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Understanding Real CO_2e Emissions in Mass Timber Production

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SUMMARY

As the AEC industry seeks environmentally sustainable alternatives to construction materials, Mass Timber (MT) has emerged as a promising solution owing to its renewable nature and its inherent biologically sequestered carbon, resulting in lower embodied carbon compared to typical structural materials such as steel and concrete. Understanding and accounting for hidden emissions from MT harvesting and fabrication is crucial, as these significantly impact a project's carbon footprint and are essential for sustainable construction practices. In 2023, the World Resources Institute (WRI) published a report challenging the AEC industry's assumption that MT is carbon neutral, causing industry contention and sparking widespread discussion.

The intent of the research sprint taken on by Corgan's research and development and sustainability teams, which culminated in this white paper, is to understand MT's hidden emissions, review and present methodologies to assess those emissions — particularly concerning the CO_2e emissions from tree residue known as slash — and to re-evaluate the overall carbon impact of MT projects, inclusive of transportation of materials. This study highlights the significant CO_2e emissions from slash left after logging, impacting the carbon footprint of MT projects. It identifies tree species used in MT, evaluates slash management scenarios, and provides a qualitative analysis of embodied carbon through an office building case study. The paper also examines the effect of raw material transport on embodied carbon and offers recommendations for designers to manage it effectively.

As a bonus outcome of this effort, the team has developed a calculation tool to assess modified biogenic carbon in the in raw material supply stage (A1) taking into account slash management practices. The results show that the differences between the current biogenic carbon and the below ground and slash-released carbon can account up to 30-34% for structural columns, flooring, and framing. This methodology provides an estimation of omitted GHG emissions and brings us closer to real embodied carbon values in MT.

Introduction

Approximately 20% of a building's total energy use over its lifetime is determined before it is even built and occupied. This is a result of the embodied carbon emitted during the extraction, production, and transportation of materials used in construction[1]. MT projects have gained attention in recent years due to their perceived "carbon-neutrality" and sustainability characteristics compared to conventional construction materials such as concrete and steel – particularly for low to mid-rise projects. As a result, the global demand for wood products is expected to quadruple by 2050. However, as the 2023 WRI report states[2], there are hidden sources of CO_2e emissions, especially as it relates to timber harvesting practices, that are often overlooked. When assessing embodied carbon in the final MT product, it is vital to analyze how the debris and waste left behind during the logging operations — including bark, roots, branches, twigs, foliage, and sometimes larger pieces of wood that are not used for commercial purposes, also known as slash — can contribute significantly to near-term CO_2e emissions[3]. Understanding the amount of CO_2e released from slash in the raw material extraction phase (A1) of the life cycle assessment (LCA) is critical for developing more accurate and effective carbon management and mitigation strategies.

This study highlights the often-overlooked CO_2e emissions from the slash left behind after logging, and their significant contribution to the carbon footprint of MT projects. For the purposes of this study, reforestation is not being assessed as part of the embodied carbon accounting. The paper identifies different tree species typically used in MT products, applies varying scenarios for managing the slash-associated CO_2e emissions, and through a case study prototype of an office building, provides qualitative analysis of embodied carbon. The study also includes the impact of the transport of raw material (A4) on the embodied carbon and makes recommendations to designers on how to manage this effectively.

THE MT CARBON ADJUSTMENT TOOL:

A tool was developed to adjust and incorporate CO_2e emissions from slash across various tree species. The tool considers different scenarios for slash management and allows for biogenic carbon adjustment in Environmental Product Declarations (EPDs) (stage A1) based on input from the user. The tool uses factors including project location, wood species, and the location of the facility to assess CO_2e emissions related to the transportation (stage A4). A case study for embodied carbon assessment of an office building with MT structural elements is discussed in this paper to illustrate the practical application of these calculations.

