A Circular Forest and Biomass Energy Decarbonization System for Bioeconomy

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A Circular System for Decarbonization

System dynamics
Circular sustainable supply chains
Entity and actions
Pathways

# Decarbonization Option, Rate and Cost

<table>
<thead>
<tr>
<th>Options</th>
<th>Practices</th>
<th>Carbon sequestration rate</th>
<th>Carbon sequestration cost</th>
<th>CO₂ utilization cost ($/t CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afforestation &amp; reforestation</td>
<td>Planting trees and bioenergy crops.</td>
<td>Average 1.50 t CO₂/ha/year, ranging from 1.19 to 4.59 t CO₂/ha/year for mixed hardwood forests¹</td>
<td>$28-$83/tC or $101-303/tCO₂</td>
<td>−40 to 10⁶</td>
</tr>
<tr>
<td>Sustainable management</td>
<td>Sustainable harvest and scheduling.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land reclamation</td>
<td>Planting biomass crops in marginal lands.</td>
<td>50.6 to 94.8 t CO₂/ha for a 19-year period of shrub willow²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioenergy with carbon capture &amp; Storage (BECCS)</td>
<td>Utilizing forest and crop biomass to produce bioenergy substituting fossil fuel-based energy while CO₂ emitted during the process is captured and stored.</td>
<td>Global carbon sequestration potential 3.4 to 5.2 Gt CO₂/year³</td>
<td>60 to 160⁶</td>
<td></td>
</tr>
<tr>
<td>Biochar</td>
<td>Pyrolyzing forest and crop biomass to produce biochar for soil amendment.</td>
<td>0.92 t CO₂ sequestered by one ton of biomass⁴</td>
<td>$11-$167/tC or $40-606/tCO₂</td>
<td>−70 to −60⁶</td>
</tr>
</tbody>
</table>

*The unit carbon sequestration cost \( (CSC)_t \) at time \( t \) of a planning period \( T \) per unit area can be expressed as:

\[
CSC_t = \frac{CC_t}{CS_t}, \quad t = 0, 1, 2, ..., T
\]

where, \( CC_t \) is the net cost of the amount of \( CS_t \) carbon sequestered at \( t \) of a planning period \( T \) for a certain size of area or per unit area of forest or biomass crops.


*CO₂ utilization cost is the cost in $/t CO₂ adjusted for revenues, by-products, and any CO₂ credits or fees. A cost of zero represents the point at which the pathway is economically viable without governmental CO₂ pricing (for example, a subsidy for CO₂ utilization) ⁶.

Forest Carbon Neutrality

A coefficient of carbon neutrality with consideration of carbon harvested, carbon growth, and life cycle emissions as:

$$ CN_t = \frac{G_t + L_T - t L_T / Y_T}{H_0} $$

Where, $t = 0, 1, ..., T$, is the year after harvest.

$G_t$ is the accumulative carbon growth of forest stand at time $t$.

$CN_t$ is the defined carbon neutrality coefficient over a life cycle of forest and harvested products.

$L_T$ is the carbon of long-lived wood products.

$H_0$ is the total carbon harvested.

$Y_T$ is the life span of long-lived wood product.

In a forest ecosystem, carbon can be stored in the following carbon pools and can be estimated using a full carbon accounting approach:

\[ TC_t = TL_t + BL_t + BD_t + SD_t + DDW_t + SH_t + FF_t \]

The objective of forest and biomass harvest scheduling process is to maximize the total revenue \( z \) of the forests and biomass in terms of carbon \( C \), timber \( W \), and biomass \( B \) values.

\[ max \quad z = C + W + B \]

For example, \( C \) is the monetary value of carbon sequestered and is calculated by equation

\[ C = r_{CO_2} p^{CO_2} \sum_{i=1}^{S} \sum_{t=1}^{T} \{ f_{ci}(a_{it}) - r_{dry} \delta x_{it}[G_{i,t-1} + f_{bi}(a_{i,t-1})] \} \]

The management strategies should consider carbon and timber prices, biomass for energy, harvest area, harvest method, carbon storage, harvest rotation, subsidy and trading.

The carbon sequestration rate of the base case scenario over the planning horizon of 50 years was 0.408 Mg · ha\(^{-1}\) · year\(^{-1}\). It ranges from 0.325 to 1.253 Mg · ha\(^{-1}\) · year\(^{-1}\) with an average of 0.917 Mg · ha\(^{-1}\) · year\(^{-1}\) as the carbon to timber price ratio increased from 0.0 to 1.0.

Among different carbon components, aboveground living stands were the major contributor (59.6%) to the total carbon storage, followed by belowground living component (15.6%).

• Marginal rate is identified when the carbon to timber price ratio is at 0.45.
• The revenue steadily increases from $1.6 to $7.1 ha\(^{-1}\) year\(^{-1}\).
• When the price ratio is greater than or equal to 0.8, the increment of forest revenue reached to a flat plateau.
• The carbon to timber price ratio is a tradeoff between carbon stock and timber demand.
• To achieve a carbon sequestration rate of C (0.64) tons/ha/yr, a carbon to timber price ratio should be P (0.33), then M (0.6) Mg \(\cdot\) ha\(^{-1}\) \(\cdot\) year\(^{-1}\) for a potential management practice.
Forest Carbon Management Strategies

Life cycle GWP of bioenergy products:

Pellet production presented the lowest GHG emissions and consumed the least amount of fresh water and fossil fuels. Pyrolysis oil production emitted the highest amount of greenhouse gas, which was double of biopower production.

The results illustrated that the global warming potential (GWP) impact of biochar production through BSI, OK, and ACB were 0.25–0.39, 0.55, and 0.61 tonne CO₂eq./tonne biochar applied to the field.

Thank You!

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