Best Practices and Challenges in Life Cycle Assessment of Forest Products

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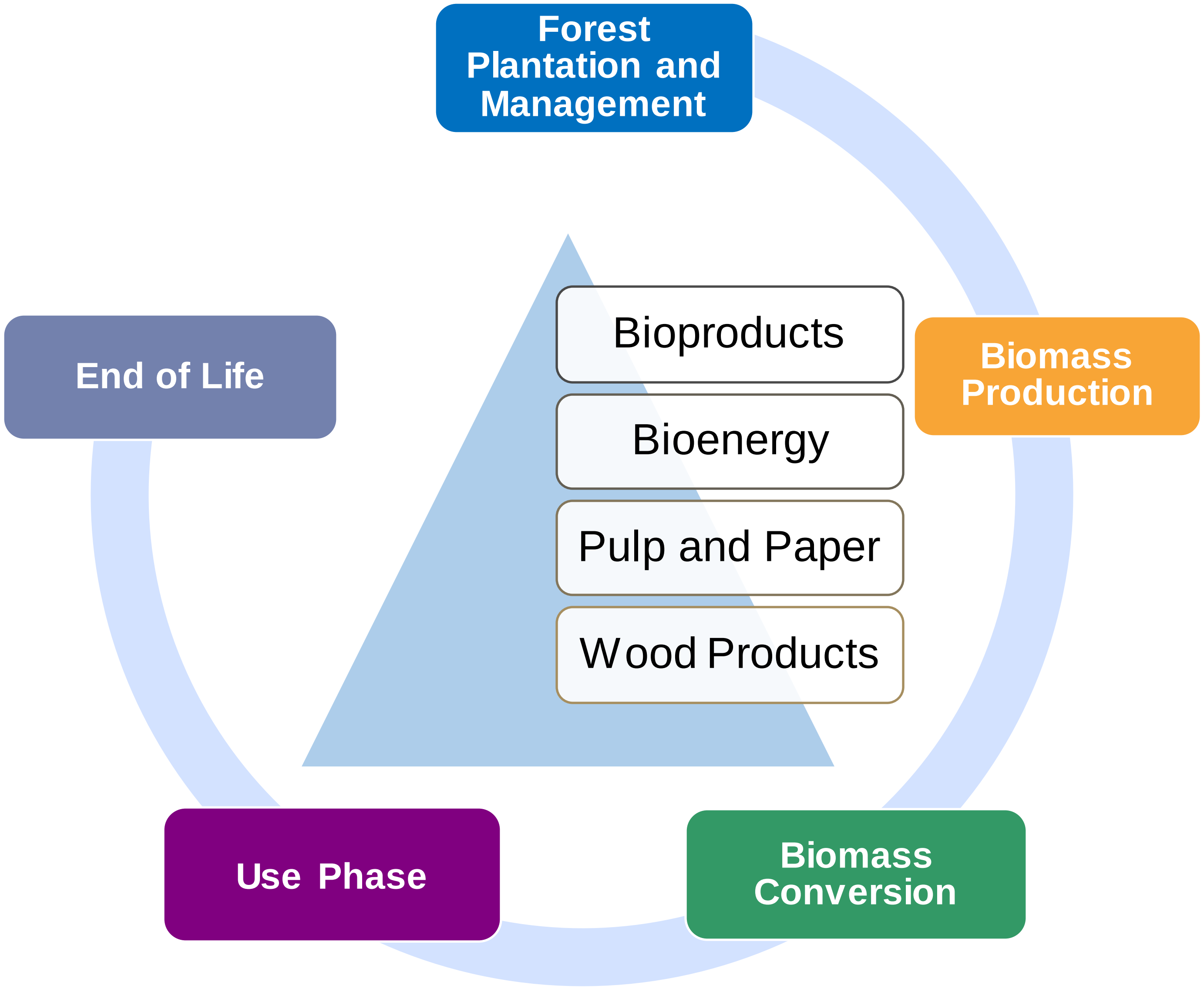
Forest-Based Products

- Bioproducts
- Bioenergy
- Pulp and Paper
- Wood Products

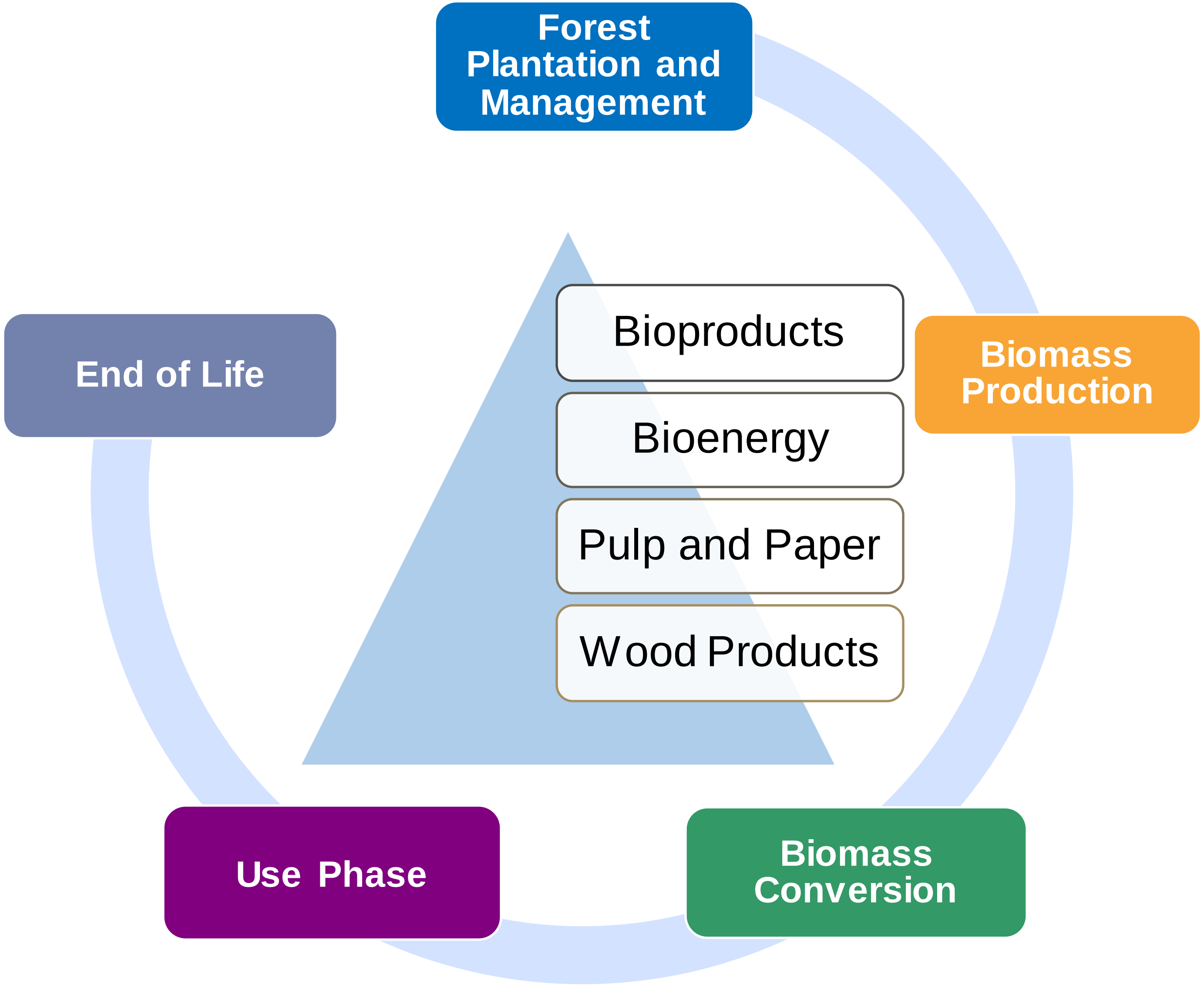
Photo from:
https://www.energy.gov/eere/bioenergy/bioenergy-basics

Forest Product Life Cycle



Challenges in Forest Product Life Cycle Assessment

- Variations in quantity and quality
- Temporal and spatial dynamics
- Impacts on ecosystems



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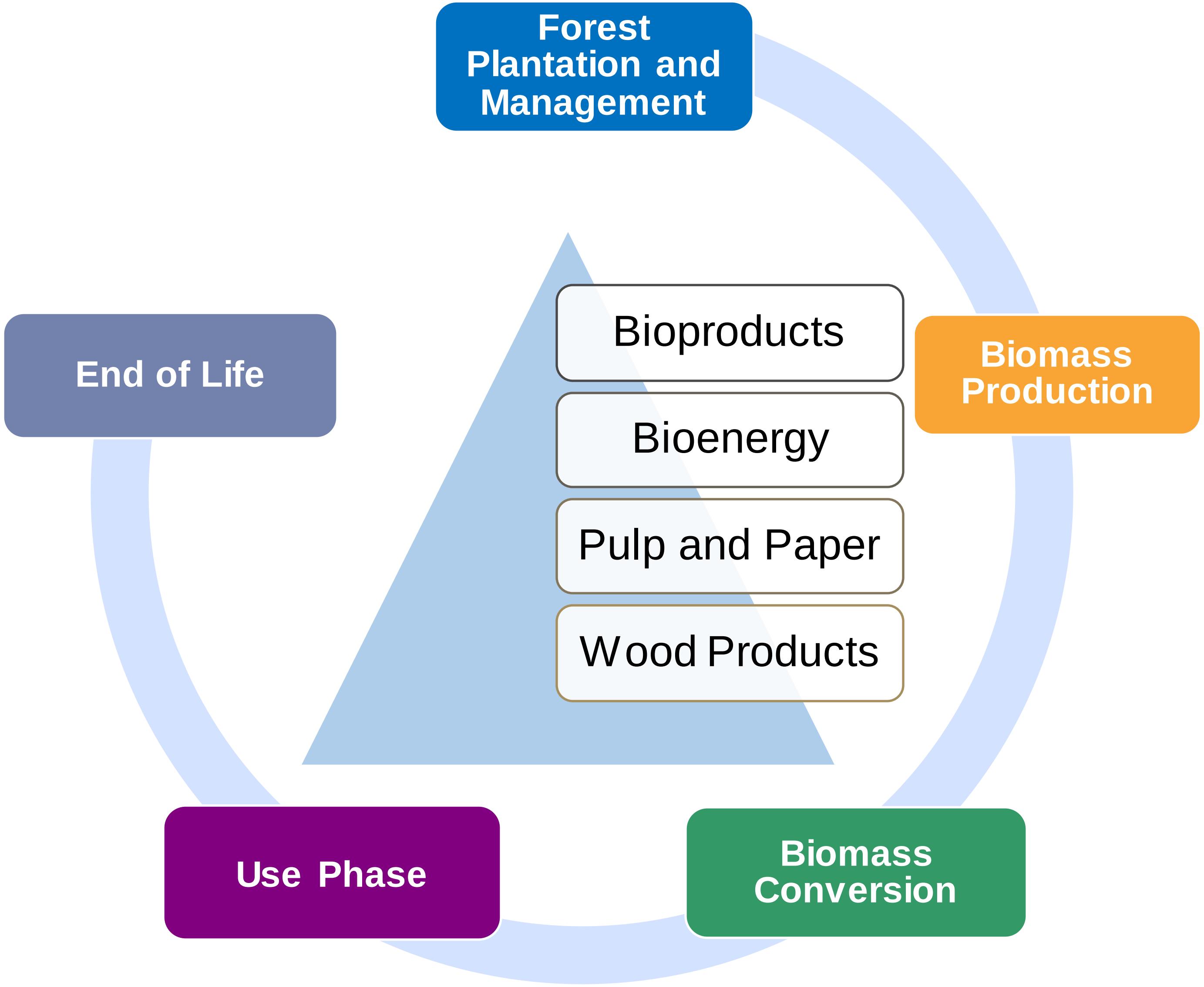


Using Machine-Learning-Assisted Life Cycle Models for Carbonaceous Materials Derived from Diverse Wood Sources

