DISCUSSION PAPER

April 2011 ■ RFF DP 11-15

Carbon Neutrality and Bioenergy

A Zero-Sum Game?

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RESOURCES FOR THE FUTURE

Carbon Neutrality and Bioenergy: A Zero-Sum Game?

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Abstract

Biomass, a renewable energy source, has been viewed as "carbon neutral"—that is, its use as energy is presumed not to release net carbon dioxide. However, this assumption of carbon neutrality has recently been challenged. In 2010 two letters were sent to the Congress by eminent scientists examining the merits—or demerits—of biomass for climate change mitigation. The first, from about 90 scientists (to Nancy Pelosi and Harry Reid, from W.H. Schlesinger et al. May 17, 2010), questioned the treatment of all biomass energy as carbon neutral, arguing that it could undermine legislative emissions reduction goals. The second letter, submitted by more than 100 forest scientists (to Barbara Boxer et al. from Bruce Lippke et al. July 20, 2010), expressed concern over equating biogenic carbon emissions with fossil fuel emissions, as is contemplated in the Environmental Protection Agency's Tailoring Rule. It argued that an approach focused on smokestack emissions, independent of the feedstocks, would encourage further fossil fuel energy production, to the long-term detriment of the atmosphere. This paper attempts to clarify and, to the extent possible, resolve these differences.

Key Words: carbon neutrality, biomass, wood biomass, bioenergy, carbon dioxide, feedstock, energy, alternative fuel, rational expectations

JEL Classification Numbers: Q2, Q23, Q4, Q42, Q5

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Introduction

An important question for policymakers seeking to mitigate global climate change is how carbon emissions of energy sources might be offset both now and in the long term. Although wind and solar offer renewable sources of energy for electrical power, only biofuels (fuels derived from wood or other plant material) are a ready alternative to fossil fuels (coal, oil, and natural gas) as a feedstock for liquid transportation fuels. Additionally, biomass and wood can provide an alternative feedstock for the generation of heat and electrical power. Biomass energy produces emissions and therefore is unlike other renewables, such as wind or solar. Nevertheless, many assessments (e.g., IPCC 2007) have treated biomass energy as carbon neutral, provided the biomass emissions are fully offset by subsequent biological growth. Recently, however, the assumption of biomass carbon neutrality has been challenged.

In 2010 two letters by eminent scientists were sent to the Congress.[1] The first letter (Schlesinger et al. 2009) noted that land converted from natural forest to bioenergy crops has the net effect of releasing otherwise sequestered carbon into the atmosphere, even if the carbon is subsequently sequestered. Thus, the timing of the conversion becomes an issue. The letter further observed that the “replacement of fossil fuels with bioenergy does not directly stop carbon dioxide emissions from tailpipes or smokestacks.” The letter was influenced by the Searchinger et al. (2009) and Farigione et al. (2008) studies in Science, which stressed the relevance of the timing of carbon emissions, and by the Manomet (2010) study, which determined that over the relatively short time periods under examination, the substitution of wood biomass for fossil fuels for producing electrical power would increase net emissions of carbon dioxide.

The second letter to the Congress, from forest scientists (Lippke et al. 2010), expressed concern over equating biogenic carbon emissions with fossil fuel emissions, as contemplated in the Environmental Protection Agency’s Tailoring Rule. These scientists argued that an approach focused on smokestack emissions, independent of their feedstocks, would encourage further

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[1] See appendix.

fossil fuel energy production and increase atmospheric concentrations of greenhouse gases. This second letter notes that although the issue appears to center on biomass carbon neutrality—whether carbon emissions from biomass are automatically offset by carbon sequestration in vegetative growth—the issue is more complex. For example, biomass carbon releases are different from those of fossil fuels not only in magnitude but also in that biomass burning does not release net additional amounts of carbon into the biosphere. By contrast, burning fossil fuels, which hold carbon captive, does release net, permanent, additional amounts of carbon.

