewhere (that is, not on the plot that was cut for fuel, but on other forests), and pretend the trees know that biomass is being burned somewhere and grow faster to compensate! Cutting and burning trees in one place does not by itself increase forest carbon uptake elsewhere.[15]

Trees aren't necessarily being replanted when they are cut to burn for biomass. This is especially true where the "biomass" is a waste product, like construction and demolition wood waste, or the "biogenic" portion of municipal solid waste.[16]

Even where there is dedicated replanting, biomass CO_2 emissions are not instantly sucked up by newly growing trees. Biomass can only truly be carbon-neutral if 100% of the CO_2 emitted by burning it is instantly canceled out by new, additional tree growth. This is clearly not happening. Even if new trees were planted, they cannot instantly absorb as much CO_2 as it took another tree a lifetime to accumulate.

> "Clearing or cutting forests for energy, either to burn trees directly in power plants or to replace forests with bioenergy crops, has the net effect of releasing otherwise sequestered carbon into the atmosphere, just like the extraction and burning of fossil fuels. That creates a carbon debt, may reduce ongoing carbon uptake by the forest, and as a result may increase net greenhouse gas emissions for an extended time period and thereby undercut greenhouse gas reductions needed over the next several decades."
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> -Letter from 90 scientists to U.S. House and Senate Majority Leaders urging proper accounting of biomass impacts on global warming, May 17, 2010. http://www.energyjustice.net/files/biomass/90scientistsletter.pdf Citing J. Fargione, J. Hill, Tilman D., Polasky S., Hawthorne P (2008), Land Clearing and the Biofuel Carbon Debt, Science, 319:1235-1238. http://www.atmos.washington.edu/2009Q1/111/Readings/Fargione2008_biofuel_land-clearing.pdf

EPA's analysis of CO_2 impacts shows that, for a given amount of CO_2 released today, about half will be taken up by the oceans and terrestrial vegetation over the next 30 years, a further 30% will be removed over a few centuries, and the remaining 20% will slowly decay over time such that it will take many thousands of years to remove from the atmosphere.[17]

To do any better than this status quo, biomass must cause *extra* plant growth to counter the 50%-higher-than-coal pulse of CO_2 released when burning. Part of the carbon neutrality argument relies on the idea that newly-growing baby trees store more carbon than mature trees. However, a 2010 study of northeastern U.S. hardwood forests found that leaving forests alone ("no management") is the best for their storing carbon.[18]

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[13] Haberl, et. al., "Correcting a fundamental error in greenhouse gas accounting related to bioenergy," Energy Policy, 45 (2012) 18–23, pp.19-20. http://www.sciencedirect.com/science/article/pii/S0301421512001681

[14] Timothy D. Searchinger, "Biofuels and the need for additional carbon," Environmental Research Letters 5 (2010) 024007. http://iopscience.iop.org/1748-9326/5/2/024007/pdf/1748-9326_5_2_024007.pdf

[15] Mark E. Harmon, Timothy D. Searchinger & William Moomaw. Letter to Washington State Legislature, Feb. 2011. http://www.energyjustice.net/files/biomass/2011-02-03_WA_Letter.pdf

[16] Massachusetts Environmental Energy Alliance, "Comments on the draft Beneficial Use Determination (BUD) issued to Palmer Renewable Energy (PRE) for its fuel supply," November 16, 2009, p.4. http://www.pfpi.net/wp-content/uploads/2011/03/MEEA-commnents-on-Palmer-BUD-11-18-09.pdf Massachusetts Department of Environmental Protection (MassDEP) rejected PRE's claim that burning construction and demolition waste could be carbon neutral, stating: "MassDEP believes it is highly unlikely that Somerset Power could make an acceptable demonstration that construction and demolition is a source of carbon neutral fuel. It would be difficult, if not impossible, to have the information necessary to provide a reliable carbon neutral life-cycle analysis that includes consideration of material source, harvesting practices, transportation, impact of any coatings or treatments applied, and land use changes. At this time, it is unclear how such an analysis would even be done and evaluated."