Activated Carbon (AC) – One of Biochar Applications

https://feeco.com/introduction-to-activated-carbon/

Research Gaps

Eucalyptus

Pine

Maple

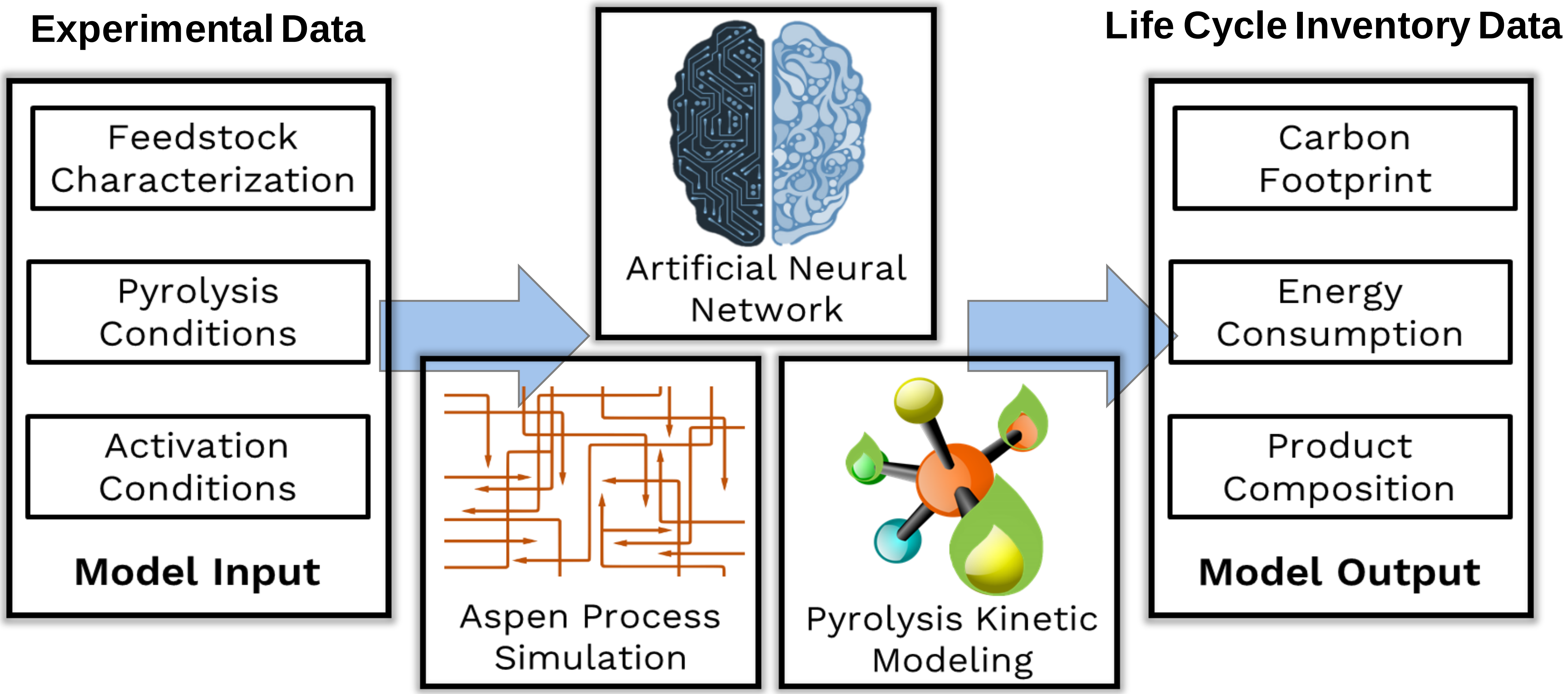
Willow

Bamboo

Many Others…

Figures from：
https://www.worldcoal.com/power/21032019/the-surprisingly-sustainable-case-for-coal/ https://feeco.com/introduction-to-activated-carbon/
https://pixabay.com/photos/bamboo-forest-tropical-forest-1028699/ https://www.srs.fs.usda.gov/compass/tag/loblolly-pine/
https://www.flickr.com/photos/42931449@N07/6815004908 https://commons.wikimedia.org/wiki/File:Willow_tree.jpg

Integrated Modeling Framework



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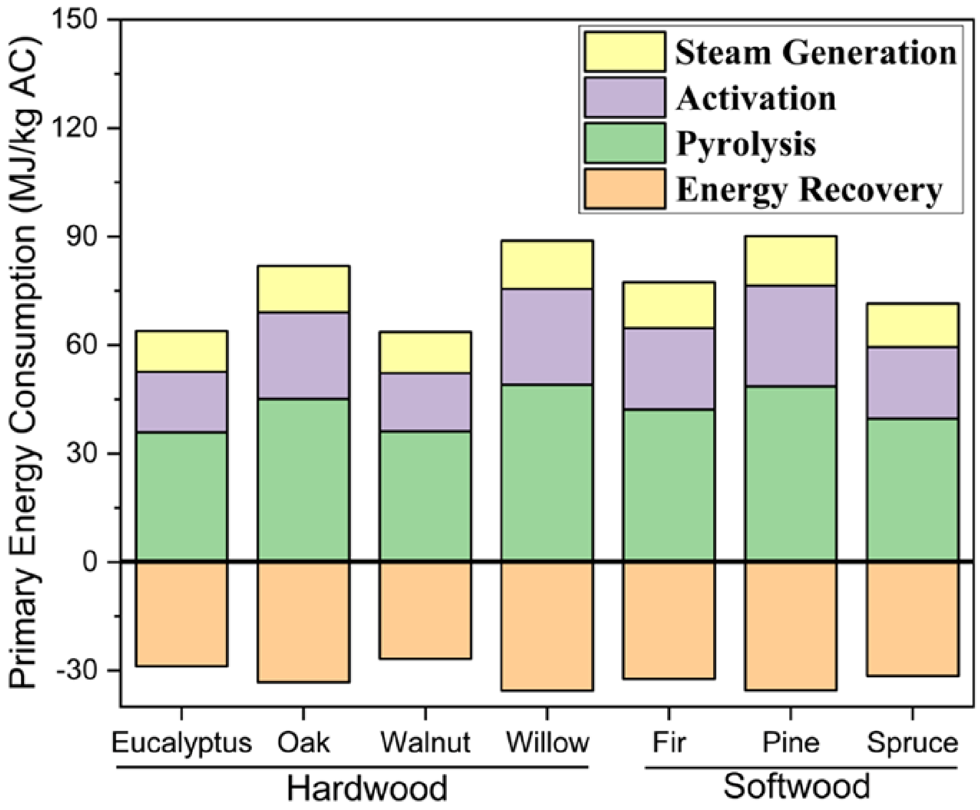
Primary Energy Consumption and GHG Emissions of Activated Carbon Production Using Seven Typical Woody Biomass



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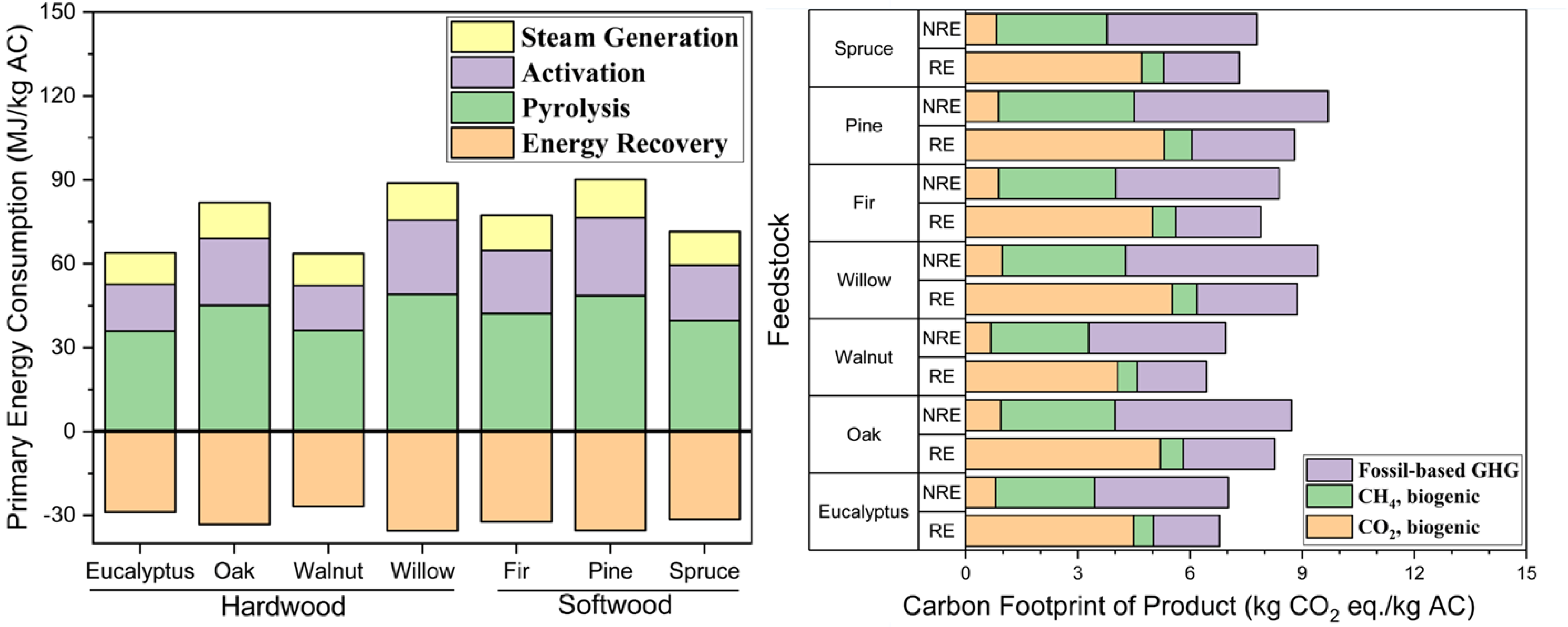

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Fill the Life Cycle Inventory Data Gap for Activated Carbon Produced from Different Biomass

- 250 biomass samples

	Softwood		Hardwood		Total	
	Average (Min-Max)	STD[a]	Average (Min-Max)	STD[a]	Average (Min-Max)	STD[a]
E_{NRE} (MJ/kg AC)	101 (43-224)	32	88 (43-277)	32	93 (43-277)	33
E_{RE} (MJ/kg AC)	65 (25-155)	23	57 (23-208)	24	60 (23-207)	24
Fossil GHG_{NRE} (kg CO_2-eq./kg AC)	8.7 (4.2-18.8)	2.6	7.4 (4.0-22)	2.4	7.9 (4.0-22)	2.6
Fossil GHG_{RE} (kg CO_2-eq./kg AC)	4.0 (1.7-9.3)	1.4	3.5 (1.5-12)	1.4	3.7 (1.5-12)	1.4
Biogenic GHG_{NRE} (kg CO_2-eq./kg AC)	5.1 (2.7-12)	1.5	4.3 (2.4-13)	1.4	4.6 (2.4-13)	1.5
Biogenic GHG_{RE} (kg CO_2-eq./kg AC)	6.7 (3.4-14)	1.9	5.9 (3.4-16)	1.8	6.2 (3.4-16)	1.9

[a]STD: Standard deviation; RE: with energy recovery; NRE: without energy recovery

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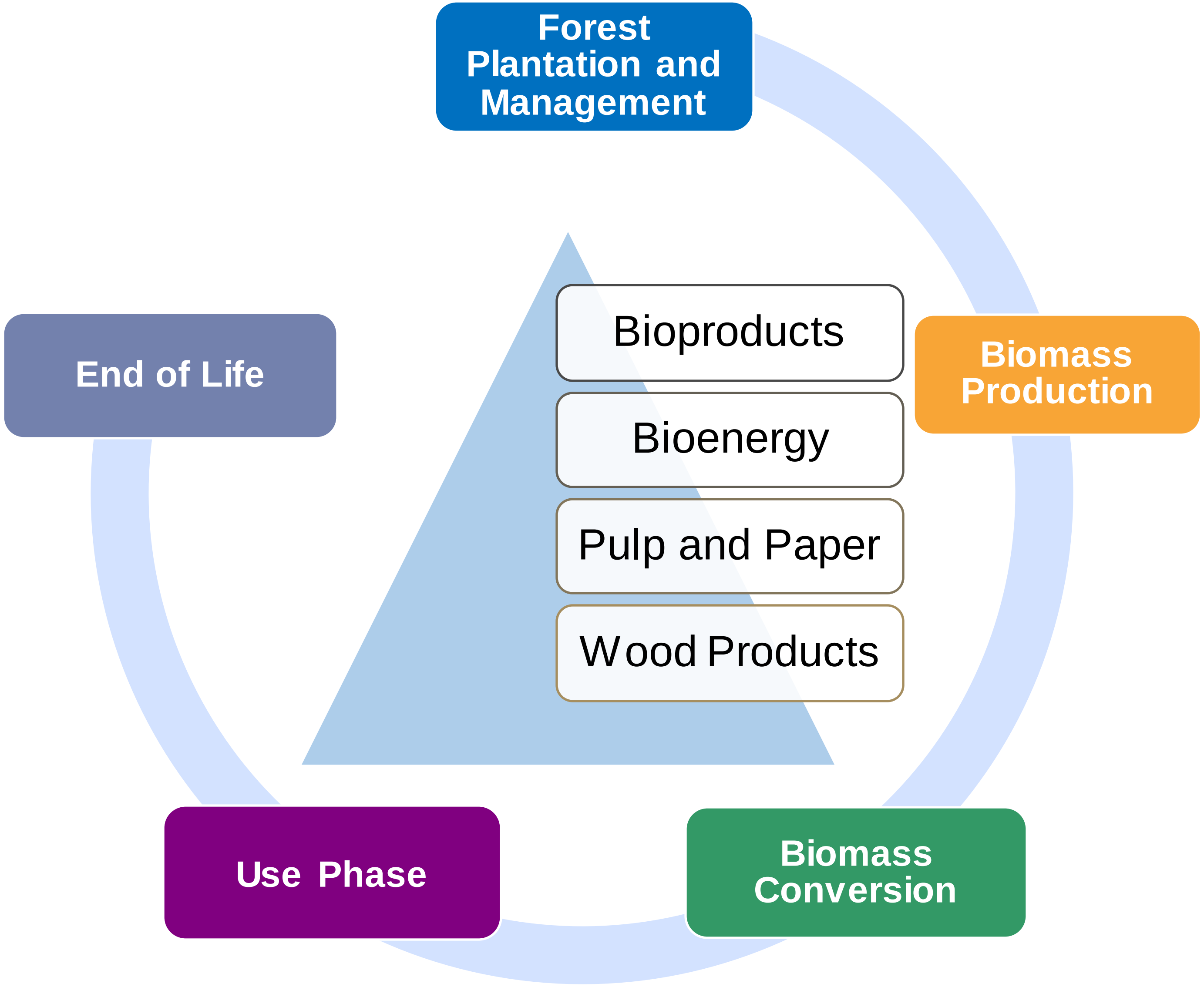