Background

The modern world's traditional energy sources, fossil fuels, appear to be becoming increasingly scarce in some areas even as they continue to contribute greenhouse gases, a major source of global warming, to the atmosphere. The general remedial approach has been to find alternative energy sources, largely renewable, to replace fossil fuels. Biomass has been offered as one of several renewable energy resources to substitute for fossil fuels, both to enhance U.S. energy security and to reduce carbon emissions. One source of biomass is wood. Both biomass and fossil fuels store large amounts of carbon. When burned, both energy sources release carbon into the biosphere—the whole area of Earth's surface, including biological materials, the atmosphere, and the seas, that is inhabited by living things. The issue raised by both groups of scientists is the likely effect on the climate produced through atmospheric carbon levels of wood biomass energy, in both the short and the long term.

If limitations in wood biomass energy force society to use more fossil fuels, the associated emissions are irreversible, in that they cannot be returned to their fossil fuel source. Of course, in the short run the carbon emissions can be captured in biomaterials and vegetation, but only with the effect of reducing the opportunities for future capture, since the world's carbon sequestration potential is presumably limited. In contrast, at any future point in time carbon dioxide in the biosphere will be lower if wood biomass is allowed to substitute for fossil fuels.

The Manomet study, commissioned by the State of Massachusetts, brought the carbon neutrality issue to a head. In its accounting examination it traced the net flow of emissions from burning biomass for energy and the carbon sequestration associated with subsequent biological growth under a business-as-usual assumption. It looked at the net changes in greenhouse gas levels, essentially carbon, in the atmosphere. Starting with harvesting and use of the wood for energy, the study showed a large release of carbon at an early time, period one, and then the gradual sequestration of the equivalent carbon through time to its complete sequestration at some distant future point. Since the emissions associated with a unit of energy production are larger for biomass than for any fossil fuel, including coal, the initial release from biomass is greater than that of a fossil fuel. The remainder of the analysis involved tracing the long time over which the forest is regenerated and gradually sequesters emissions equivalent to those it released in period one.

Issues

A number of issues should be clarified. First, both letters recognize that some biomass, such as dead wood and forest debris, can constructively be used for bioenergy, since it will otherwise release carbon through natural decomposition on the forest floor; thus no net emissions result from its use as energy. Similarly, agriculture waste that would normally decompose can be used for fuel without net emissions effects. Thus, a careful systems management approach can reduce net carbon releases by increasing the biomass in anticipation of its energy use and/or by using otherwise waste wood and biomass as a substitute for fossil fuel energy.

Second, the release of carbon from fossil fuels is an irreversible flow that permanently adds to the total amount in the biosphere. For biomass, by contrast, the amount of carbon in the biosphere does not change (although that in the atmosphere may have over some period). Only the form changes as carbon captured in biomass is released into the atmosphere and then recaptured in biomass. That is, the release of fossil fuel emissions is, in principle, irreversible, whereas biomass emissions can be returned to biomass. As the forest scientists' letter notes, carbon dioxide released from the combustion of wood biomass is part of the global cycle of biogenic carbon and "does not increase the amount of carbon in circulation" in the biosphere, as do fossil fuel emissions.

This lack of equivalence is not without consequence: although short-term emissions, whether from biomass or fossil fuels, accumulate in the atmosphere and contribute to global warming, the long-term implications of fossil fuel emissions for the biosphere are a lasting change in total biosphere carbon. Also, the very nature of a short-term emissions approach does not lend itself to life-cycle analysis. However, comprehensive life-cycle analyses have suggested the environmental superiority of the longer-term approach to carbon management (Zhang et al. 2009).

Third, carbon may be sequestered in anticipation of the expected future use of wood biofuel energy. Because of trees' longevity, the planting of forests necessarily involves the anticipation of future use. Planting trees to meet future bioenergy requirements involves the establishment of the biomass and the embodied sequestered carbon in advance of its actual use.

Thus, some associated carbon sequestration will offset at least some portion of the carbon releases, even before the actual biomass is burned.

An Additional Approach: Rational Expectations

Early intertemporal analysis ignored expectations of future in the management decisions, instead basing its behavioral assumptions on past experience, as noted by Muth (1992). To address this issue, Takayama and Judge (1971) developed spatial and temporal price and allocation models that built future expectations explicitly into prior management decisions. This "rational expectations" approach defines future expectations as the *best guess of the future* (the optimal forecast), using all available information. Forestry, by its nature, involves many intertemporal decisions that take place over many decades. Thus, it is an ideal sector in which to apply a rational expectations approach using dynamic optimization. The "forward-looking" approach is used in forestry projections models (e.g., Sedjo and Lyon 1990; Sohngen et al. 1999) and in the FASOM model (e.g., Burton et al. 1994, Alig et al. 1997).

