Synthesis of Net Carbon Impacts of Biomass Energy Development in the Northern Forest

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Completion date: March 2020

- Northern forests are projected to generate a net sequestration of an average of 4.2 metric tons of CO_2e per hectare per year over the next 50 years under current harvest regimes - a business as usual baseline (BAU). This term includes storage in wood products and displacement of fossil fuel emissions from biomass energy.
- Increasing the proportion of the BAU harvest used as a bioenergy feedstock leads to a slightly higher (4.4 mt/ha/yr) net sequestration. But scenarios that increase harvest rates above current levels produce net carbon sequestration that is marginally lower (maximum of 4.1 metric tons CO_2e per hectare per year) over the same time period.
- Neither the BAU scenario nor any of the more intensive harvest scenarios resulted in net carbon sequestration that exceeded a "no harvest" scenario within the 140 year period of our analyses.
- Net carbon impact "parity points" - at which the cumulative net carbon sequestration from alternate harvest regimes with more intensive feedstock production exceed the business as usual baseline - range from 27 to 76 years.
- It is important to emphasize, however, that all of the scenarios result in significant positive net carbon sequestration every year by northern forests for the next 100 years.

Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service.
http://www.nsrcforest.org

Project Summary

One of the principal motivations for the development of biomass energy in the Northern Forest has been the assumption that its use would replace fossil fuel use with a feedstock that was either carbon neutral or with significantly lower net release of carbon to the atmosphere ("net carbon impact") per unit of energy produced than from fossil fuels. That assumption has been widely debated in both the scientific literature and public media outlets.

Establishing a credible "business as usual" (BAU) baseline for forest dynamics, harvest rates, and the fate of forest products, including displacement of fossil fuel emissions through use of biomass energy, is the first and most important step in assessing net carbon impacts of biomass energy development in the northern forest. We have linked state-of-the-art models for northern forest dynamics (SORTIE-ND) and greenhouse gas assessment (ForGATE) to examine the net carbon impact of a suite of scenarios of biomass energy production in northern forests.

Forests in the 4-state region are projected to sequester an average of 4.2 metric tons of CO_2e per hectare per year over the next 50 years under the business as usual (BAU) baseline. Scenarios that increase harvest rates and the proportion of harvests diverted to bioenergy feedstocks result in net carbon sequestration that is marginally lower (maximum of 4.1 metric tons CO_2e per hectare per year) over the same time period. Net carbon impact "parity points" – the time before cumulative net carbon sequestration from alternate harvest regimes with more intensive feedstock production exceed the business as usual baseline - range from 27 to 76 years. However it is important to emphasize that all of the scenarios result in significant positive net carbon sequestration (including fossil fuel emission displacement) every year for the next 100 years.

There are 18.4 million hectares of forest land in the 4-state region. Under our most intensive biomass feedstock scenario, and assuming a 50% efficiency in displacement of fossil fuel emissions, the combination of carbon sequestration in forests and forest products and forest biomass energy production would displace 9.3% of the region's current fossil fuel CO_2e emissions.

Background and Justification

- Proposals and policies designed to increase biomass energy production from northern forests have been controversial, with often wildly different claims about the potential climate mitigation effects of biomass energy.

- Much of the research on this issue has focused on the very different working forest landscapes and markets for biomass energy feedstocks in the southeastern U.S.

- There is a critical need for northern-forest-specific analyses that take into account the very different nature of the northern forest and its management.

- Assessment of the net carbon impacts of forest biomass energy require a holistic and quantitative analysis that can project the consequences of different proposals and policies for:
  1. Changes in carbon in stocks of live and dead biomass within forests, averaged across the entire northern forest landscape
  2. Changes in stocks of carbon stored in forest products and landfills
  3. Emissions of carbon in the form of CO_2 and methane from decomposition in forests and landfills, and
  4. Emissions of CO2 from forest biomass energy production, balanced against potential displacement of fossil fuel emissions required to produce equivalent energy.

Methods

- Establishing a credible "business as usual" baseline for forest dynamics, harvest rates, and the fate of forest products, including displacement of fossil fuel emissions through use of biomass energy, **is the first and most important step** in assessing net carbon impacts of biomass energy development in the northern forest.