Cross-Laminated Timber (CLT)

CLT Photo:
https://www.usda.gov/media/blog/2018/03/30/blast-testing-shows-clt-can-take-heat

https://www.archdaily.com/893442/cross-laminated-timber-clt-what-it-is-and-how-to-use-it

Cross-Laminated Timber Life Cycle

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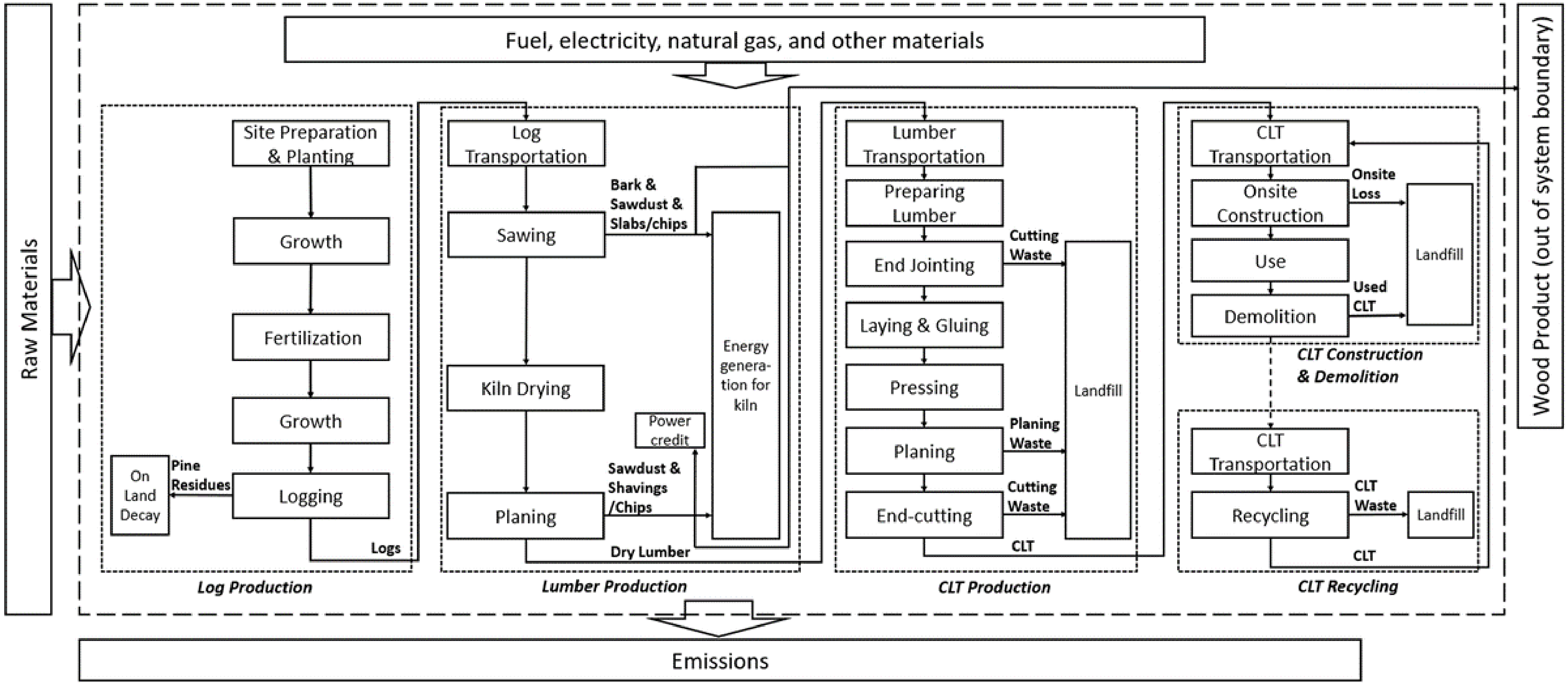




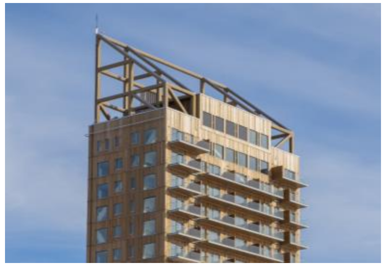

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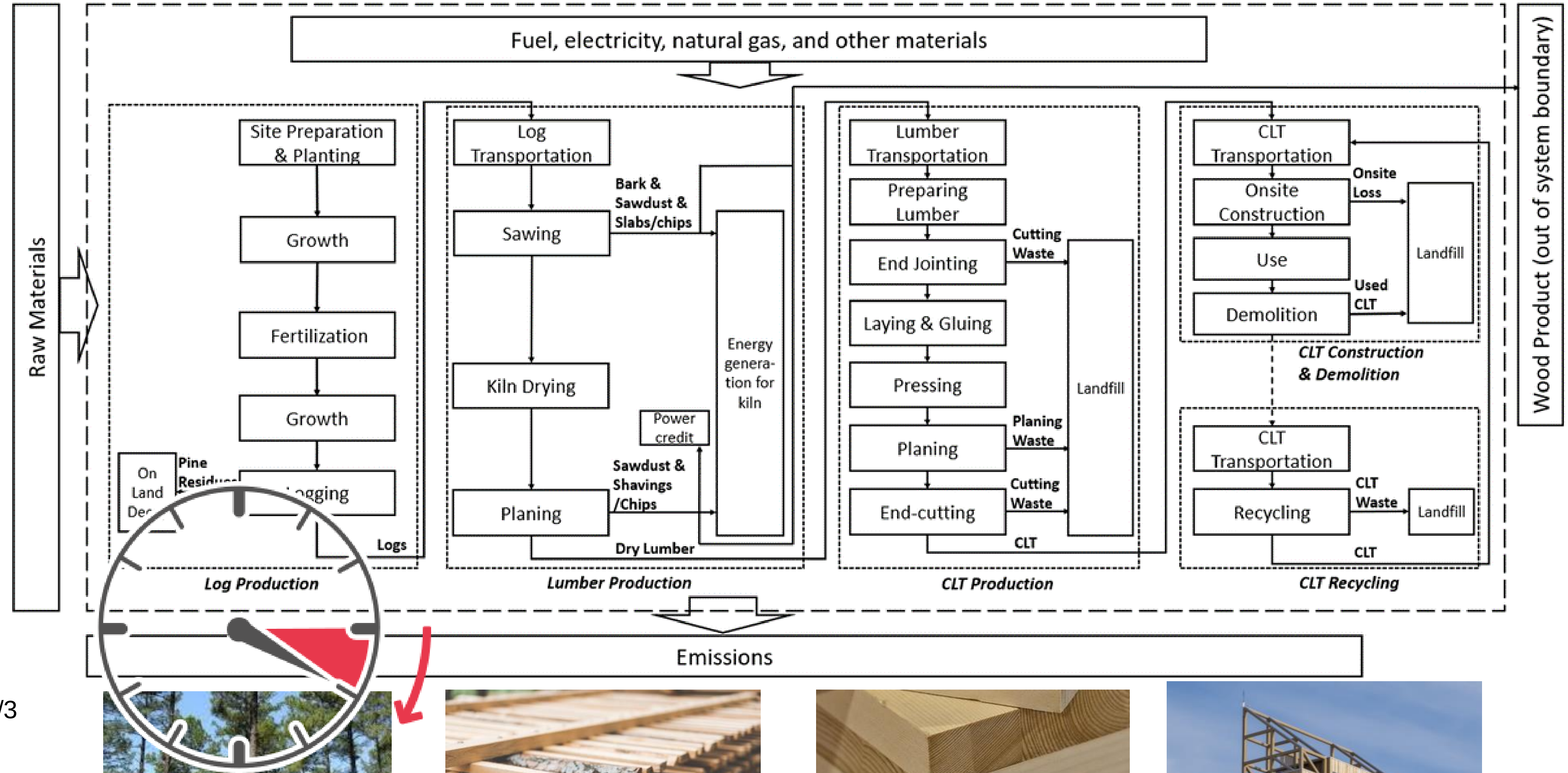

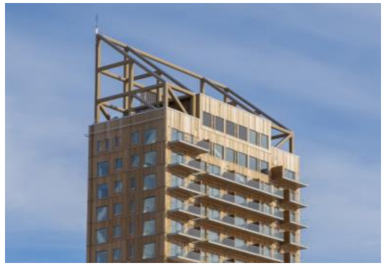

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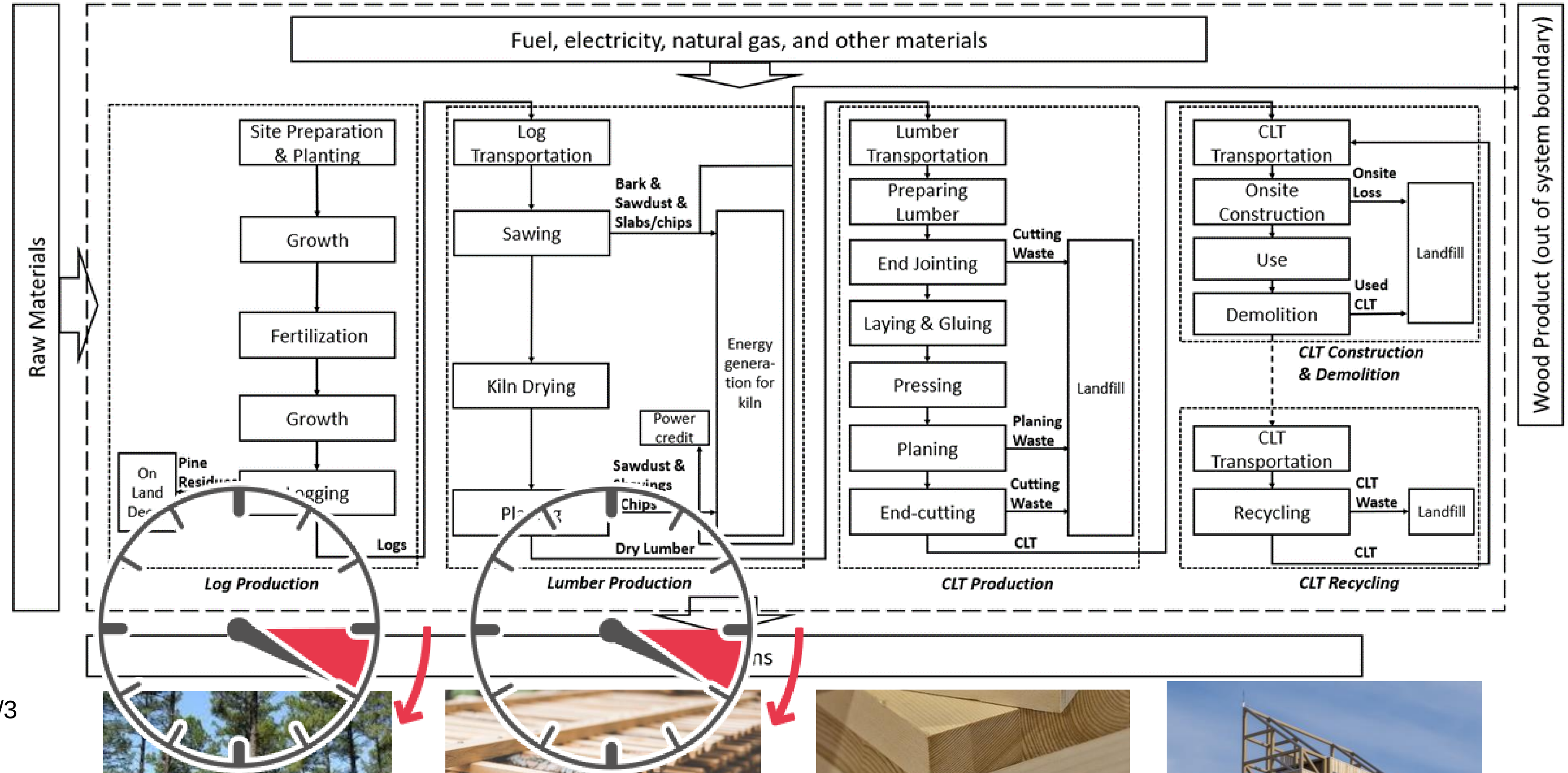