Current Practices in Wood Harvesting & Mass Timber Production

Building material selection can significantly impact greenhouse gas (GHG) emissions throughout its life cycle. However, according to a recent paper published in Nature[4], wood harvests will add 3.5 to 4.2 billion metric tons of GHGs to the atmosphere annually by 2050, primarily due to emissions from harvesting, processing, and transporting wood. Additionally, the decomposition of slash and other residues left behind after logging significantly contributes to these emissions. Up to 50% of a tree's dry weight is sequestered as carbon through its lifecycle, however, with current timber harvesting practices, trees lose a significant amount of their stored carbon via slash.

Wood harvesting includes felling trees, crosscutting the felled trees into sections, debarking, and stacking in preparation for transport. Through this process, wood fragments are left in the forest which can occur in the felling sites, loading points, and log yards[5].

Slash: An Overview of Harvest Residues

As mentioned earlier, harvest residuals, or slash, are branches, leaves, and other non-commercial tree parts left after logging. They play a key role in the carbon cycle by initially storing biogenic carbon absorbed by trees. However, as slash decomposes over the years, stored carbon is gradually released back into the atmosphere[6]. Effective management of harvest residuals can mitigate the immediate release of biogenic CO_2 emissions by reducing slash decomposition and other post-harvest waste processes. This approach enhances the net biogenic carbon retention in mass timber products, thereby increasing the carbon storage potential within the built environment over the product's service life.

Figure 1 describes the journey that harvested wood takes before it is used in buildings. This process highlights the value chain and material allocation in the wood industry.

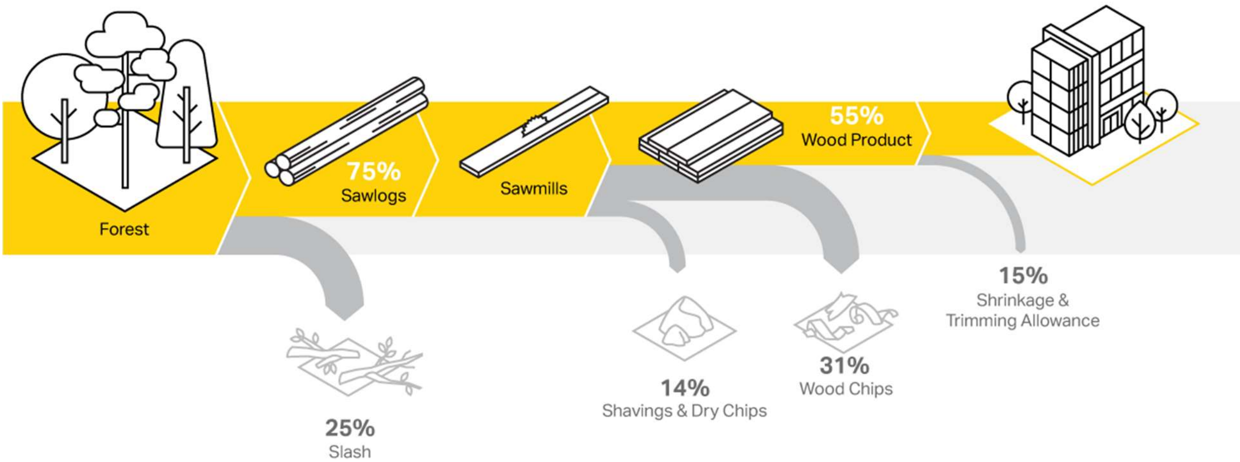

Image Adapted from [Wood-working basics](), UNSW Sydney[7]

Figure 1. The process of transforming harvested wood from the forest into building material, illustrating the percentage of residues generated at each stage.

Slash Management

PILING AND BURNING

Pile burning is a method for clearing woody debris that reduces fire risk, controls pests, and prepares soil for new plantings. It is beneficial where biomass facilities are unavailable and near urban-wildland interfaces. This technique adapts to various weather and terrains, ensuring quick fuel consumption with minimal smoldering. However, it has significant drawbacks, including high carbon emissions, air quality concerns, and nutrient loss[8,9,1011].