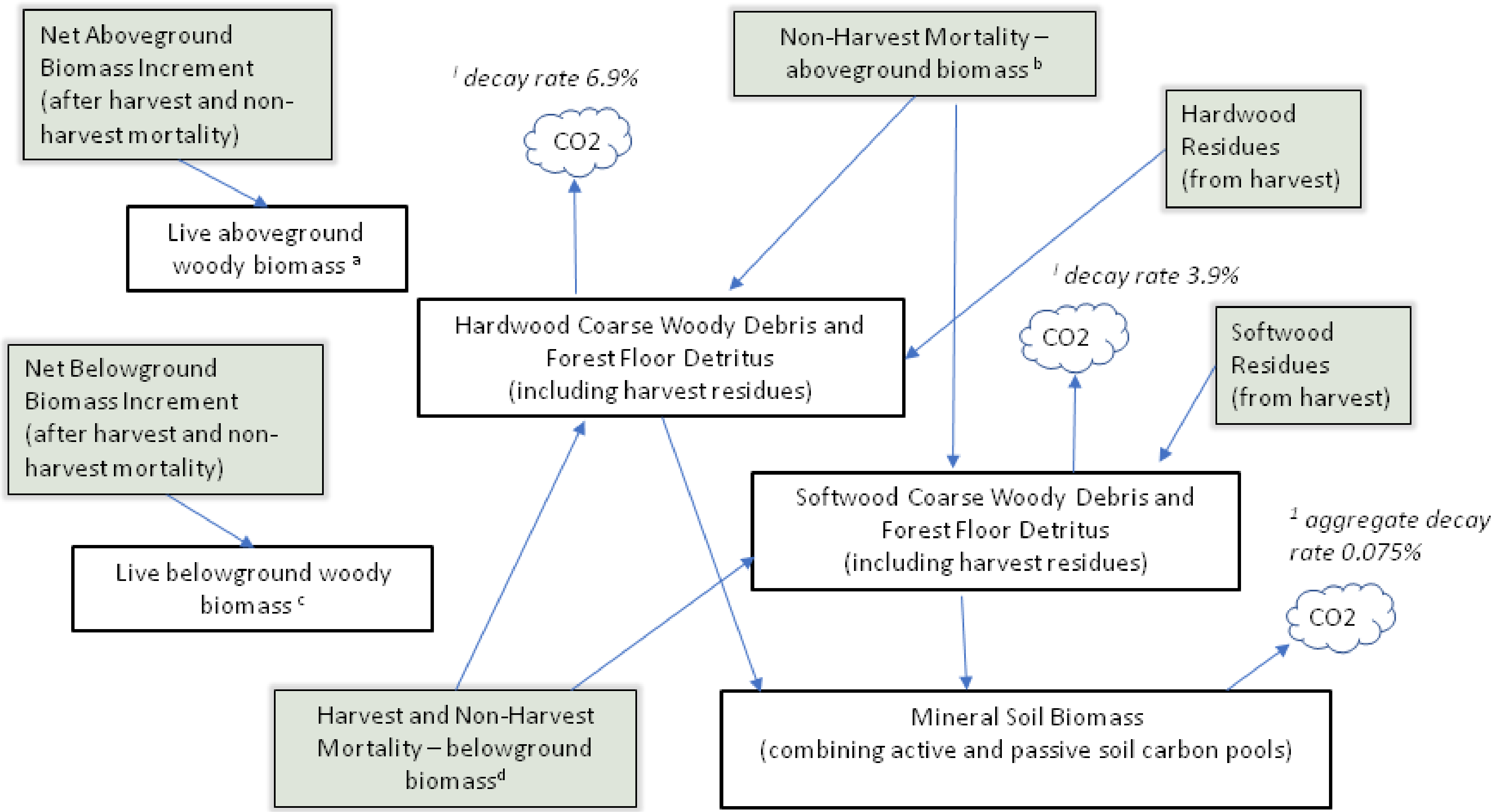
- Our analysis of future forest dynamics in the 4-state region makes use of a state-of-the-art model of forest dynamics (SORTIE-ND) parameterized from thorough analyses of FIA data[1]
  - The model includes an empirical statistical model that predicts the probability of harvest, the fraction of biomass removed if harvested, and the species and sizes of trees removed in the harvest
  - The model tracks forest carbon stocks in 5 key pools: aboveground live woody biomass, belowground live woody biomass, hardwood detritus and coarse woody debris, softwood detritus and coarse woody debris, and mineral soil carbon