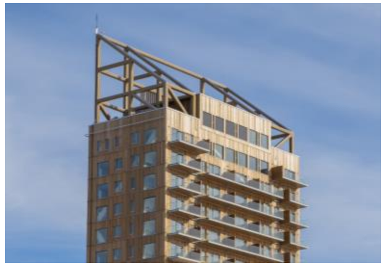

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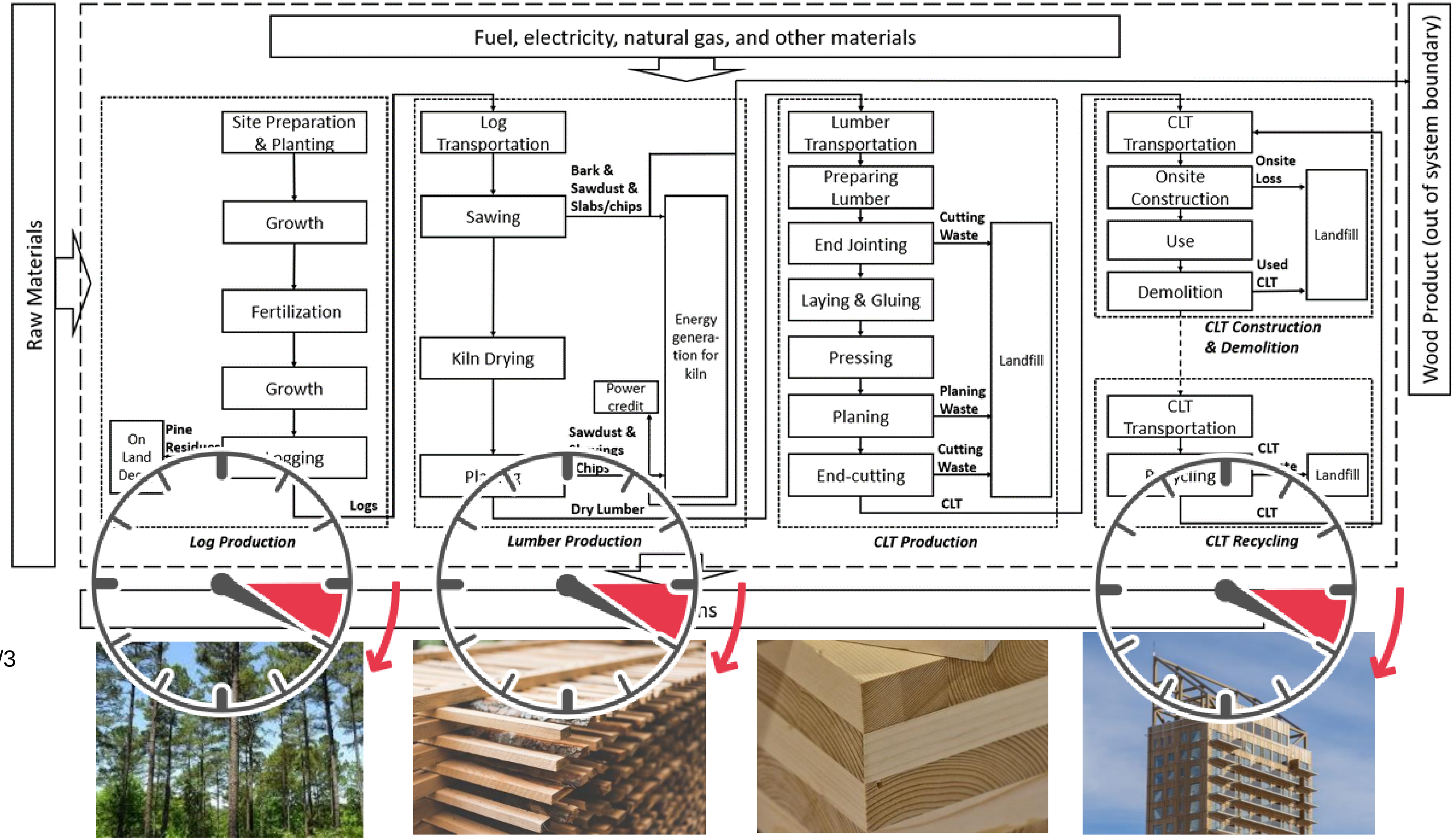

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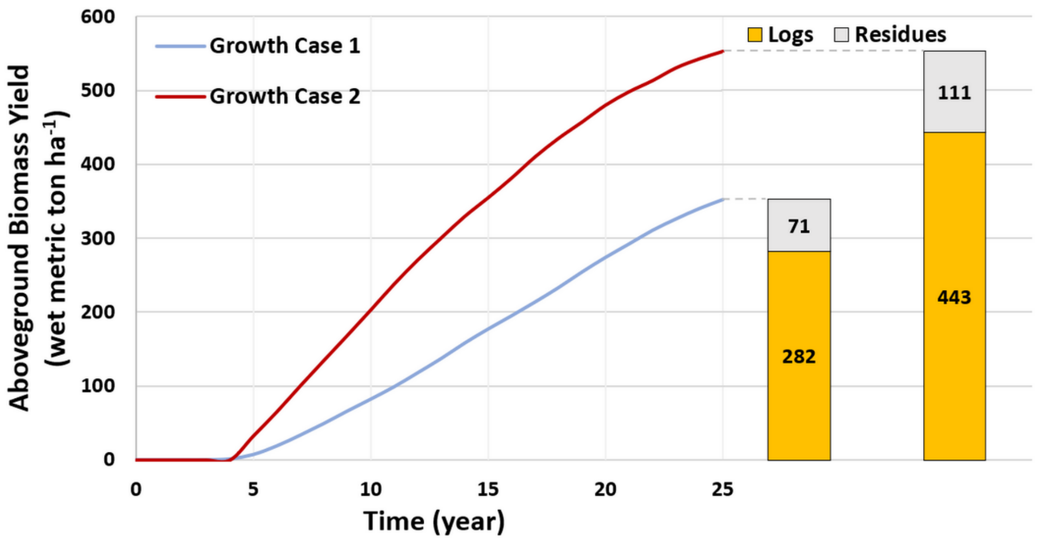
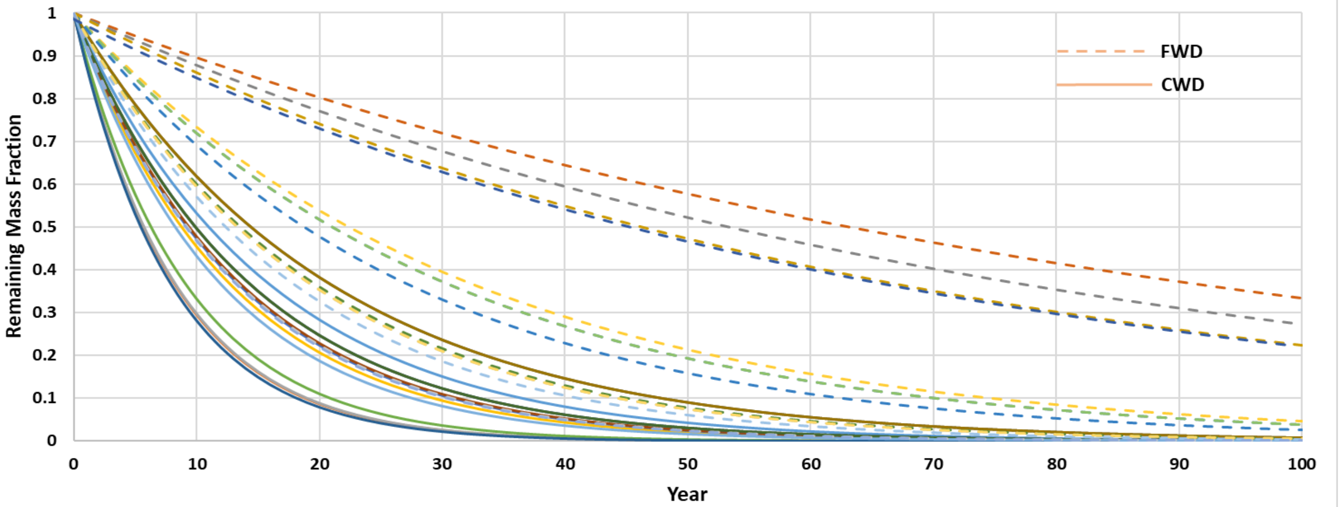
Cross-Laminated Timber and Carbon Dynamics

Dynamic Forest Growth



Dynamic Forest Residues Decay



Coarse Wood Debris (CWD), Fine Wood Debris (FWD)

IPCC First Order Decay Model

$$C_{decomposed} = W \cdot DOC \cdot DOC_f \cdot (1 - e^{-kt})$$

$$CH_{4\,generated} = [(C_{decomposed} \cdot MCF \cdot F \cdot 16/12) - R] \cdot (1 - OX)$$

$$M_{Remain,i} = M_{Remain,0} \cdot e^{-i \cdot K}$$

- $M_{Remain,i}$ is remained mass per of residue on site in year *i*.
- *K* is the decay rate.

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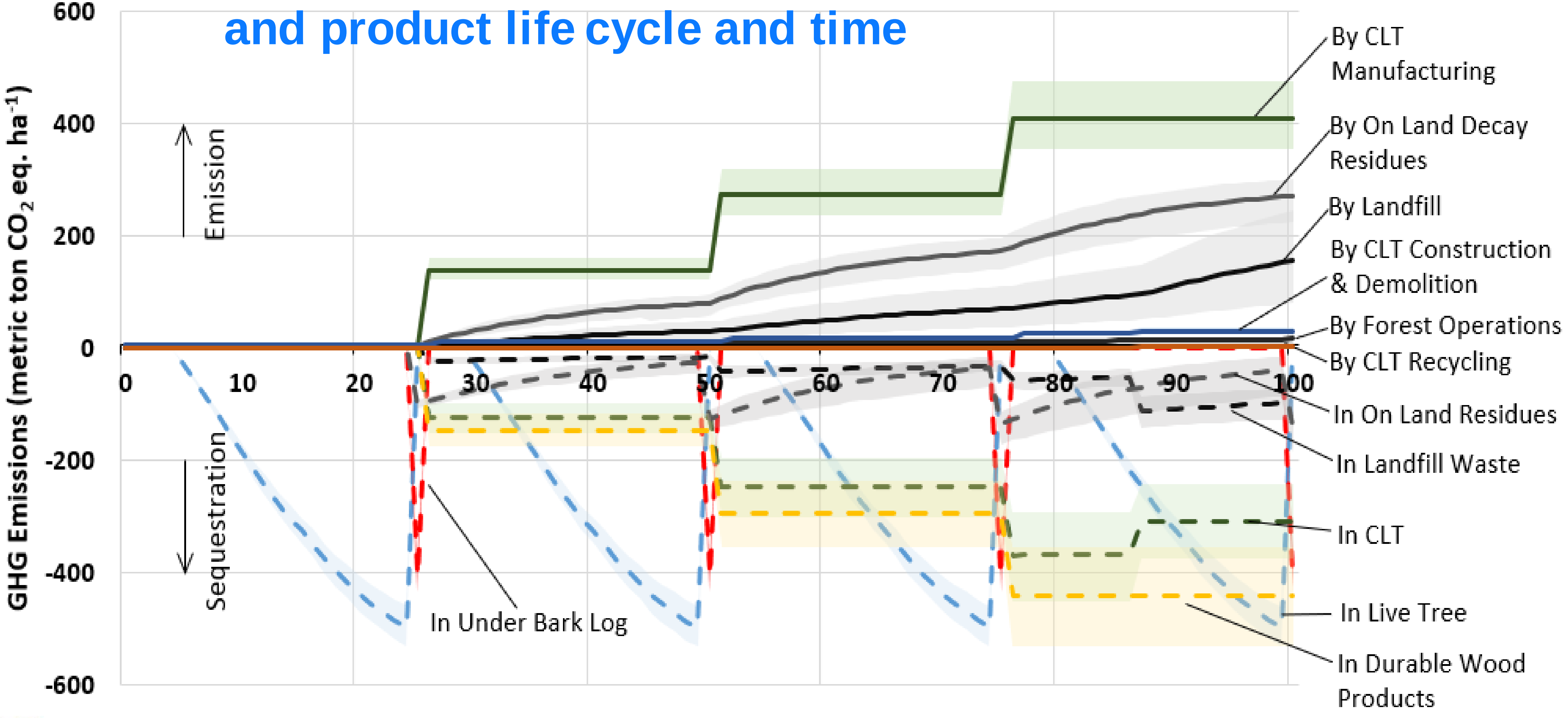
100-year accumulative GHG flows of 1-hectare pine forest land used for CLT production

