Evaluating Forest Biomaterials with Environmental Life Cycle Assessment

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Overview

• Role of MI forests in environmental protection and ecosystem services
• The importance of forests in global carbon and greenhouse emissions
• Case Study: Environmental Life cycle assessment (LCA) to understand impacts of forest products on greenhouse gas emissions.
Ecosystems - Management

Support Processes
Soil formation, biogeochemical cycles, water purification

Image credit: Michigan Forest Products Council
Business Advocacy for the Forest Products Industry
Case Study: Climate and Forests

Global Forest Data

Sandra Brown  http://www.fao.org/docrep/w0312e/w0312e03.htm

world's forests contain more than **55 percent** of the carbon stored in vegetation

most vegetation biomass is in the tropical zone, but most soil C is in the boreal zone

US has more temperate zone forest C than all other countries and regions

C fluxes are positive (uptake by land) in temperate and boreal zones due to re-growth after prior human disturbances (harvesting), but negative in the tropical zone (deforestation)
Summary of Forests and Climate

• Environmental effects of forest products must account for changes in condition of forest lands
• Environmental effects will also depend on activities tied to harvesting, processing, transporting, and storing biomass
• Increasing forest products may displace other products in the industrial sphere, with additional effects
Life Cycle Assessment Method

• The boundary of the analysis is the “cradle-to-grave” product system including; forest carbon, product chain, and displaced product systems (cement, steel, fossil fuels).
Forest Product System

Industrial wood

CO₂: burn, decompose

Waste recycling

Energy recycling

Thermal use

Use of the product in construction and furniture sector

Photosynthetic CO₂

Roundwood

First material use
  - Craftmanship
    (e.g. solid wood products)
  - Industry
    (board production)

Material recycling

Industry
  - board production
  - finishing
  - recycling
**Life Cycle Assessment Uses**

- Understand a product system’s effect on the environment
- Minimize environmental impacts
- LCA can be used to support product declarations on environmental benefits compared to other products
Case Study: Biofuels from MI Forests

Dr. Jiqing Fan, Postdoc, SFI (MTU), Dr. Robert Froese, SFRES (MTU)

• A generic forest-based biofuels pathway

Biomass Production: Model changes in C stocks on MI aspen forests over time from more intensive harvesting compared to business as usual (BAU)

Conversion: Model cellulosic ethanol and pyrolysis bio-oil

C Accounting: Model GHG emissions for use of fossil fuels along the pathway as well as emissions of biogenic CO$_2$ from changes in forest C stocks
## Carbon Budget Model for the Canadian Forest Sector (CBM-CFS3)

Table: Carbon pools in the CBM-CFS3 and pools recommended by IPCC GPG

<table>
<thead>
<tr>
<th>CBM-CFS3 pools</th>
<th>IPCC GPG pools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merchantable &amp; bark (SW, HW)</td>
<td>Aboveground biomass</td>
</tr>
<tr>
<td>Other wood &amp; bark (SW, HW)</td>
<td>Aboveground biomass</td>
</tr>
<tr>
<td>Foliage (SW, HW)</td>
<td>Aboveground biomass</td>
</tr>
<tr>
<td>Fine roots (SW, HW)</td>
<td>Belowground biomass</td>
</tr>
<tr>
<td>Coarse roots (SW, HW)</td>
<td>Belowground biomass</td>
</tr>
<tr>
<td>Snag Stems DOM (SW, HW)</td>
<td>Dead wood</td>
</tr>
<tr>
<td>Snag branches DOM (SW, HW)</td>
<td>Dead wood</td>
</tr>
<tr>
<td>Medium DOM</td>
<td>Dead wood</td>
</tr>
<tr>
<td>Aboveground fast DOM</td>
<td>Litter</td>
</tr>
<tr>
<td>Aboveground very fast DOM</td>
<td>Litter</td>
</tr>
<tr>
<td>Aboveground slow DOM</td>
<td>Litter</td>
</tr>
<tr>
<td>Belowground fast DOM</td>
<td>Dead wood</td>
</tr>
<tr>
<td>Belowground very fast DOM</td>
<td>Soil organic matter</td>
</tr>
<tr>
<td>Belowground slow DOM</td>
<td>Soil organic matter</td>
</tr>
</tbody>
</table>
Forest C dynamics simulation

- The CBM-CFS model estimates the aboveground biomass from the merchantable timber volume based on yield-to-biomass equations developed by Boudewyn 2007.
- The CBM-CFS then estimates aboveground C increments (0.5 kg C/kg biomass).
- Once the aboveground C increment is estimated, belowground biomass and C increment are calculated using equations from Li 2003.
- The model estimates biomass turnover to represent biomass mortality using annual turnover rate. Then the model uses litterfall transfer rates to assign C to different DOM pools.
- Decomposition is modeled by a temperature-dependent decay rate that determines the amount of organic matter that decomposes in a DOM pool every year.
- The CBM-CFS3 uses a simulation initialization procedure that links biomass, DOM dynamics and historic disturbance regimes at the beginning of a model run.