In a dynamic optimization approach, the entire intertemporal system is solved simultaneously, with the specified future conditions directly affecting current decisions. Although individual expectations may turn out to be incorrect, they should not deviate systematically from the expected values. The approach assumes only that individual decisions are correct *on average*. This approach contrasts with earlier modeling techniques in forestry, where the current-period decision was based entirely on current conditions, thus not allowing future expectations to directly inform the current decision (e.g., Adams and Haynes 1980).

The use of a forward-looking perspective dramatically changes calculations of the carbon footprint associated with biomass energy. If trees are planted in anticipation of their *future* use for biofuels, then the carbon released upon the burning of the wood was previously sequestered in the earlier biological growth process. From a broad forest system perspective, the biomass burning does not release new carbon but simply releases previously sequestered carbon that was captured in an earlier period in anticipation of future biomass burning.

The analysis of the Manomet study and the letter that it inspired essentially assumes that the expected increased use of biomass for energy will not stimulate changes in forest management prior to the harvest for bioenergy. However, forest investment decisions in recent decades have involved substantial consideration and expectations of future market conditions. For example, the rapid establishment of plantation forests in the United States after the 1970s is associated with expectations and concerns about future timber availability. One result has been that U.S. wood supply has been more than adequate to offset the reduction in federal harvests from national forests that began in the late 1980s (Sedjo et al. 1994).

Other Considerations

The growth of a forest is not constant. Although young trees grow rapidly and hence sequester substantial carbon, mature forests experience little net growth and therefore sequester little additional carbon. Mature forests are typically not harvested for biomass energy because of their more valuable use in forest products. Thus, most wood biomass is likely to come from wood residues from industrial forestry and from young, low-value pulpwood. Dead wood and debris, which typically decomposes in the forest, releasing carbon to the atmosphere, can also constructively be used for energy. Thus, a careful systems management approach can generate near-term offsets to carbon releases by using otherwise waste wood to reduce fossil fuel emissions and by “promoting” low sequestration sites to higher levels of sequestration, thereby providing for a carbon-neutral utilization of biomass energy in the near term as well as over time.[2]

A forest *system* also behaves differently from a site. In the United States, for example, large landscapes are managed as forest systems. Management activities in one place are related to activities elsewhere in the system, beyond the specific site. For example, a steady flow of wood may not be possible in sufficient volumes from an individual site but can be achieved from a system. The same could be true for carbon emissions, where sequestration on one site offsets emissions from another. Although the Manomet study purported to treat the Massachusetts forest as a system, in fact it did not. Rather, each site was treated as an independent, stand-alone forest, with biomass drawn from one site not influencing the harvests or management that was occurring on the other sites. This formulation assumed that no net changes in the stock of carbon accumulating elsewhere in the system were being induced by the use of wood from one site for biomass. This assumption thus precludes any systemwide adjustments that may offset carbon

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[2] For many forests the forest volume (and carbon content) follows a logistic growth path, increasing slowly at first, accelerating through a phase as it reaches a peak growth rate, after which the growth rate gradually declines as total volume and carbon move to a constant, stable level. Drawing biomass from the stable and slow-growing sites while promoting more rapid growth elsewhere provides management opportunities for offsetting more biomass energy emissions.

releases on a specific site. The relevant unit of analysis for Manomet became the independent sites, not the integrated forest system.[3]

We know that today in the United States, more carbon is absorbed into the forest system than is being released by biomass energy. The optimum use involves conditions at the margin. Simply put, if the marginal increase in the forest system's carbon stock (including products) is equal to or greater than the marginal addition of carbon to the atmosphere from the biomass energy releases, then the system is contributing to reducing carbon in the atmosphere. Such a condition is occurring today, and there is no reason to presume that these circumstances will not continue to be met for a considerable period of time.

In summary, forest biomass can contribute to reducing carbon emission in two ways: (1) by sequestering carbon and (2) by substituting for fossil fuels. Although the benefits of substituting biomass energy for fossil fuels are not realized for a given site in the short term, the benefits may apply for the overall system. This is particularly true if anticipatory planting and/or management are being undertaken. Over the longer term, however, fossil fuel emissions will undoubtedly add to the total stock of permanent carbon in the biosphere—both in the atmosphere and in biomass—whereas biomass energy will merely involve recycling carbon within the components of the biosphere.