- Our analysis of the fate of harvested biomass is based on the ForGATE model for greenhouse gas assessment[2]
  - Our adaptation of the model tracks the flow of hardwood and softwood sawlogs, pulpwood, and residues through different products and long-term forest product pools, as well as diversion for use as bioenergy feedstocks.

[1] Results of the forest modeling are reported in Brown et al. (2018) (see references)

[2] The ForGATE model is described in Hennigar et al. (2013)

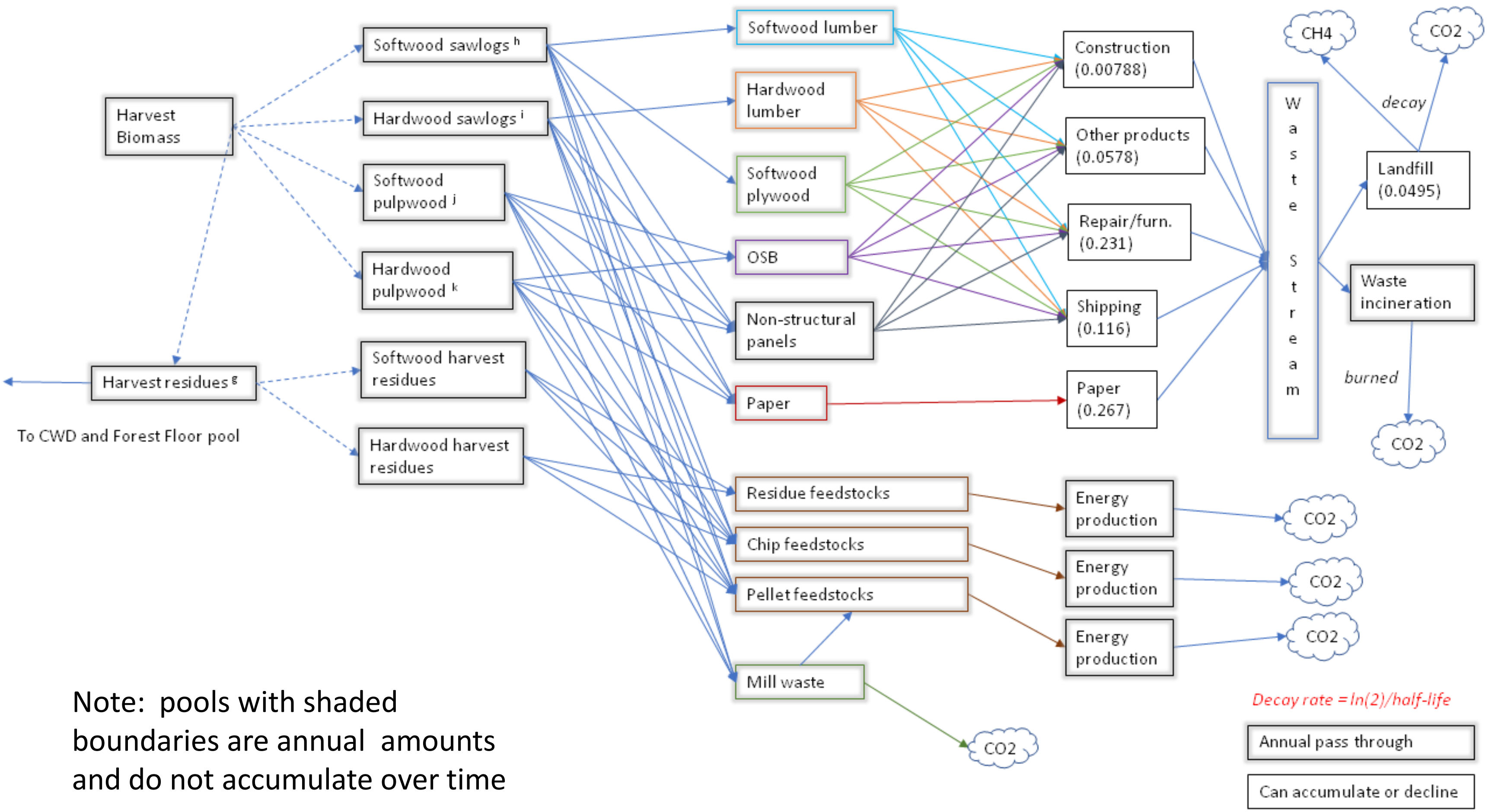
SORTIE-ND: Forest Biomass Pools and Fluxes