Slash burning can release 92–94% of its carbon content in a short period of time, significantly increasing emissions[12].

MASTICATION

Mastication cuts, chops, or grinds vegetation into mulch left on site, and is useful where burning is difficult and for preparing prescribed fire sites. Benefits include reducing fuel loads, improving soil health, enhancing water retention, and mitigating fire risk. However, it requires specialized, costly equipment and may cause soil compaction[13]

LEAVING SLASH ON SITE

This practice involves retaining logging residues on the forest floor or piled in designated areas which helps with returning nutrients to the soil and with preventing soil erosion. However, it can hinder forest regeneration and pose a potential fire hazard if not managed properly.[14]

Material Life Cycle

The life cycle assessment (LCA) is divided into four stages (A-D). This study focuses on forest and site (A1 and A4) life cycle phases of the material — A2 and A3 are considered constant.

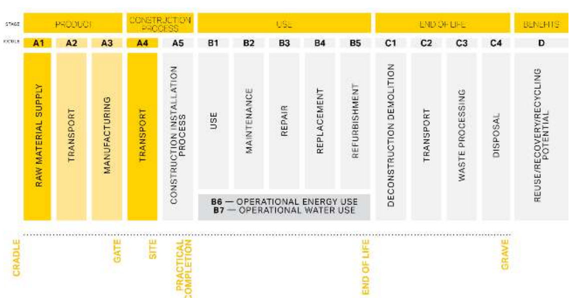

Figure 2. Life cycle assessment stages, with scope of the study highlighted.

Assumptions and Study Scope

This research addresses the question: What is the impact of tree leftover parts; and wood species selection; and its typical geographical location on carbon emissions; and how should these factors be integrated into carbon calculations?

To answer this, the following assumptions are considered:

- Four scenarios for timber harvesting:
  - Leaving all the slash and log leftovers in the environment.
  - Burning all the slash.
  - Mastication, or mulch returned to the forest floor.
  - Using the byproducts; wood residues can find a secondary market.
- Carbon emissions associated with the product stage transport (A2) are considered negligible since the sawmill factories are mostly built near the forests and hence are assumed as a constant value in all scenarios.
- The methodology and outcomes of the assessments are qualitative in nature, since the inputs are based on other sources including reports and papers and not on actual observation and measurement of slash on-site.
- The CO_2e from cutting machinery in the forest is to be presumed constant in all scenarios and thus not included.
- The study does not cover the burning of biomass in the manufacturing process (A3).
- The CO_2e from manufacturing equipment in A3 is to be presumed constant in all scenarios and thus not included.