Need to track GHG flows across forest and product life cycle and time

CLT - Cross Lamented Timber



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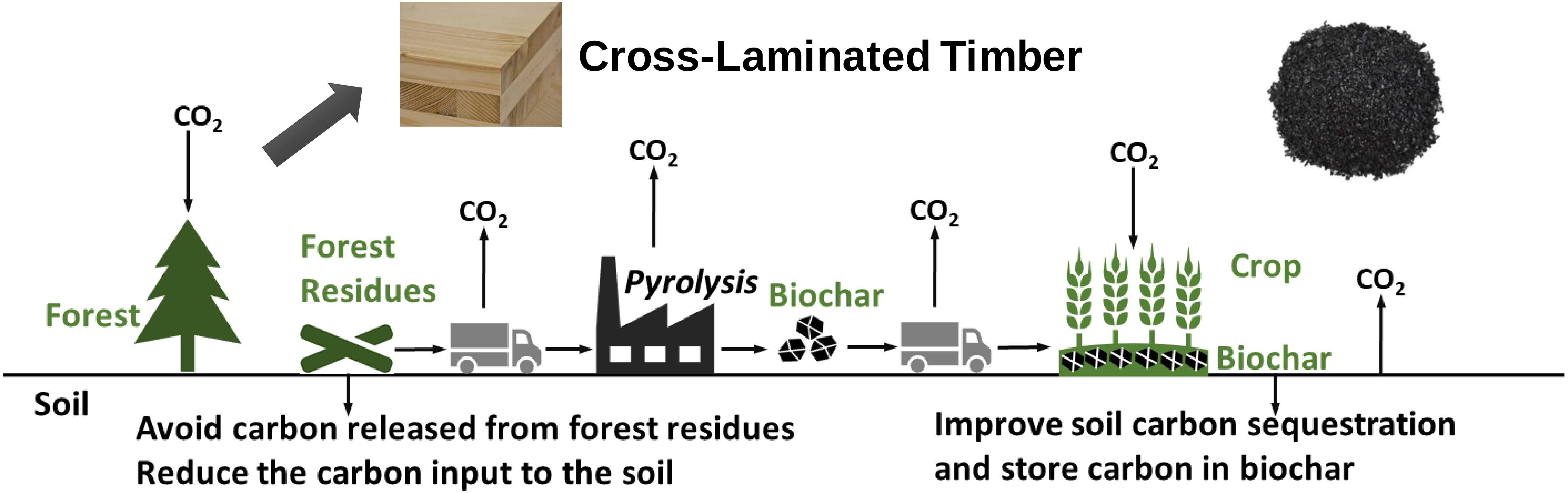
Commercial Afforestation/Reforestation for Innovative Wood Products



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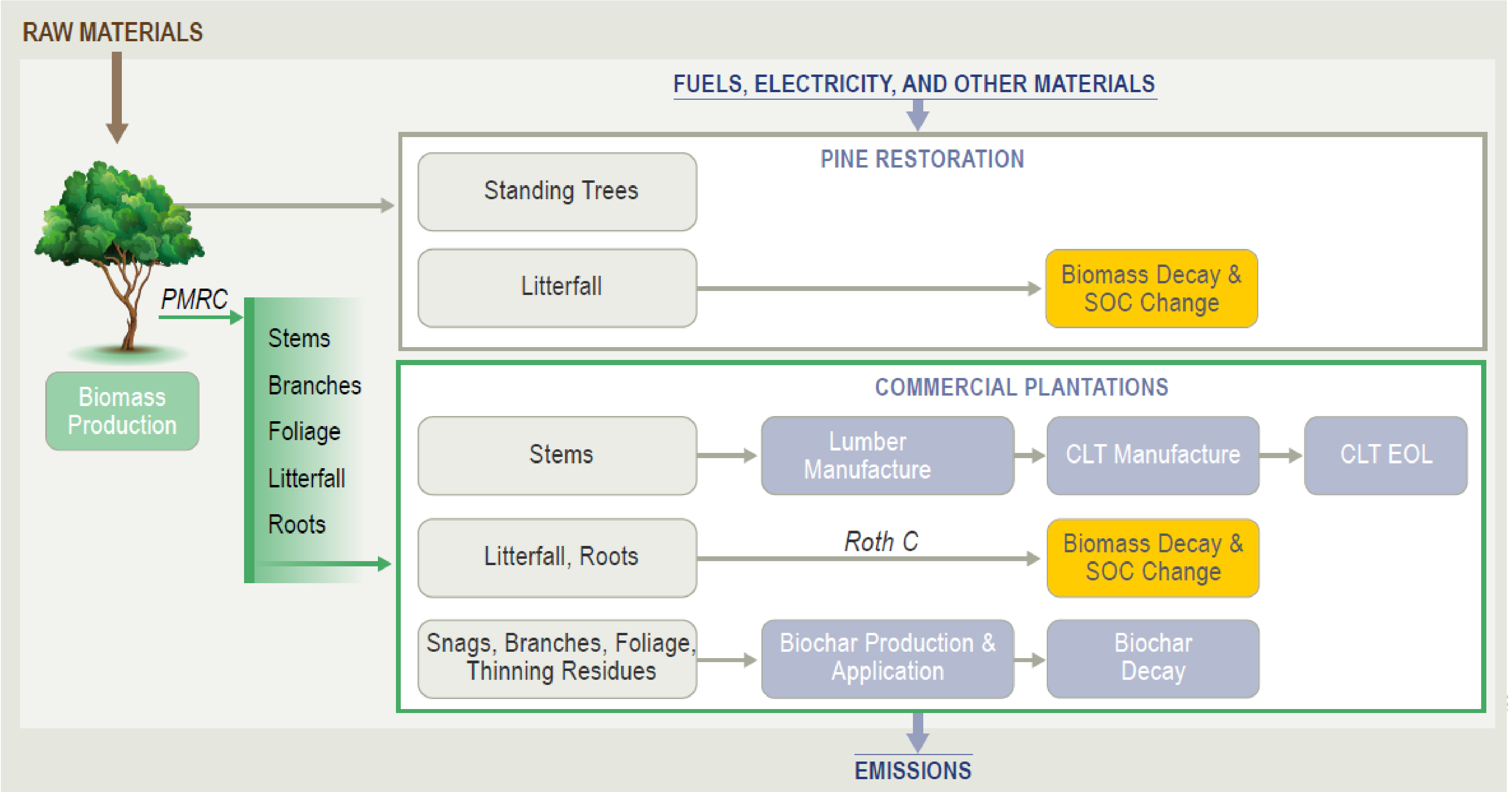
Life Cycle Modeling Framework



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Roads to Removal: Options for Carbon Dioxide Removal in the United States, December 2023, Lawrence Livermore National. Laboratory, LLNL-TR-852901

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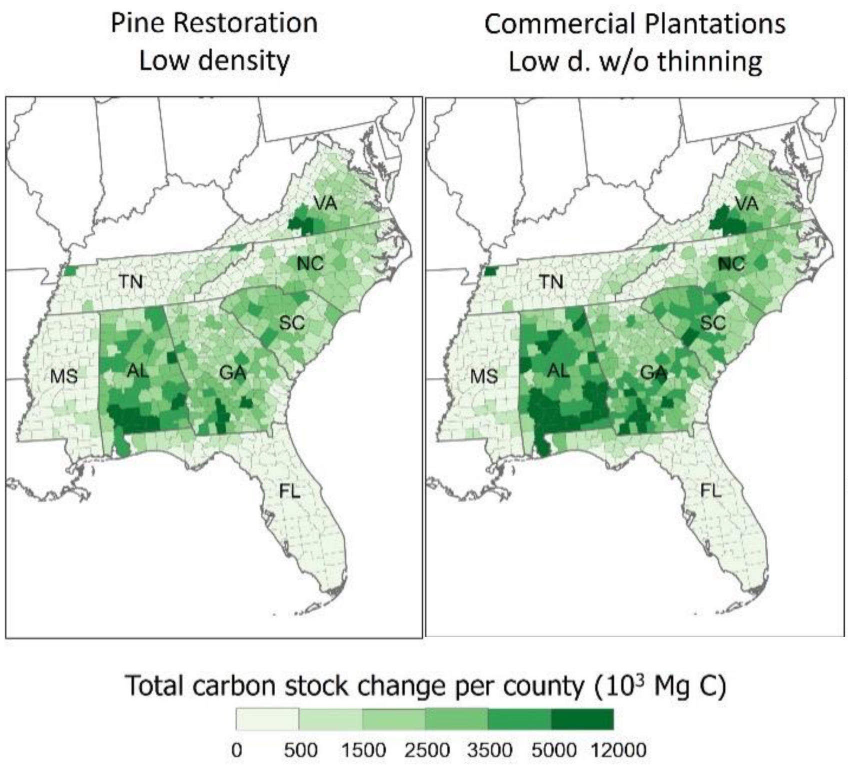
Spatial dynamics of utilizing forest products for carbon removal



Carbon stock increase by planting loblolly pine trees on 2.1 million hectares (ha) of land across the southeastern United States over 100 years.

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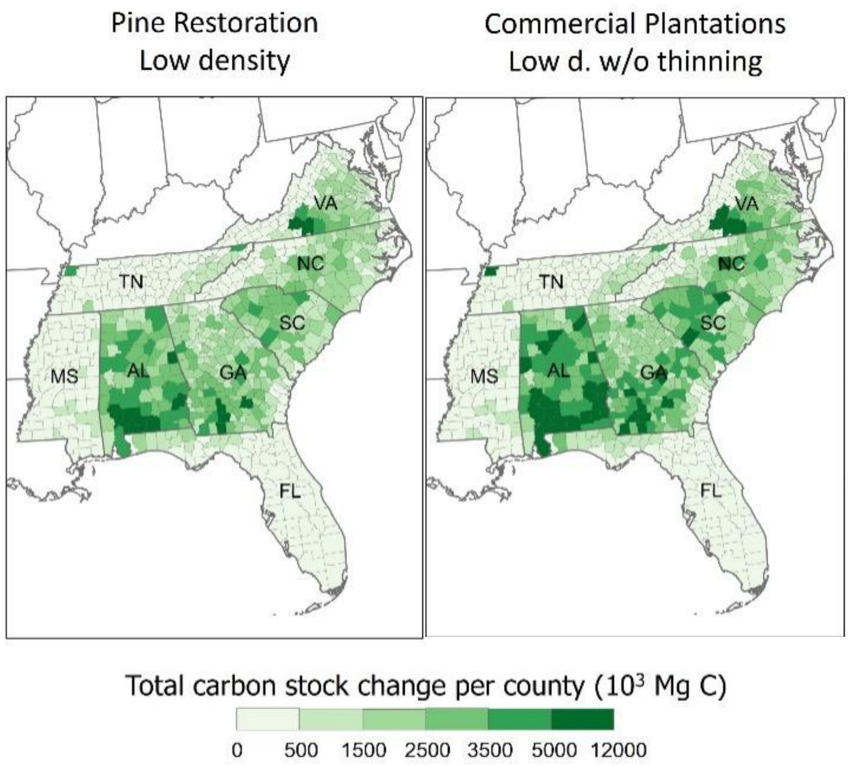

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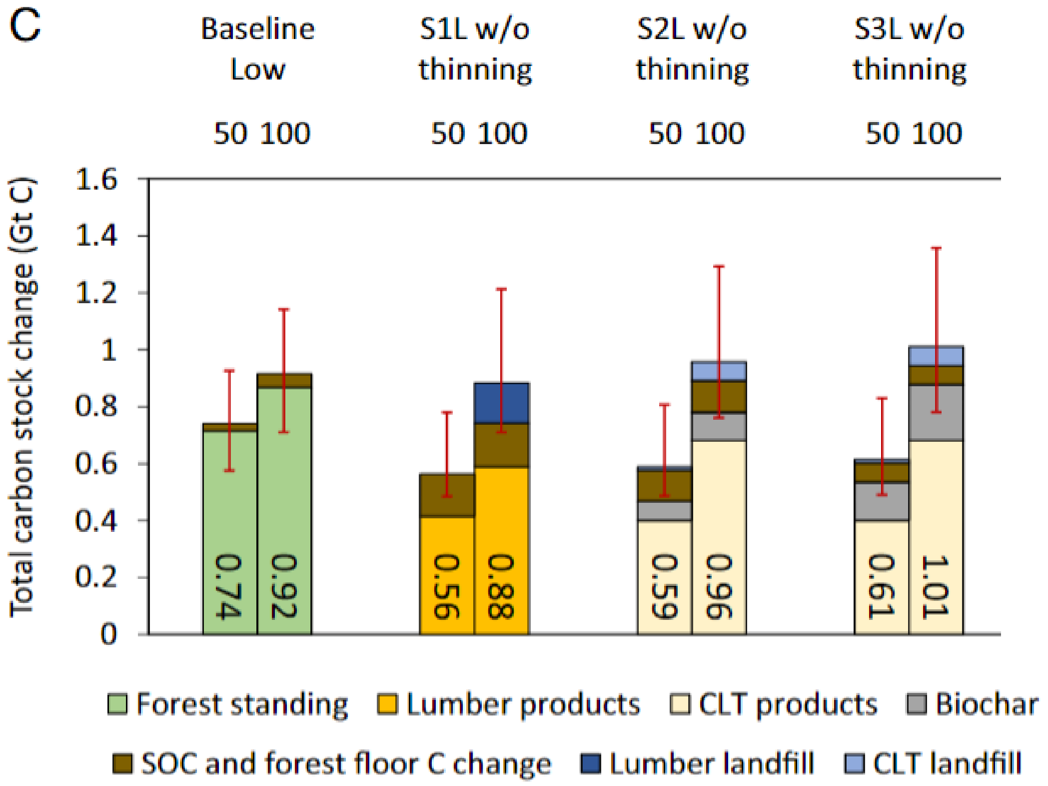