[l] Annual decay rates from Russell et al. (2014) and Tonitto et al. (2014)

Note: pools in shaded boxes are annual fluxes and do not accumulate

Carbon ForGATE – Harvest, Forest Product, and Feedstock Pools and Fluxes



Note: pools with shaded boundaries are annual amounts and do not accumulate over time

Harvest Regimes and Bioenergy Feedstock Scenarios Examined

- The baseline harvest regime (**Run 1**) was estimated empirically from FIA data for the 4-state region – the probability of harvest in a stand and the fraction of basal area removed if harvested vary as a function of:
  - Forest type (spruce/fir, aspen/birch, northern hardwood, oak/hickory)
  - Region (Maine vs. the other 3 states for northern hardwood forests)
  - Distance from the nearest improved road

- We examined 4 alternates, including a “no-harvest” regime (**Run 0**). The other three alternatives increased either harvest frequency or intensity or both
  - **Run 2**: a 50% increase in the average fraction of basal area removed
  - **Run 4**: a 75% increase in the probability that a stand was harvested
  - **Run 5**: a 50% increase in fraction of basal area removed and a doubling of the probability that a stand was harvested

- There were 3 different **scenarios** of biomass feedstock production:
  - **Scenario 0:** no bioenergy feedstock except mill waste
  - **Scenario 1**: 5% of sawlogs, 20% of pulpwood and 25% of harvest residues used as feedstocks (in addition to mill waste) [*this was considered the business as usual case*]
  - **Scenario 2**: 20% of sawlogs, 80% of pulpwood, and 50% of harvest residues used as bioenergy feedstocks – this was designed as an aggressive feedstock production regime

  - The biomass was evenly divided among “residue”, “chip” and “pellet” feedstocks

Definition of “Net Carbon Impact”

Our assessment of the effects of a given scenario on fluxes of carbon to and from the atmosphere from northern forests **has three main components**

- **Emissions** of carbon (in units of metric tons of CO_2 equivalents per hectare of forest) to the atmosphere from:
  - Decomposition of detrital pools of carbon within forests (including coarse woody debris, the forest floor, and mineral soil pools)
  - Decomposition of forest products that end up in landfills and combustion of forest products in waste incinerators
  - Carbon emissions from combustion of forest biomass feedstocks for energy production
- **Sequestration** of carbon (in units of CO_2 equivalents per hectare of forest) in:
  - Net increases in the 5 forest carbon pools (live woody aboveground biomass, live woody belowground biomass, and the 3 detrital pools of carbon)
  - Net increases in carbon stored in the 5 forest product pools tracked in ForGATE plus carbon from forest products in landfills
- **Displacement** of fossil fuel CO2e emissions by the energy produced from forest biomass energy

Thus: Net Carbon Impact = Sequestration + Displacement – Emissions

When NCI is positive, we refer to this as “Net Carbon Sequestration” (i.e. sequestration plus displacement, net of emissions).

Summary of Results

- Forests in the 4-state region are projected to sequester an average of **4.2 metric tons of CO_2e per hectare per year over the next 50 years** under a business as usual (BAU) baseline (i.e. starting with the current mix of forests across the region, with the current harvest regimes by forest type, and the current modest production of bioenergy). This term includes storage in forest products, and the effective displacement of fossil fuel emissions from biomass energy.