Conclusions

Although similar in many aspects, carbon emissions from biomass are different from those of fossil fuels in at least one respect: emissions from biomass to the biosphere are reversible whereas those from fossil fuel sources are not. Thus, biomass carbon can be a zero-sum game—in the long run—while fossil fuel carbon cannot. Biomass emissions may contribute to atmospheric carbon for many short-run situations, and in fact, a static accounting assessment, such as was done by Manomet, reveals that biomass, including wood, releases more carbon per unit of energy than natural gas. However, the idea that bioenergy emissions will necessarily increase atmospheric carbon is not valid so long as, over time, complete regrowth is allowed and

[3] In the United States, the total net stock of carbon sequestered in forest biomass has continued to rise for nearly a century, reflecting the continuing expansion of the stock of the total U.S. forest system (Smith 2007). This increase is occurring despite continued harvest for forest products and bioenergy and large losses due to infestation and fire. Also, there are net increases in the carbon captured in long-lived forest products.

the carbon can be recaptured and returned to the biosphere. By contrast, carbon released from fossil fuels cannot be recaptured in fossil fuels.

The Manomet study assumed no tree planting or forest management in anticipation of the increased future use of wood for biofuel, even though forest investments usually precede wood utilization. In forestry, trees are planted decades before their anticipated use, and today's economic models regularly incorporate expectations of future behavior into their structure. Dynamic optimization models are commonly used in economics and particularly in intertemporal forest models. Where anticipatory behavior occurs, planting and forest management precede utilization, and therefore substantial amounts of carbon are sequestered before being released during actual biomass energy utilization. An approach that does not recognize this behavior, such as the Manomet study, will fail to account for this important adjustment mechanism.[4]

Two points emerge from this paper. First, the short- and long-term carbon footprint of biomass emissions on the biosphere will likely be different. Second, if management is anticipatory, net biomass growth and carbon sequestration will precede the actual increased use of biomass for energy, and a static estimate of carbon emissions will overestimate the actual net emissions associated with the use of biomass for energy. This would be true even in the short run.

Global warming is a long-term challenge to humanity. Even if policymakers look for short-run approaches, long-term sustainable solutions will undoubtedly be required. The contest is a marathon, not a sprint. Lowering carbon emissions from energy production by 2020, in itself, does not address the fundamental problem of reducing net emissions over the centuries. There is no silver bullet for climate change: we need all the tools we can bring to bear. Forests and biomass energy, correctly utilized, can contribute significantly to reducing net carbon emissions and do much to assist in addressing the fundamental problem.

[4] The Manomet study's contractual directives and the nature of the relatively small forest the scientists were assessing appear to have precluded the use of an anticipatory approach to the managed of the forest.

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Appendix: Letters to Congress

See following pages.

May 17, 2010

The Honorable Nancy Pelosi
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Fax: (202)225-4188

The Honorable Harry Reid
Majority Leader
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Dear Speaker Pelosi and Majority Leader Senator Reid,

We write to bring to your attention the importance of accurately accounting for carbon dioxide emissions from bioenergy in any law or regulation designed to reduce greenhouse gas emissions from energy use. Proper accounting can enable bioenergy to contribute to greenhouse gas reductions; improper accounting can lead to increases in greenhouse gas emissions both domestically and internationally.

Replacement of fossil fuels with bioenergy does not directly stop carbon dioxide emissions from tailpipes or smokestacks. Although fossil fuel emissions are reduced or eliminated, the combustion of biomass replaces fossil emissions with its own emissions (which may even be higher per unit of energy because of the lower energy to carbon ratio of biomass). Bioenergy can reduce atmospheric carbon dioxide if land and plants are managed to take up additional carbon dioxide beyond what they would absorb without bioenergy. Alternatively, bioenergy can use some vegetative residues that would otherwise decompose and release carbon to the atmosphere rapidly. Whether land and plants sequester additional carbon to offset emissions from burning the biomass depends on changes both in the rates of plant growth and in the carbon storage in plants and soils. For example, planting fast-growing energy crops on otherwise unproductive land leads to additional carbon absorption by plants that offsets emissions from their use for energy without displacing carbon storage in plants and soils. On the other hand, 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[1].