Carbon stock breakdown by carbon pools

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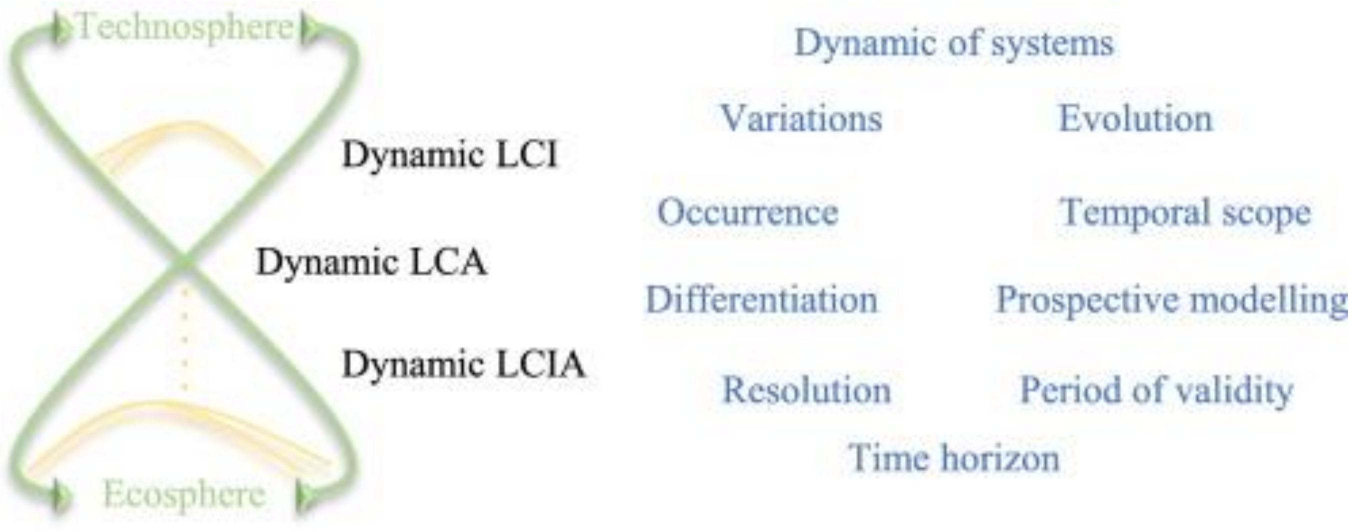
Dynamic Life Cycle Assessment



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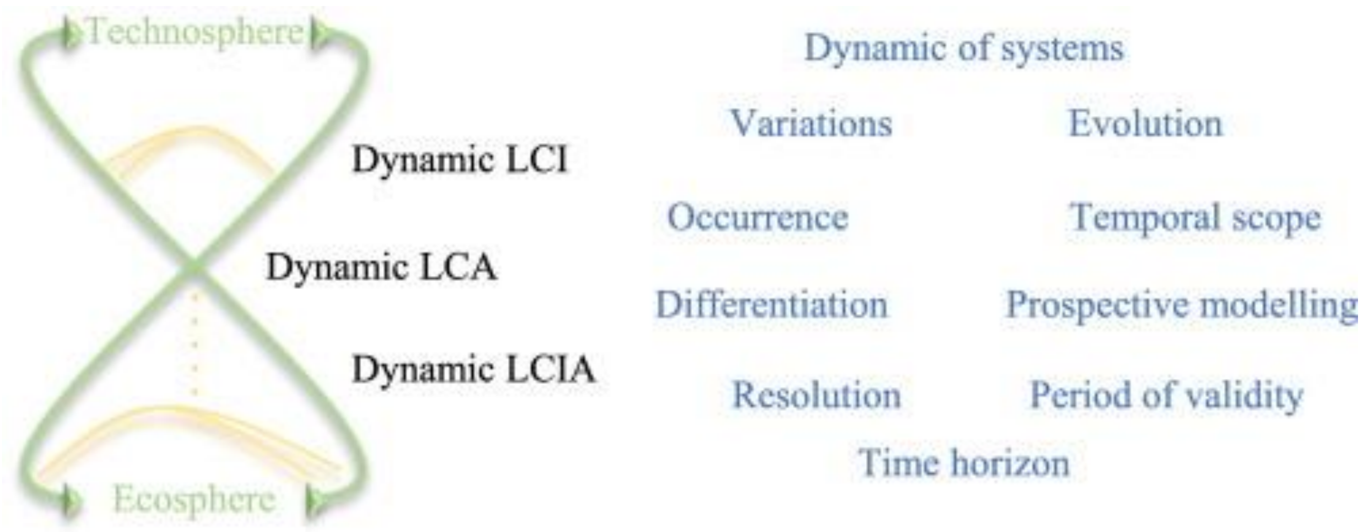

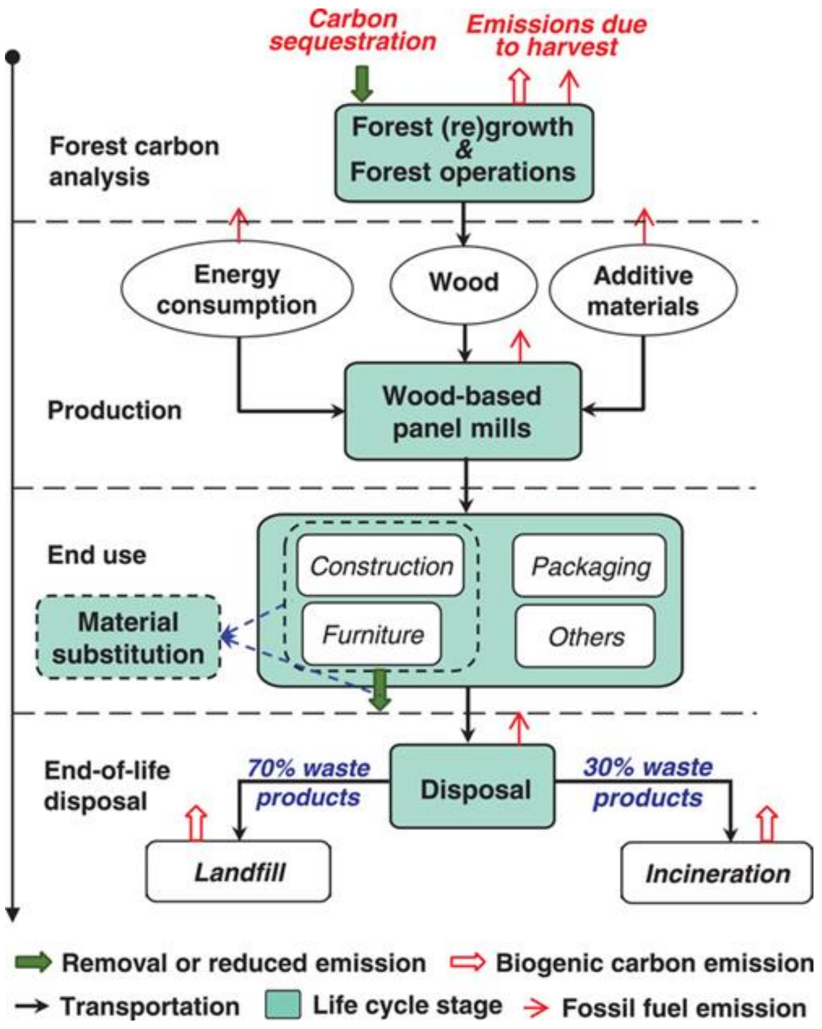

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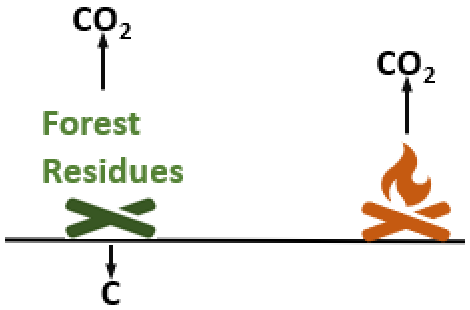
Life Cycle Assessment of Forest Residue Utilization

Forest Plantation and Management

Residual Management



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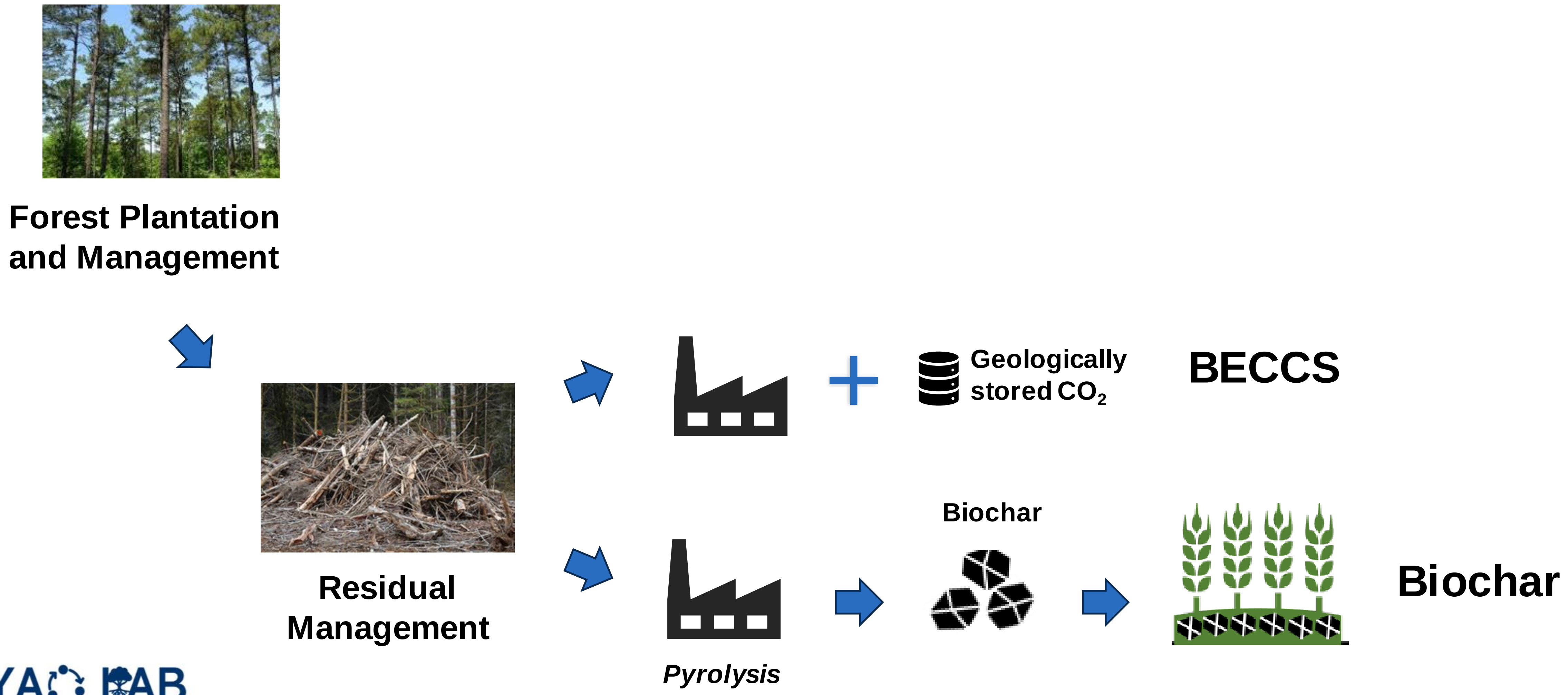


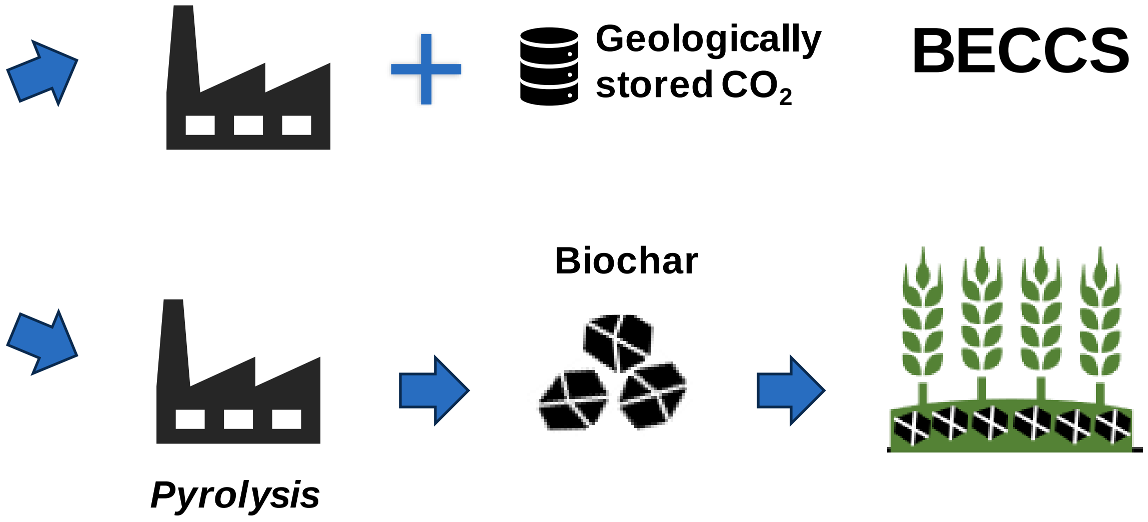
Life Cycle Assessment of Forest Residue Utilization