- **Increasing the proportion of the BAU harvest used as a bioenergy feedstock** leads to a slightly higher (**4.4** mt/ha/yr) net sequestration. But scenarios that increase harvest rates above current levels produce net carbon sequestration that is marginally lower, with a maximum of **4.1** metric tons CO_2e per hectare per year over the same time period.

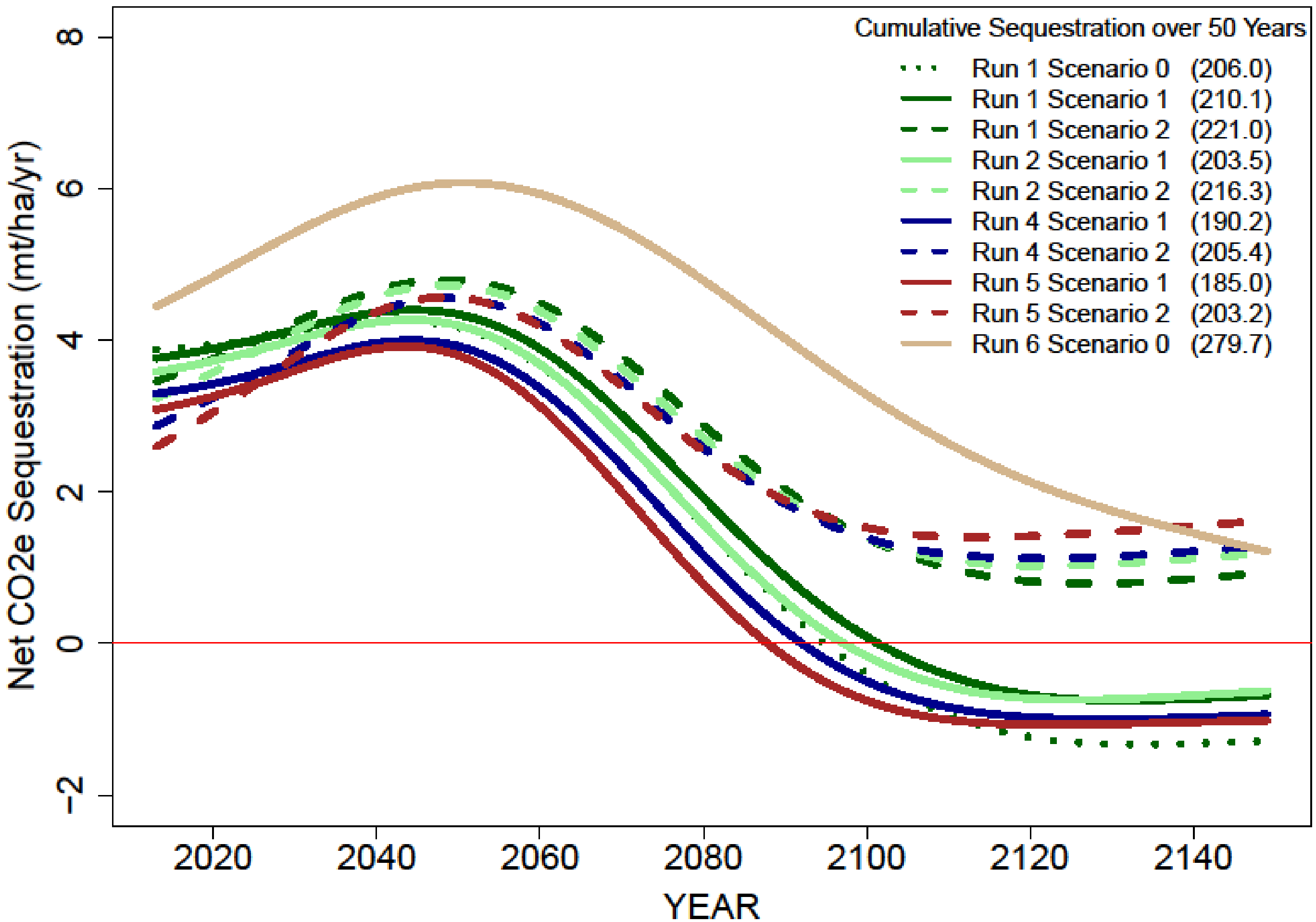
- Neither the BAU scenario nor any of the more intensive harvest scenarios resulted in net carbon sequestration that exceeded a **"no harvest"** scenario (**5.6** mt/ha/yr over the next 50 years). This was true throughout the 140 year period of our analyses.