Figure: C flow between biomass and DOM pools in the CBM-CFS3 Adapted from Kurz 2009
Aspen harvesting

Table: Current age distribution (in ha) of aspen in Michigan (USDA 2013)

<table>
<thead>
<tr>
<th>age</th>
<th>0-19</th>
<th>20-39</th>
<th>40-59</th>
<th>60-79</th>
<th>80-99</th>
<th>100-119</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspen/birch group</td>
<td>225,000</td>
<td>311,000</td>
<td>385,000</td>
<td>278,000</td>
<td>87,000</td>
<td>13,000</td>
<td>1,299,000</td>
</tr>
</tbody>
</table>

- Growth curves are the fundamental data for forest C modeling
- The red curve represents “business as usual” (BAU) aspen growth and harvesting for existing uses (pulp and paper,..)
- The green curve is an improved growth curve for aspen representing active best practice management

Figure: Growth curves of aspen in Michigan
Harvested biomass: Business as usual (BAU) and intensive (INT) harvesting

- In the BAU scenario, 7200 ha of aspen is assumed to be harvested every year to match FIA data, while INT scenario doubles the areas to 14400 ha.
- The extra biomass harvested in the INT scenario additional to the BAU scenario (205 million metric ton) is used for biofuel and bioenergy production.

Figure: Total biomass harvested in the BAU and INT scenarios over 250 years
Forest C Stocks in Aspen

Figure 7: Ecosystem C stored in the BAU and INT scenarios
Direct land use change (dLUC) CO$_2$ emissions of biofuels and bioenergy

Figure: dLUC of biofuel and bioenergy over 250 years
Life cycle GHG emissions of biofuels and bioenergy

GHG emissions w/o LUC:

• EtOH: -3.74 g CO\textsubscript{2} eq/MJ (GREET 2012)

• Pyrolysis oil: 16.35 g CO\textsubscript{2} eq/MJ (Fan, 2012)

• Pyrolysis electricity: 130.8 g CO\textsubscript{2} eq/kWh (Fan, 2012)

Figure: GHG emissions (w/dLUC) of EtOH, pyrolysis oil and electricity over 250 years, comparing to their petroleum counterparts
Bioenergy system total emissions

\[ GHG_{\text{tot}}(t) = \Delta FC(t) + GHG_{\text{bio}}(t) \]

(Mckechnie, 2011)

Emissions from fossil fuels displaced are subtracted from the biofuel system emissions from the previous slide.

A GHG emissions “debt” is overcome between 50 and 100 years in the future.

In the short term, MI forest-based biofuels from INT harvesting emits more than fossil fuels.

\[ \Delta FC(t) \]: change in forest carbon at any time \((t)\) due to biomass harvest for bioenergy, calculated by \(C_{\text{ecosystem}}^{\downarrow}INT\)

Figure: Total GHG emissions of forest-based biofuels system
Summary on Forest-Based Biofuels

• Biofuels produced from forest resources that are harvesting more intensively than the normal harvest level will incur direct land use change emissions of CO$_2$

• The dLUC emissions will cause a C debt early in the production cycle that range over many 10s of years.

• Improved management of forest for such intensive harvests can moderate or eliminate the dLUC emissions

• Forest plantations on abandoned agricultural may offer benefits for biofuels production by eliminating the C “debt”
LCA of Forest Products for Homes

PNW Forest C Pools for Different Harvest Rotations

Figure 1. Carbon in forest pools for different rotations

CORRIM (2004)
LCA of Forest Products for Homes
*Short- and Long-Lived C Pools, Displaced energy, Concrete Sub.*

*Figure 3. Carbon in the forest and product pools with concrete substitution for the 45 year rotation*

CORRIM (2004)
Conclusions

• Producing products from forest resources can have long-term benefits to the environment (C storage in products, avoided emissions from fossil fuels,..)

• Environmental life cycle assessment (LCA) is a comprehensive method to understand impacts across a product’s life cycle

• LCA of forest products must include these key features;
  ➢ Modeling of forest management with respect to C storage and other environmental effects (biodiversity, water quality, ...)
  ➢ Modeling of the activities and process for cultivation, harvest, transport, and manufacturing processes
  ➢ End of life processes such as recycle and disposal
  ➢ Substitution of equivalent products in the market