Forest Plantation and Management

- **Consider GHGs of forest management activities**
- **More recent studies that consider counterfactual scenarios, e.g., decay, prescribed burning**

- **GAP: do not include the impacts of removing forest residues on soil carbon**

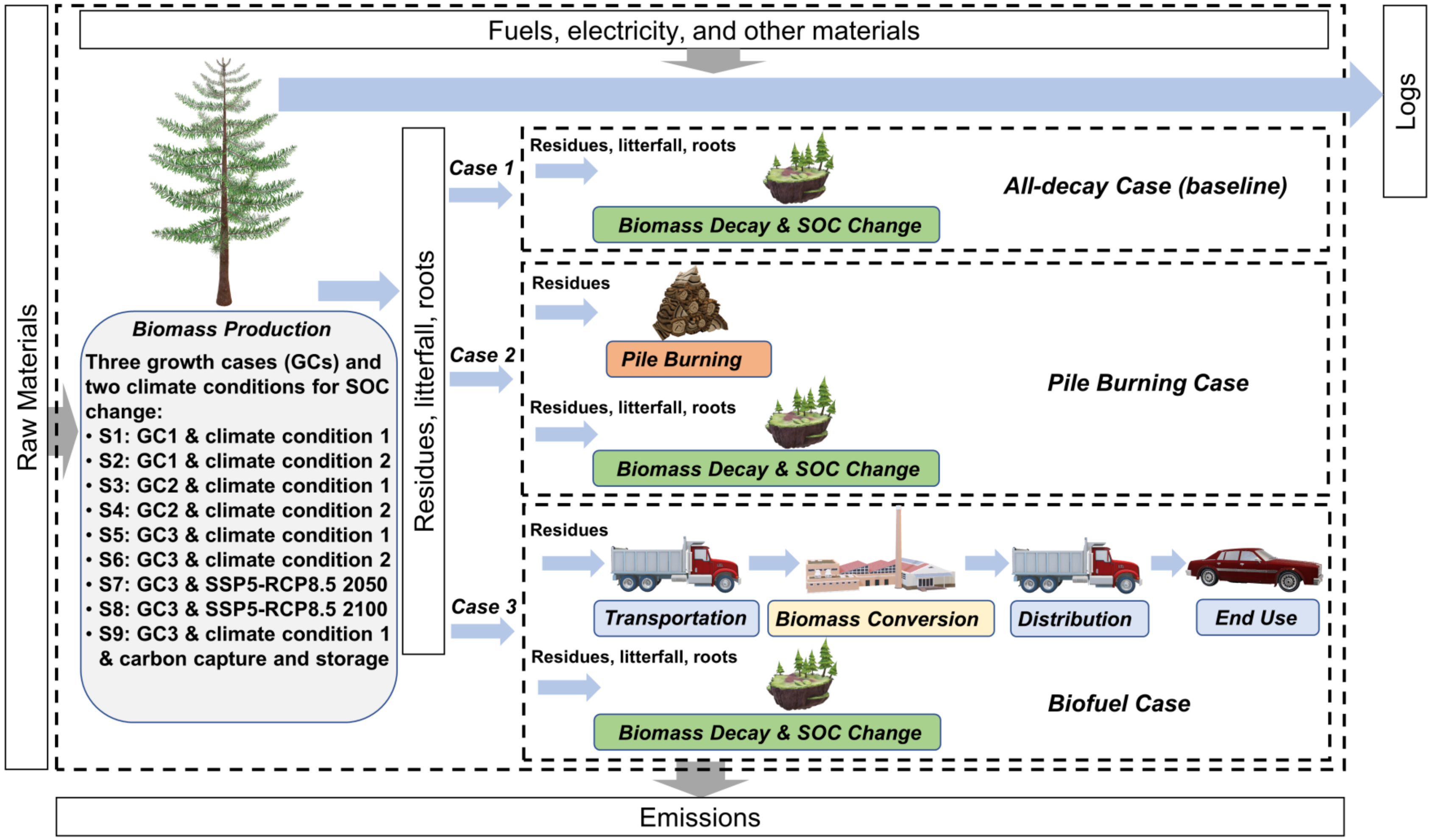
Residual Management



BECCS

Biochar

Life Cycle Assessment of Forest Residue to Biofuels



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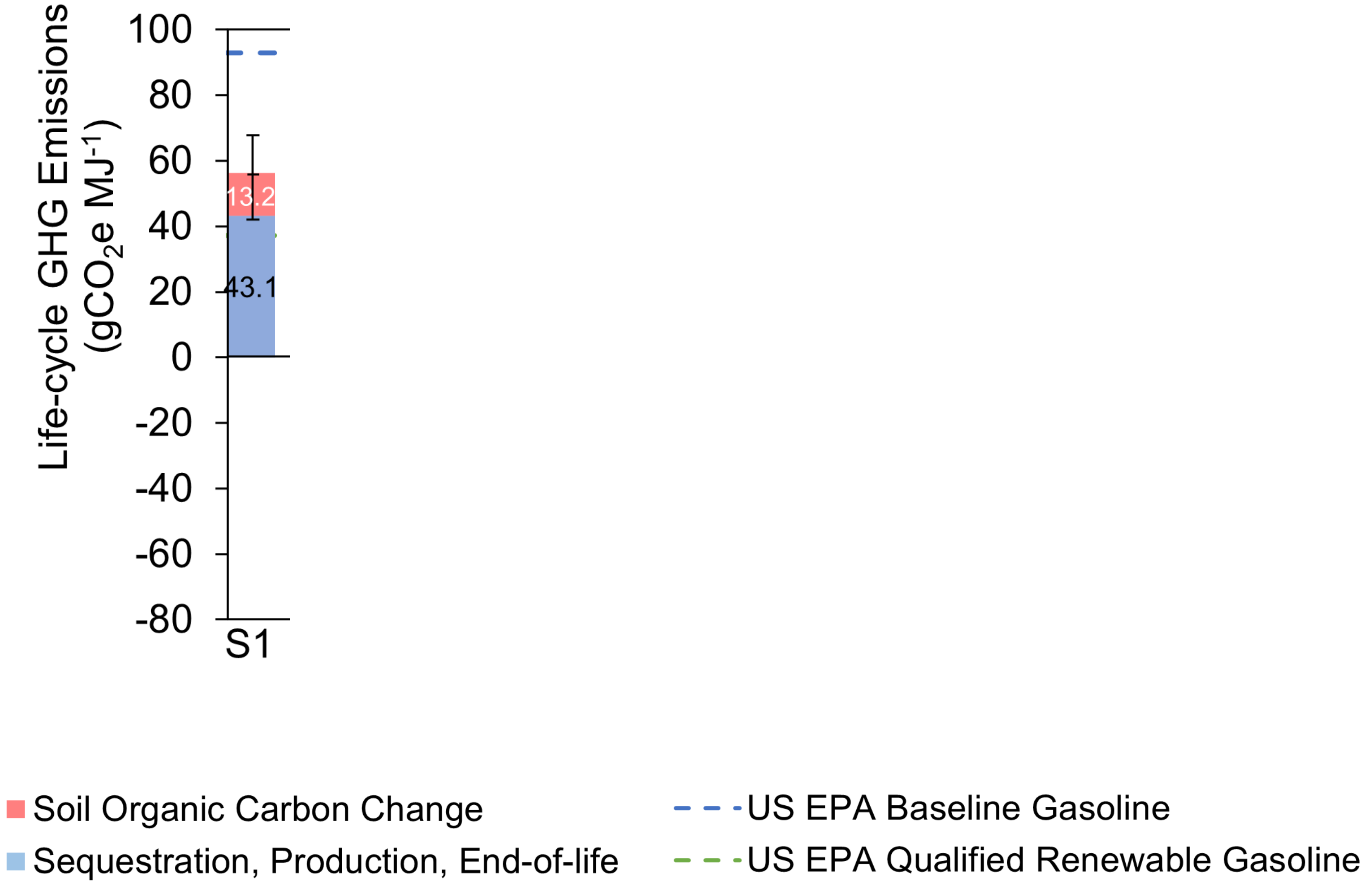

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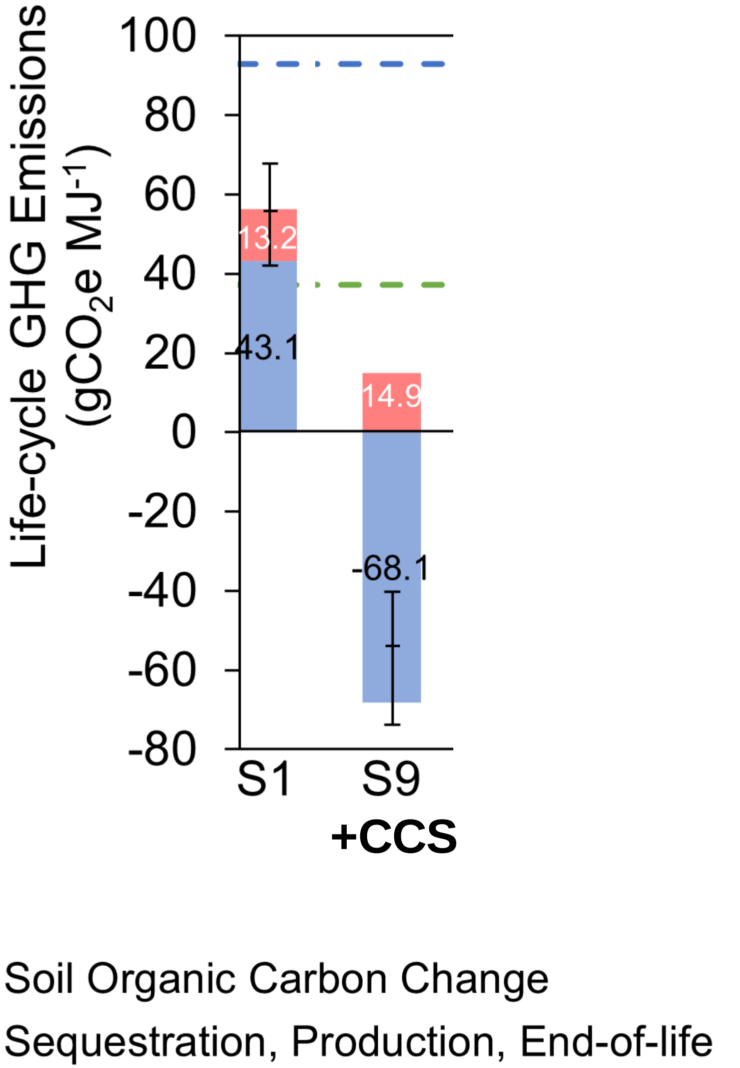