[17] 74. Fed Reg.18886, p.18899, April 24, 2009, Proposed Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act. http://www.gpo.gov/fdsys/pkg/FR-2009-04-24/pdf/E9-9339.pdf

[18] Nunery, J.S. and W.S. Keeton, "Forest carbon storage in the northeastern United States: Net effects of harvest frequency, post-harvest retention, and wood products," Forest Ecology and Management, 259 (2010) 1363-1375. http://www.uvm.edu/giee/pubpdfs/Nunery_2010_Forest_Ecology_and_Management.pdf

Biomass is not carbon neutral in a meaningful time-frame.[19] The "it'll grow back" argument neglects the fact that it takes too long to recapture the CO_2 that is instantly released from burning. With global warming already upon us, we cannot afford to be relying on fuels that release more CO_2 than coal, then wait decades for nature to compensate. This is especially true in light of the need to avoid global warming tipping points (like the melting of ice sheets and arctic tundra) in the next 1-2 decades to avert catastrophic levels of warming. Studies have shown that it takes about 45-75 years of tree regrowth to just get the extra pulse of CO_2 down to the level where it's just as bad as coal burning. In that time lag, real CO2 molecules in the atmosphere are heating up the planet, pushing us toward more and more tipping points.

In 2010, the Commonwealth of Massachusetts commissioned the Manomet Center for Conservation Sciences to conduct the landmark study that showed this carbon debt, making biomass worse than coal for the climate over the first 45-75 years.[20,21] Even these shocking figures are conservative and likely underestimate the global warming impacts of biomass, meaning that it takes even longer for biomass to become equivalent to coal. This is due to several assumptions in the Manomet report, including that large trees are used for biomass (cutting smaller trees has a greater impact), that logged stands are not recut before they can fully take in the carbon they released, that a high portion of tree tops and limbs are burned, and that soil carbon emissions are negligible (they aren't).[22] Further studies have affirmed that parity with fossil fuels could take as much as 200-300 years.[23,24]

Of course, parity with fossil fuels is not carbon neutrality. It takes centuries to millennia to approach carbon neutrality, which is never truly reached – especially since trees are likely to be harvested again before such neutrality could be approached.[25] Since trees are likely to be harvested again before parity with fossil fuels can be reached, this negates any equivalence with fossil fuels, and making the carbon balance far worse than coal burning. From a strictly carbon-centric perspective, it makes more sense to burn coal and plant trees than to burn trees and plant trees. Of course, coal is dangerous for many other reasons, and this comparison should not be interpreted as an endorsement of any fossil fuels. There are clean alternatives to both, as are outlined later in this report.

Is burning biomass better than letting it rot?

No. Biomass proponents will sometimes argue that decaying biomass will release CO_2 and methane anyway, harming the climate, in order to justify not counting the emissions from biomass burning as anything additional to the status quo.

In fact, this depends a lot on the type of biomass and what would happen to it. However, it's hard to emit as much global warming pollution as biomass incineration does, or as quickly.

Most "biomass" burning is wood cut specifically to burn for energy, or "wood waste," which could mean anything from parts of trees that normally would be left in the forest, to wood pieces cut in lumber mills that don't become part of the product, to construction and demolition (C&D) wood waste or disaster debris.

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[19] Alessandro Agostini, Jacopo Giuntoli & Aikaterini Boulamanti, Luisa Marelli (ed.), "Carbon accounting of forest bioenergy – Conclusions and recommendations from a critical literature review," Joine Research Centre, European Commission, 2013 (Report EUR 25354 EN), pp.15-18. http://iet.jrc.ec.europa.eu/bf-ca/sites/bf-ca/files/files/documents/eur25354en_online-final.pdf

[20] Thomas Walker, et. al., "Biomass Sustainability and Carbon Policy Study," Manomet Center for Conservation Sciences Report to the Commonwealth of Massachusetts Department of Energy Resources, June 2010 (Report NCI-2010-03). http://www.manomet.org/sites/default/files/publications_and_tools/Manomet_Biomass_Report_Full_June2010.pdf