- **Net carbon impact "parity points"** - at which the cumulative net carbon sequestration from alternate harvest regimes with more intensive feedstock production exceed the business as usual baseline - **range from 27 to 76 years**.

- It is important to emphasize, however, that **all of the scenarios** result in significant positive net carbon sequestration (including fossil fuel emission displacement) every year for the next 100 years.

- There are **18.36 million hectares of forest land** in the 4-state region. Under our most intensive biomass feedstock scenario (Run 5, Scenario 2), and assuming a 50% efficiency in displacement of fossil fuel emissions, the combination of carbon sequestration in forests and forest products and forest biomass energy production **would displace 9.3% of our current fossil fuel CO_2e emissions.**

Net annual sequestration under the different harvest regimes and feedstock scenarios



Note: Assumes 50% efficiency of displacement of fossil fuel emissions from use of biomass energy feedstocks. Scenario 2 has the more aggressive diversion of harvest biomass to energy feedstocks.

Scenarios 0 and 1 in all harvest regimes (Runs 1-5) result in net emissions of CO_2e beginning in 2100 because of methane from decomposition of forest products that end up in landfills

Further Details

- Our results highlight the importance of **capturing methane from landfills** in the region. Only roughly 40% of landfills in the northeastern US currently capture methane from landfills.
  - *Given the very high global warming potential of methane, increasing the fraction captured before release from decomposition of forest products in landfills would increase the net CO2e sequestration of all of the harvest regimes/scenarios substantially.*

- The cumulative net sequestration estimates are also sensitive to the **efficiency** with which biomass feedstocks are used to generate energy, and the **exact mix** of other energy sources (and their carbon emissions) displaced by biomass energy.
  - *Thus changes in both technology and the current fuel mix for energy production will affect our estimates, particularly as other renewable energy sources become more common.*

- Our analyses show no evidence of "**additionality**" in which increases in harvest rates result in larger than BAU carbon stocks.
  - *But the reduction in forest carbon stocks under more intensive harvest regimes is not as great as the magnitude of additional harvest removals. So the regional system is not a zero-sum game, and our analyses reveal that total harvest from northern forest states can be increased without a 1:1 decrease in the rate of addition to forest carbon stocks. This is effectively a very modest form of additionality.*

Planned Outreach Efforts

- Our peer-reviewed scientific publications form the necessary foundation for our planned outreach efforts.

- Debates about the policy implications and net carbon impacts of forest biomass energy have been hampered by the complexity of the calculations needed to provide rigorous assessments of net carbon impacts of different alternatives.

- This has been exacerbated by the need for media outlets to vastly simplify stories, often removing important context for specific claims.

- Thus, we plan to establish a website, hosted by the Cary Institute (www.caryinstitute.org) in which we summarize our results in lay terms for key groups of stakeholders, including
  - Policy makers
  - Forest landowners
  - General public

- Much of the debate about forest biomass energy in both the scientific literature and public media has been dominated by issues specific to the forest industry of the southeastern US. Our website will include a specific section that illustrates how the issues in northern forests differ from the narrative in southeastern forests.

Implications and applications in the Northern Forest region

- Our analyses clearly indicate that maintaining the current low level of biomass energy production under the business as usual scenario has higher net carbon sequestration than alternatives that increase harvest rates and feedstock production over the next 50 years.

- Scenarios that significantly increase biomass energy production from northern forests result in modest decreases in the potential net carbon sequestration and climate mitigation from northern forests.

- It is important to note that an increase in bioenergy production in the Northern Forest region would require significant changes in the current economics of forest harvest. Current biomass prices are unlikely to justify significant increases in extraction of biomass feedstocks.

- Thus, if the only policy consideration is to maximize the climate mitigation potential from northern forests, proposals to increase biomass energy production would not be as beneficial as maintaining business as usual.