Many international treaties and domestic laws and bills account for bioenergy incorrectly by treating all bioenergy as causing a 100% reduction in emissions regardless of the source of the biomass. They perpetuate this error by exempting carbon dioxide from bioenergy from national emissions limits or from domestic requirements to hold allowances for energy emissions. Most renewable energy standards for electric utilities have the same effect because bioenergy is viewed as a renewable energy even when the biomass does not eliminate or even reduce greenhouse gas emissions. This general approach

[1] J. Fargione, J. Hill, Tilman D., Polasky S., Hawthorne P (2008), Land Clearing and the Biofuel Carbon Debt, *Science* 319:1235-1238

appears to be based on a misunderstanding of IPCC guidance[2]. Under some scenarios, this approach could eliminate most of the expected greenhouse gas reductions during the next several decades.

U.S. laws will also influence world treatment of bioenergy. A number of studies in distinguished journals have estimated that globally improper accounting of bioenergy could lead to large-scale clearing of the world's forests[3].

The lesson is that any legal measure to reduce greenhouse gas emissions must include a system to differentiate emissions from bioenergy based on the source of the biomass. The National Academy of Sciences has estimated significant potential energy production from the right sources of biomass[4]. Proper accounting will provide incentives for these sources of bioenergy.

Sincerely,

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Cc: Carol Browner, White House Office of Energy and Climate Change Policy
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July 20, 2010

The Honorable Barbara Boxer
Senate Environment and Public Works Committee
Washington, DC

The Honorable James Inhofe
Senate Environment and Public Works Committee
Washington, DC

The Honorable Jeff Bingaman
Senate Energy & Natural Resources Committee
Washington, DC

The Honorable Lisa Murkowski
Senate Energy & Natural Resources Committee
Washington, DC

The Honorable Blanche Lincoln
Senate Agriculture Committee
Washington, DC

The Honorable Saxby Chambliss
Senate Agriculture Committee
Washington, DC

Dear Chairmen Boxer, Bingaman, and Lincoln and Ranking Members Inhofe, Murkowski, and Chambliss:

We write to express our concern that equating biogenic carbon emissions with fossil fuel emissions, such as contemplated in the EPA Tailoring Rule and other policies, is not consistent with good science and, if not corrected, could stop the development of new emission reducing biomass energy facilities. It could also encourage existing biomass energy facilities to convert to fossil fuels or cease producing renewable energy. This is counter to our country's renewable energy and climate mitigation goals.

The carbon dioxide released from the combustion or decay of woody biomass is part of the global cycle of biogenic carbon and does not increase the amount of carbon in circulation. In contrast, carbon dioxide released from fossil fuels increases the amount of carbon in the cycle.

The EPA's final Tailoring Rule defines what stationary sources will be subject to greenhouse gas (GHG) emission controls and regulations during a phase-in process beginning on January 2, 2011. In the draft Tailoring Rule, the EPA proposed to calculate GHG emissions relying on the EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks. In the final rule, EPA ignored its own inventory methods and equated biogenic GHG emissions with fossil fuel emissions, which is incorrect and will impede the development of renewable biomass energy sources.

The carbon released from fossil fuels has been long separated from the global carbon cycle and adds to the total amount of carbon in active circulation between the atmosphere and biosphere. In contrast, the CO_2 released from burning woody biomass was absorbed as part of the "biogenic" carbon cycle where plants absorb CO_2 as they grow (through photosynthesis), and release carbon dioxide as they decay or are burned. This cycle releases no new carbon dioxide into the atmosphere, which is why it is termed "carbon neutral". It is unrelated to the GHG emissions produced from extracting and burning fossil fuels, except insofar as it can be used to offset or avoid the introduction of new carbon dioxide into the atmosphere from fossil fuel sources. Biogenic GHG emissions will occur through tree mortality and decay whether or not the biomass is used as an energy source. Some regions of the United States have rampant wildfires contributing pulses of greenhouse gases to the atmosphere. Capturing the energy value of these materials thereby offsetting fossil fuel emissions generates a net effect from burning biomass that is better than carbon neutral.