[21] Thomas Walker, "USDA Bioelectricity and GHG Workshop," Oral Presentation – "Manomet & Biomass: Moving Beyond the Soundbite," Washington, DC, November 15, 2010. Figures from Manomet study summarized in Table 1, p.12 ("Years to Achieve Equal Cumulative Flux with Fossil Fuels") in "Is Biopower Carbon Neutral?" by Kelsi Bracmort, Congressional Research Service, July 19, 2013 (Rept. No. report # R41603). http://www.fas.org/sgp/crs/misc/R41603.pdf

[22] Mary Booth, "Review of the Manomet Biomass Sustainability and Carbon Policy Study," Clean Air Task Force, July 2010. http://www.catf.us/resources/whitepapers/files/201007-Review_of_the_Manomet_Biomass_Sustainability_and_Carbon_Policy_Study.pdf

[23] Giuliana Zanchi, Naomi Pena & Neil Bird, "The Upfront Carbon Debt of Bioenergy," Joanneum Research, May 2010, p.2. http://www.birdlife.org/europe/pdfs/Bioenergy_Joanneum_Research.pdf

[24] Haberl, et. al., "Correcting a fundamental error in greenhouse gas accounting related to bioenergy," Energy Policy 45 (2012) 18-23, p.20. http://www.sciencedirect.com/science/article/pii/S0301421512001681

[25] Bjart Holtsmark, "The outcome is in the assumptions: analyzing the effects on atmospheric CO_2 levels of increased use of bioenergy from forest biomass," GCB Bioenergy (2012). http://onlinelibrary.wiley.com/doi/10.1111/gcbb.12015/abstract (full copy online at: http://www.maforests.org/Biomass%20Assumptions.pdf)

Proper carbon accounting[26] for forest biomass needs to recognize that trees left standing in a forest don't die and decompose instantly, but take 10-30 years for 90% of wood to decompose naturally once the tree eventually dies, or once logging waste is left behind.[27] In this process, much of the carbon ends up locked up in soils.[28,29] Not all of it ends up in the atmosphere where it can contribute to global warming. However, when a tree is burned, all of its carbon is instantly injected into the atmosphere.

Only waste that would end up in landfills poses a serious threat of generating major global warming pollution, because some of it forms methane when the organic waste breaks down in the absence of oxygen (anaerobically). Landfill gas – a combination of about half CO_2 and half methane – is released, and even the best gas capture systems still allow much of the gas to escape uncaptured. Captured gas usually ends up being burned, reducing nearly all of the methane to CO_2. However, the methane that does escape is a potent global warming pollutant, since it's now understood to be 105 times more powerful than CO_2 at heating the atmosphere, when measured over a 20-year time frame (about 33 times worse than CO_2 over a 100 year time-frame).[30] This landfill gas problem can be avoided by digesting organic waste before landfilling it, so that methane-generating potential is largely removed in a place where all of the methane can be captured.

The argument that biomass is better for the climate if burned than landfilled is not appropriate for two reasons. First, even in landfills, much of the carbon is not released into the atmosphere, but is sequestered long-term, as is recognized by EPA modeling.[31] This is true, even for organics that rapidly degrade, like grass clippings and food waste. Second, the types of things burned for biomass are not these wetter wastes that degrade fast, but dry material – either construction and demolition wood waste (which takes much longer to degrade) or things that are not landfilled, like poultry litter or clean wood.

The issue isn't "terrestrial" carbon, but atmospheric carbon

The biomass promoters who insist on the difference between "fossil carbon" and "biogenic carbon" make a big mistake when they assume two things: (1) that the atmosphere can tell the difference between a CO_2 molecule from a fossil fuel source compared to a biogenic source, and (2) that any "terrestrial" carbon adds to climate change regardless of whether it's in the air, or sequestered in plant matter or soils. What matters is whether the carbon is in the air or not. A global warming researcher said that assuming from the outset that biomass combustion is carbon neutral means that a forest would have the same carbon footprint whether it is standing or cut down.[32] More pointedly, biomass promoters will pretend that a standing forest has the same impact as one that has been cut and burned, as the carbon is still "terrestrial" (not below ground, like fossil fuels).