- Net carbon impacts, however, are just one component that needs to be considered when assessing alternative scenarios of forest biomass energy development in the Northern Forest.

- Other considerations include potential economic benefits to northern forest communities and landowners, and a comprehensive assessment of the ecological and social consequences of changes in the northern forest landscape as a result of changes in forest harvest regimes.

Future Directions

- Our methodology allows us to explore a wide range of additional scenarios.
  - *This includes more detailed consideration of both the ways that biomass is used as an energy feedstock, and the energy sources (and emissions) displaced by that use.*
- Our current modeling includes a projected climate change of a 3^{o} C increase in mean annual temperature over the next 100 years, and a 15% increase in mean annual precipitation across the region.
  - *Many of the northern forest conifers are the most sensitive of northern forest tree species to climate change*[1]
  - *Future scenarios should consider additional climate change scenarios and the effects of the many different pests and pathogens that threaten northern forests.*

[1] Canham and Murphy (2018).

List of products

Three technical, peer-reviewed scientific articles are being produced by this award.

The first is a detailed analysis of greenhouse gas emissions of local wood pellet heat from the Northern Forest. That analysis used regional pellet industry survey data and forest inventory and harvest data to analyze GHG emissions from pellet production across a range of harvest and economic scenarios. Building on the Forest Sector Greenhouse Gas Assessment Tool for Maine (ForGATE) the paper models GHG emissions for different wood supply areas over 50 years.

Buchholz, T., J. S. Gunn, and D. S. Saah. 2017. Greenhouse gas emissions of local wood pellet heat from northeastern US forests. Energy 141:483-491.

The second paper focuses on the effects of changes in forest harvest regimes to increase overall yield of forest biomass energy feedstocks on productivity, structure and composition of the Northern Forest. The manuscript reports analyses of current harvest regimes for different forest types and regions across the Northern Forest using data from the Forest Inventory and Analysis Program. The harvest regimes are then implemented in SORTIE-ND, an individual-tree based forest stand model.

Brown, M. L., C. D. Canham, L. Murphy, and T. M. Donovan. 2018. Timber harvest as the predominant disturbance regime in northeastern U.S. forests: effects of harvest intensification. Ecosphere, 9(3):e02062. 10.1002/ecs2.2062.

The third manuscript builds on the analyses above and presents the results of detailed calculations of the net carbon emissions associated with different options for use of the biomass energy feedstocks produced under different harvest and feedstock production scenarios. We expect to submit this for publication in Spring, 2020.

Brown, M. L., C. D. Canham, T. Buchholz, J. S. Gunn, and T. M. Donovan. Net carbon impacts of biomass energy development in the northern forest. (in prep.)

The results of these three papers provide the rigorous scientific foundation for the online summary and synthesis website for policy makers, forest owners, and the general public (in preparation).

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Brown, M. L., C. D. Canham, L. Murphy, and T. M. Donovan. 2018. Timber harvest as the predominant disturbance regime in northeastern U.S. forests: effects of harvest intensification. Ecosphere 9(3):e02062. 10.1002/ecs2.2062

Canham, C. D., and L. Murphy. 2016. The demography of tree species response to climate: seedling recruitment and survival. Ecosphere 7(8):e01424. 10.1002/ecs2.1424

Hennigar, C., J. Gunn, L. Amos-Binks, D. A. MacLean, R. Cameron, and M. Twery. 2013. ForGATE – A Forest Sector Greenhouse Gas Assessment Tool for Maine: Calibration and Overview. U.S.D.A. Forest Service General Technical Report NRS-116.

Russell, M. B., C. W. Woodall, S. Fraver, A. W. D'Amato, G. M. Domke, and K. E. Skog. 2014. Residence Times and Decay Rates of Downed Woody Debris Biomass/Carbon in Eastern US Forests. Ecosystems 17:765-777.

Tonitto, C., C. L. Goodale, M. S. Weiss, S. D. Frey, and S. V. Ollinger. 2014. The effect of nitrogen addition on soil organic matter dynamics: a model analysis of the Harvard Forest Chronic Nitrogen Amendment Study and soil carbon response to anthropogenic N deposition. Biogeochemistry 117:431-454.