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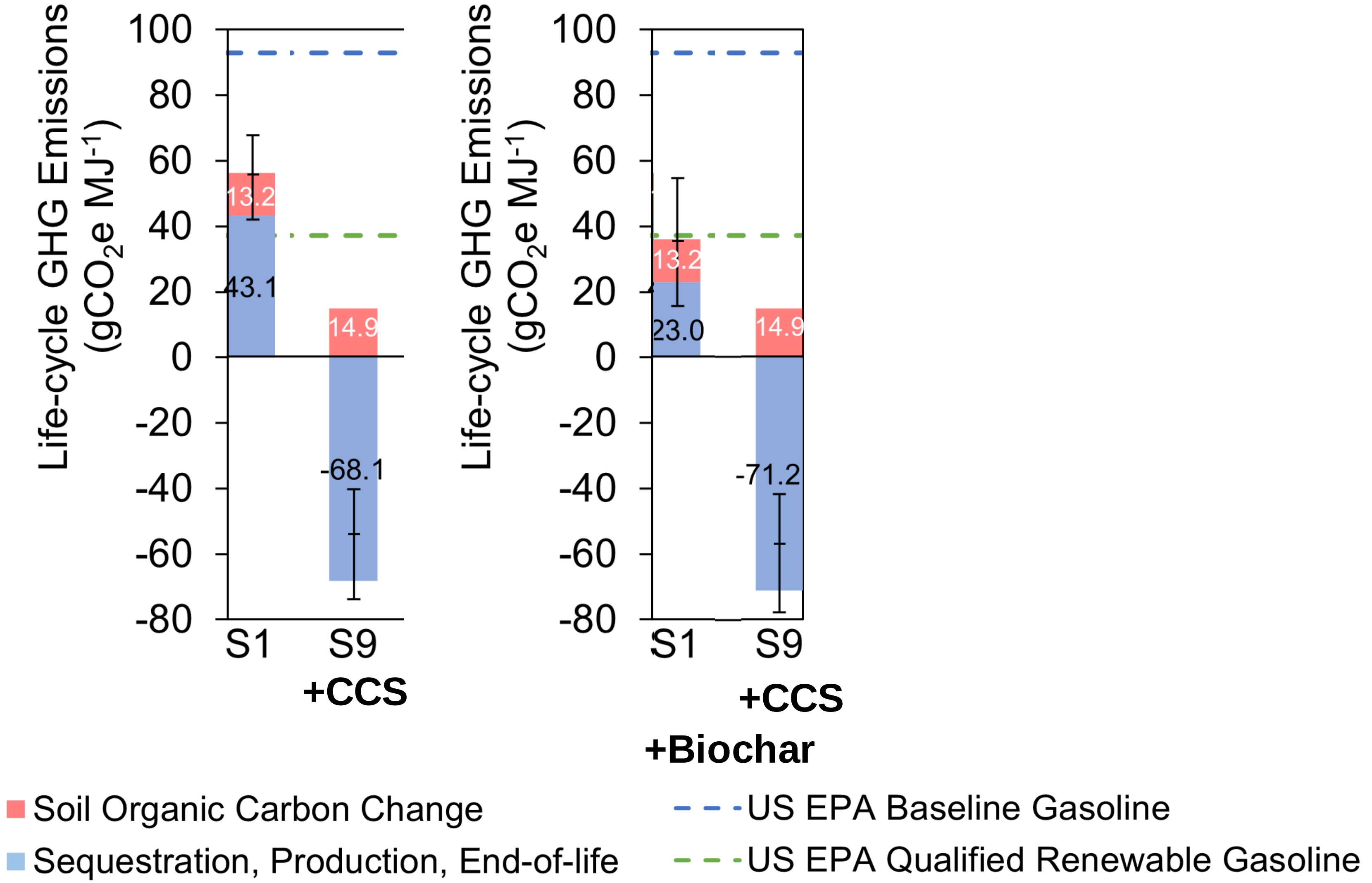

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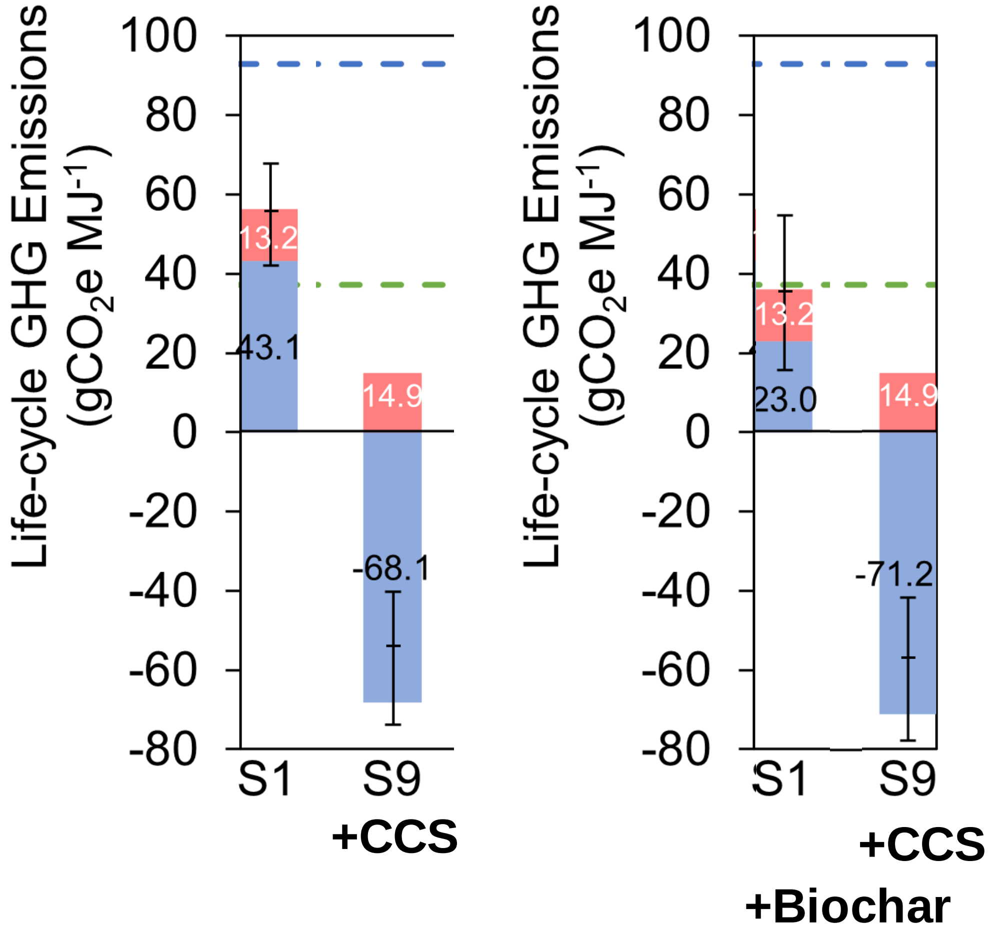
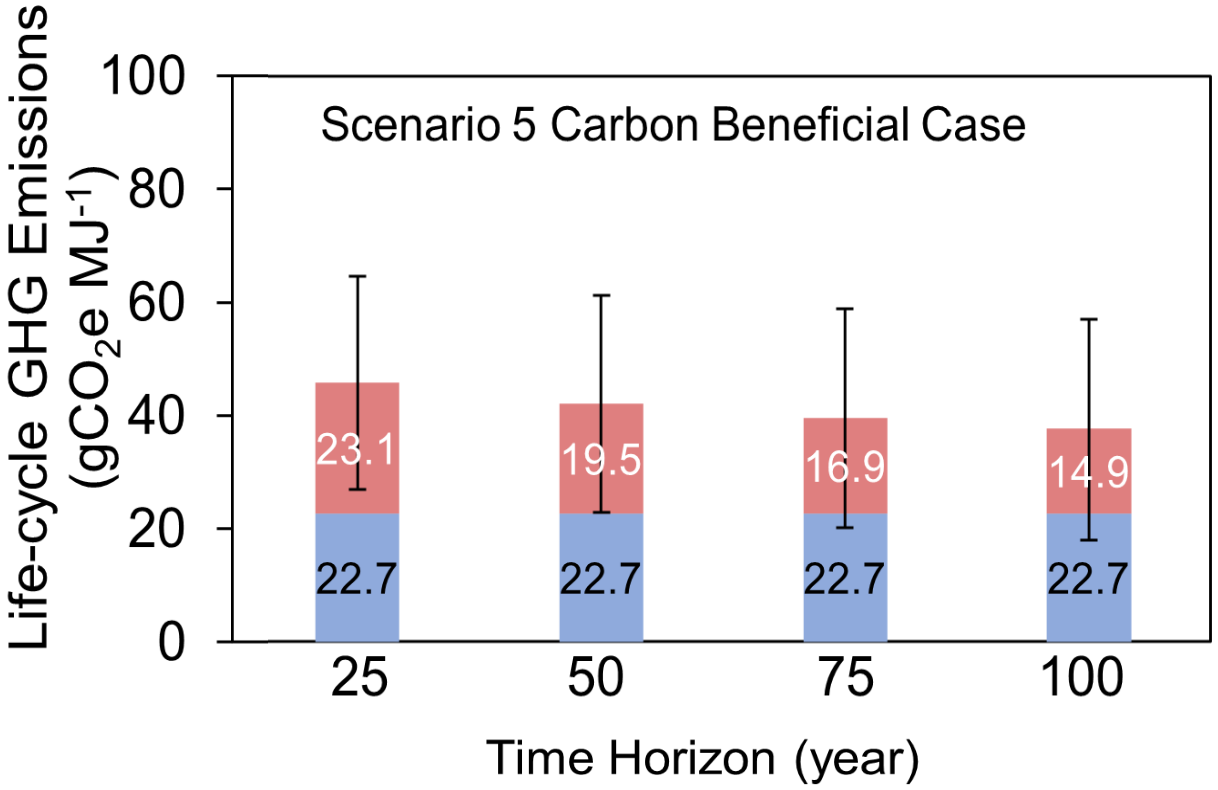
Need to include soil carbon assessment in LCAs of products using forest residues!





Soil Organic Carbon Change

Sequestration, Production, End-of-life

US EPA Baseline Gasoline

US EPA Qualified Renewable Gasoline

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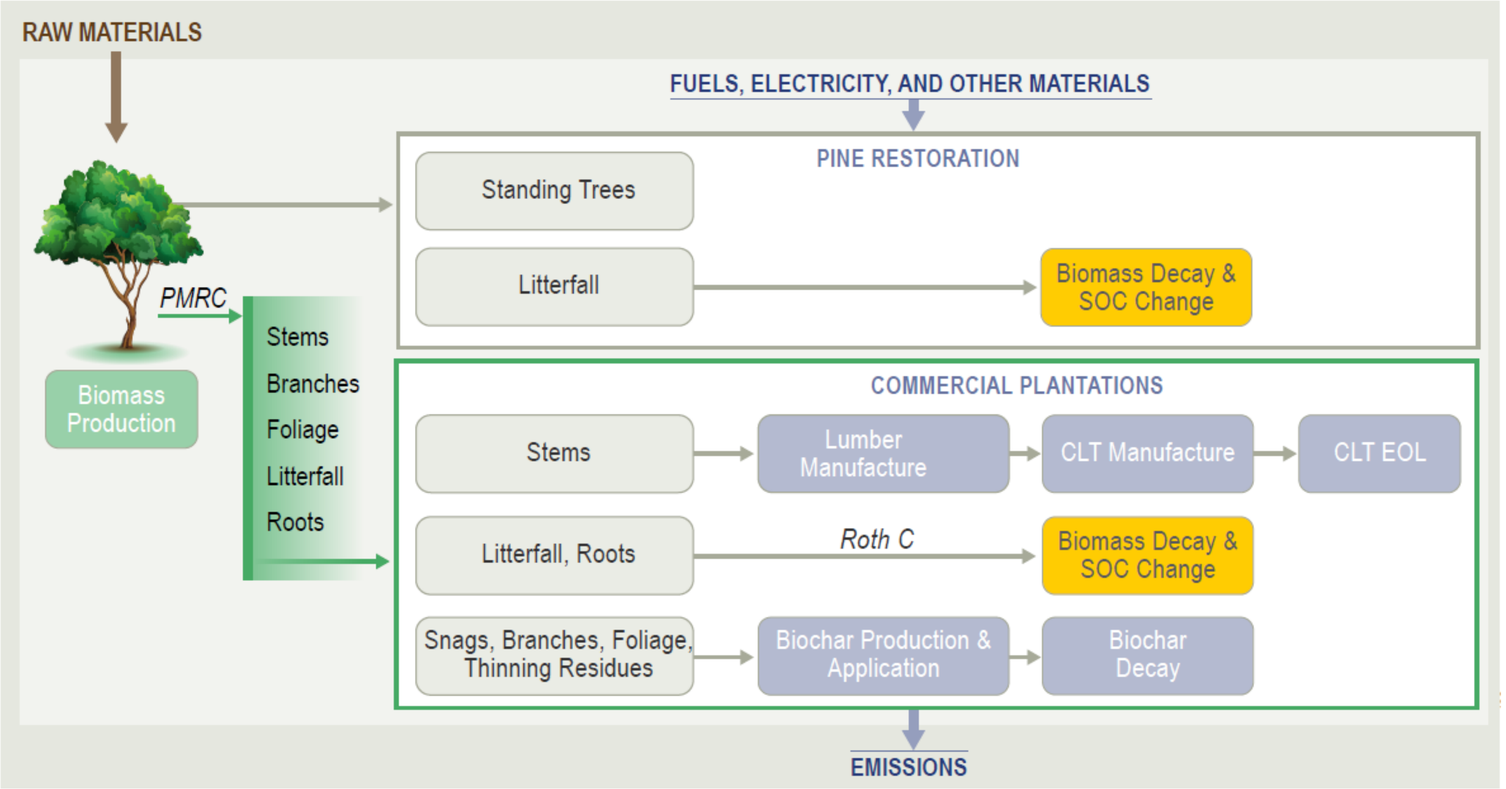

Takeaway Messages

- **Biogenic carbon flows from/to different carbon pools**
- **How they would differ by time, locations, and forest management strategies**
- **Counterfactual scenarios**
- **Don't forget about soil**

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One last thought – consequential LCA and market-mediated effects

Other wood products?

- **How the increased reliance on wood harvests affect global land use and carbon stored in global forests?**
- **How does the new use of wood affect the traditional wood use and corresponding carbon pools?**
- **How those market-mediated effects could be incorporated into the consequential LCA of wood products?**

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Acknowledgment

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- Yale Center for Natural Carbon Capture
- North Carolina State University

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