Carbon neutrality ignores CO_2 emissions from logging and transportation

Biomass power requires millions of gallons of diesel fuel for harvesting equipment and shipping. Harvesting and transporting one ton of wood chips requires about 1.8 gallons of diesel fuel, assuming a 30-35 mile average hauling distance.[33,34] A 50 MW plant requires about one million gallons of diesel per year for wood harvesting and transportation. This amount of diesel use would increase if hauling wood longer distances, which would be

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[26] Greenpeace Canada, "Fueling a BioMess," November 2011, p.18. http://www.greenpeace.org/canada/bioMESS/
[27] Mary Booth, "Comments from the Partnership for Policy Integrity to EPA on 'Deferral for CO2 Emissions from Bioenergy and Other Biogenic Sources under the Prevention of Significant Deterioration (PSD) and Title V Programs,' 76 Fed. Reg. 15,249 (March 21, 2011) DOCKET ID: EPA-HQ-OAR-2011-0083," May 5, 2011, pp.16-17. http://www.pfpi.net/wp-content/uploads/2011/05/PFPI-comments-EPA-HQ-OAR-2011-0083.pdf
[28] *Id.* at 7.
[29] Greenpeace Canada, "Fueling a BioMess," November 2011, p.18. http://www.greenpeace.org/canada/bioMESS/
[30] Drew T. Shindell, Greg Faluvegi, Dorothy M. Koch, Gavin A. Schmidt, Nadine Unger & Susanne E. Bauer, "Improved Attribution of Climate Forcing to Emissions," Science 326, 716 (2009). http://www.sciencemag.org/content/326/5953/716.full
[31] U.S. Environmental Protection Agency, "Landfill Carbon Storage in EPA's Waste Reduction Model, Oct. 27, 2010. http://epa.gov/epawaste/conserve/tools/warm/pdfs/landfill-carbon-storage-in-warm10-28-10.pdf
[32] Eric Johnson, "Goodbye to carbon neutral: Getting biomass footprints right," Environmental Impact Assessment Review, Vol. 29, No. 3 (2009), pp.165-168. http://www.sciencedirect.com/science/article/pii/S0195925508001637
[33] Innovative Natural Resource Solutions LLC, "Biomass Fuel Availability – North Springfield, Vermont," Sept 2011, p.32. http://psb.vermont.gov/sites/psb/files/orders/2012/2012-2/Exh.%20Pet.%20EWK-2.2.pdf
[34] 30-35 mile average hauling distance confirmed with Eric Kingsley, INRS Vice President, personal communication Jan 6, 2014.

necessary if supplying a larger plant, if the geography of wood supply is limited or if competition from other wood users requires going further for fuel. It's generally estimated that hauling beyond a 30-45 mile range is uneconomical, though hauling up to 100 miles is feasible if there is a backhaul (if haulers are paid to bring other materials in the opposite direction, so that they're not going back empty).[35,36,37,38] In western states like Oregon, transportation subsidies make greater hauling distances possible.

The use of fuels and electricity for operating machines and transportation vehicles requires energy equivalent to about 7–9% of the electric energy delivered from the biomass facility.[39]

Storage of wood chips can also be a major (and ignored) source of greenhouse gas emissions. Methane (105 times as potent as CO_2 over a 20 year time frame) can be emitted when wood piles heat up while decaying, and nitrous oxide (N_2O), which is 310 times as potent as CO2, is released when temperature falls and the decay process slows down.[40] These greenhouse gas emissions can be so significant that, in some cases, they are greater than the emissions from the rest of the biofuel production and transportation chain.[41] Methane emissions in wood pellet shipping have been high enough that they have sometimes reached explosive concentrations, found in one study to have led to an explosion and fatality.[42]