In terms of their greenhouse gas properties, there is no difference between biogenic and fossil fuel carbon dioxide. The difference derives from where the carbon was sourced. Burning fossil fuels that are mined from millennia-old deposits of carbon produces an addition to carbon in the atmosphere, whereas burning woody biomass recycles renewable plant growth in a sustainable carbon equilibrium producing carbon neutral energy. Fossil fuels also produce other greenhouse gases and pollutants with more negative environmental impacts than woody biomass.

Though biogenic carbon is part of the natural carbon cycle, to be considered "absolutely carbon neutral" in the short term, biomass must be re-grown at the same rate it is consumed. Because forests and trees are changing constantly, this does not happen everywhere at once. For example, the current bark beetle epidemic in the western United States has killed 17 million acres of forests. This will result in an unavoidable 'pulse' of carbon dioxide over several years and decades unless that material is used for products or energy that can offset the emissions from fossil fuels. Humans can mitigate some natural disturbances, but cannot stop them. As a result, the only way to ensure biomass is being replaced at the rate its removed is through sustainable forest management. The regeneration of the forest along with setting the volume of removals to be no greater than new growth less mortality results in stable levels of carbon in the forest and sustainable removals as a carbon neutral source for energy or other products.

While avoiding deforestation is important in developing countries and is of some concern around urban growth areas in the United States, reforestation, certification systems and programs promoting sustainable management of our working forests have resulted in forest increases exceeding losses. Currently, there are 750 million acres of forest land in the United States and this number is largely stable even as some forest land has been converted for development.[1] Forest growth nationally has exceeded harvest resulting in the average standing volume of wood per acre nation-wide increasing about 50% since 1952; in the eastern United States, average volume per acre has almost doubled. In the southeast, net volume of all trees increased 12% from 1997 to 2007 and forests are reforested and growing well.[2]

Forests are our nation's primary source of renewable materials and second largest source of renewable energy after hydropower. Sustainable development of new and traditional uses of our forests helps reduce GHG emissions[3] and has the important benefit of providing economic incentives for keeping lands in forests and reducing the motivation for land conversion.

A consortium of research institutions has, over the last decade, developed life cycle measures of all inputs and all outputs associated with the ways that we use wood: a thorough environmental footprint of not just managing the forest, but harvesting, transportation, producing products or biofuels, buildings or other products, maintenance and their ultimate disposal.[4] Results of this research are clear. When looking across the carbon life cycle, biomass burning does produce some fossil fuel emissions from harvesting, transportation, feedstock preparation and processing. These impacts, however, are substantially more than offset by eliminating the emissions from using a fossil fuel. Sustainable removals of biomass feedstocks used for energy produce a reduction in carbon emissions year after year through a reduction in fossil fuel emissions far greater than all of the emissions from feedstock collection and processing. When wood removals are used to produce both renewable materials as well as bio-energy, the carbon stored in forest products continues to grow year after year, more than off-setting any processing emissions while at the same time permanently substituting for fossil fuel intensive materials displacing their emissions.

Finally, biomass power facilities generally contribute to a reduction of greenhouse gases beyond just the displacement of fossil fuels. The use of forest fuels in a modern boiler also eliminates the methane (CH_4) emissions from incomplete oxidation following open burning, land filling, or decomposition which occurs in the absence of a higher and better use for this material. Methane is a 25 times more powerful greenhouse gas than CO_2. In contrast, the mining of coal and exploration for oil and gas release significant amounts of methane and other harmful pollutants into the environment. Any modeling to examine the impact of carbon-based fuel sources must account for all of these impacts.

We thank you for the opportunity to share our concern with the EPA's Tailoring Rule and other pending policies.

Sincerely,

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[1] Mila Alvarez, The State of America's Forests (2007), 5.
[2]Smith, W.B., P.D. Miles, C.H. Perry and S.A. Pugh. 2009. Forest Resources of the United States, 2007. General Technical Report WO-78. U.S. Department of Agriculture, Forest Service. Washington, DC.
[3] CORRIM, "Maximizing Forest Contributions to Carbon Mitigation: The Science of Life Cycle Analysis – a Summary of CORRIM's Research Findings." CORRIM Fact Sheets #5, #6, #7 (2009).
[4] IPCC Fourth Assessment Report: Climate Change 2007. Working Group III: Mitigation of Climate Change. Chapter 9. Forestry

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