Carbon neutrality ignores significant CO_2 losses from soils after logging

About half of Earth's terrestrial (non-underground) carbon is stored in forests, of which approximately two-thirds is stored in soils. After logging takes place, an average of 8% of this soil carbon is lost.[43] Erosion, exposure of soils, and accelerated decomposition of roots and debris left after logging (branches, tops, and brush) contribute to these significant soil carbon losses.[44,45] A replanted clearcut actually gives off more CO_2 than it absorbs for as long as 20 years, despite the rapid growth rate of young trees. This is due to the fact that microbes in the forest soil, which release CO_2 as they break down dead branches and roots, work more quickly after a stand is logged.[46]

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[35] Salman Zafar, "How is Biomass Transported," BioEnergy Consult, December 23, 2013. http://www.bioenergyconsult.com/biomass-transportation/ "transportation distances beyond a 25–50 km [16-31 mi] radius (depending on local infrastructure) are uneconomical."
[36] Erin Searcy, Peter Flynn, Emad Ghafoori & Amit Kumar, "The Relative Cost of Biomass Energy Transport," Applied Biochemistry and Biotechnology, Vol. 136–140, 639-652, p.643. "Small" (50MW) biomass plant's average driving distance is 68 km (42.25 mi) for wood chips. http://wearemichigan.com/JobsAndEnergy/Biomass/Documents/The_relative_cost_of_biomass_energy_transport.pdf
[37] Forest Bioenergy, "Cost Factors in Harvesting and transporting Woody Biomass – Fact Sheet 4.7," Sustainable Forestry for Bioenergy and Bio-based Products, 2007, p.153. http://www.forestbioenergy.net/training-materials/fact-sheets/module-4-fact-sheets/fact-sheet-4-7-cost-factors-in-harvesting-woody-biomass/ "One hundred miles is generally considered a maximum haul distance in forest operations."
[38] Eric Kingsley, INRS Vice President, personal communication Jan 6, 2014. 100 mi is feasible if there is a backhaul.
[39] Göran Forsberg, Biomass energy transport: Analysis of bioenergy transport chains using life cycle inventory method. Biomass and Bioenergy , 2000. 19(1): p. 17-30. http://www.sciencedirect.com/science/article/pii/S0961953400000209
[40] Margareta Wihersaari, "Evaluation of greenhouse gas emission risks from storage of wood residue," Biomass and Bioenergy 28, 444–453, 2005. http://www.sciencedirect.com/science/article/pii/S0961953404002144
[41] *Id.*
[42] Svedberg, U., et al, "Hazardous off-gassing of carbon monoxide and oxygen depletion during ocean transportation of wood pellets," Annals of Occupational Hygiene, 52:259-266, 2008. http://annhyg.oxfordjournals.org/content/52/4/259.full.pdf
[43] Lucas E. Nave, Eric D. Vancec, Christopher W. Swanstond & Peter S. Curtisa, "Harvest impacts on soil carbon storage in temperate forests," Forest Ecology and Management, 259:857-866. http://www.sciencedirect.com/science/article/pii/S0378112709008780
[44] Lynne M. Zummo & Andrew J. Friedland, "Soil carbon release along a gradient of physical disturbance in a harvested northern hardwood forest," Forest Ecology and Management, 261(6): p. 1016-1026 (2011). http://www.sciencedirect.com/science/article/pii/S0378112710007255
[45] Mark E. Harmon, William K. Ferrell & Jerry F. Franklin, "Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests," Science, 247(4943), 1990, p.699. http://academic.evergreen.edu/curricular/ftts/downloadsw/harmonetal1990.pdf
[46] Center for Biological Diversity, "Comments on Timber Harvesting Plan: Swamped (4-08-020-CAL)," December 2008, pp.9-10. http://www.biologicaldiversity.org/programs/climate_law_institute/pdfs/Swamped_THP_Comments.pdf