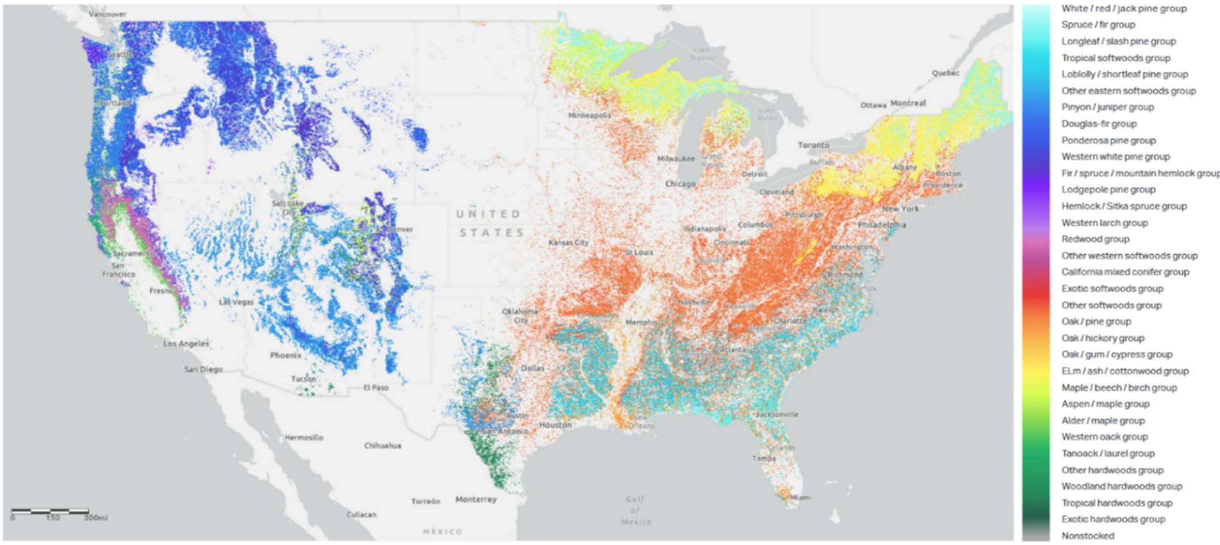

Figure 3. Different types of U.S. forest groups used as timber supply. Source: (Corgan, 2023)

- The EPDs for the wood products is sourced from OneClick LCA.
- The analysis uses MT for specific structural elements in the building, namely:
  I. Structural beams
  II. Structural columns
  III. Structural floors

This research investigates the wood characteristics of tree species from various North American forests, as depicted in Figure 3~~Figure 3~~. The study covers the abundance and prevalence of tree species, which vary due to geographic and climatic differences across different regions.

- Northeast: The research highlights that the predominant species used for MT are Spruce Pine Fir and White Pine.
- Southeast: It identifies Southern Yellow Pine as the most utilized species for MT.
- Pacific Northwest: The study explores several key species, including Douglas Fir and Western Hemlock, that are prevalent in this region.
- Southwest: The research notes a lower level of manufacturing and use of MT. However, it documents that projects in this area often employ wood from other regions, with Ponderosa Pine being the closest local species.

The manufacturer-provided EPDs, compliant with ISO 21930, consider MT carbon-neutral when sustainably sourced. This assessment is based on full life cycle evaluations and precise carbon accounting. In this framework, the CO_2 absorbed during tree growth offsets emissions generated during processing and end-of-life stages. However, this carbon neutrality is not applicable if the wood is unsustainably sourced, lifecycle assessments are incomplete, sequestration is delayed, or other carbon stocks are displaced.

These findings underscore the regional variations in species availability and use, which significantly impacts the selection of wood for MT construction projects across North America.

Study Limitations

This study has several limitations that should be acknowledged to provide a clear understanding of the scope and constraints:

1. Estimation Methodology:

- A general formula is used for estimating the slash generated per tree. There has been no on-site data collection for this aspect, which may affect the precision of the estimates.

2. Tree Age and Health Variability:

- The study does not account for variability in tree age and health, relying instead on industry averages. This could lead to less accurate representations of wood characteristics.

3. Life Cycle Assessment:

- The research only examines cradle to site (A1-A4) life cycle phase of the material, excluding the use and end-of-life stages. This limitation may provide an incomplete view of the material's overall environmental impact.

4. Geographic Limitations:

- The study is restricted to specific regions within North America. This geographic limitation might result in missing broader insights that could be applicable in other areas.

5. Data Source Reliability:

- There is a dependence on secondary data sources, which might not be as comprehensive or up-to-date as primary data. This reliance could influence the accuracy and relevance of the findings.

6. Product Sourcing:

- Determining sustainable sourcing and forest management practices other than slash were not evaluated and not focused on for this study.

By recognizing these limitations, readers can better interpret the results and conclusions of this research within the context of these constraints.

Methodology

In the first step (Figure 4), to account for the slash generated as a percentage of the tree during the A1 stage, the researchers conducted a comprehensive literature review using USDA forestry and academic databases[15].

Next, three main scenarios for slash's end-of-life scenario have been considered.

- **Site Composting**: Leaving all the slash and log leftovers in the environment.
- **Pile Burning**: Burning all the slash in a controlled environment.
- **Mastication**: Creating mulch and spreading them in the forest.

Figure 4 below shows the framework of the research methodology.

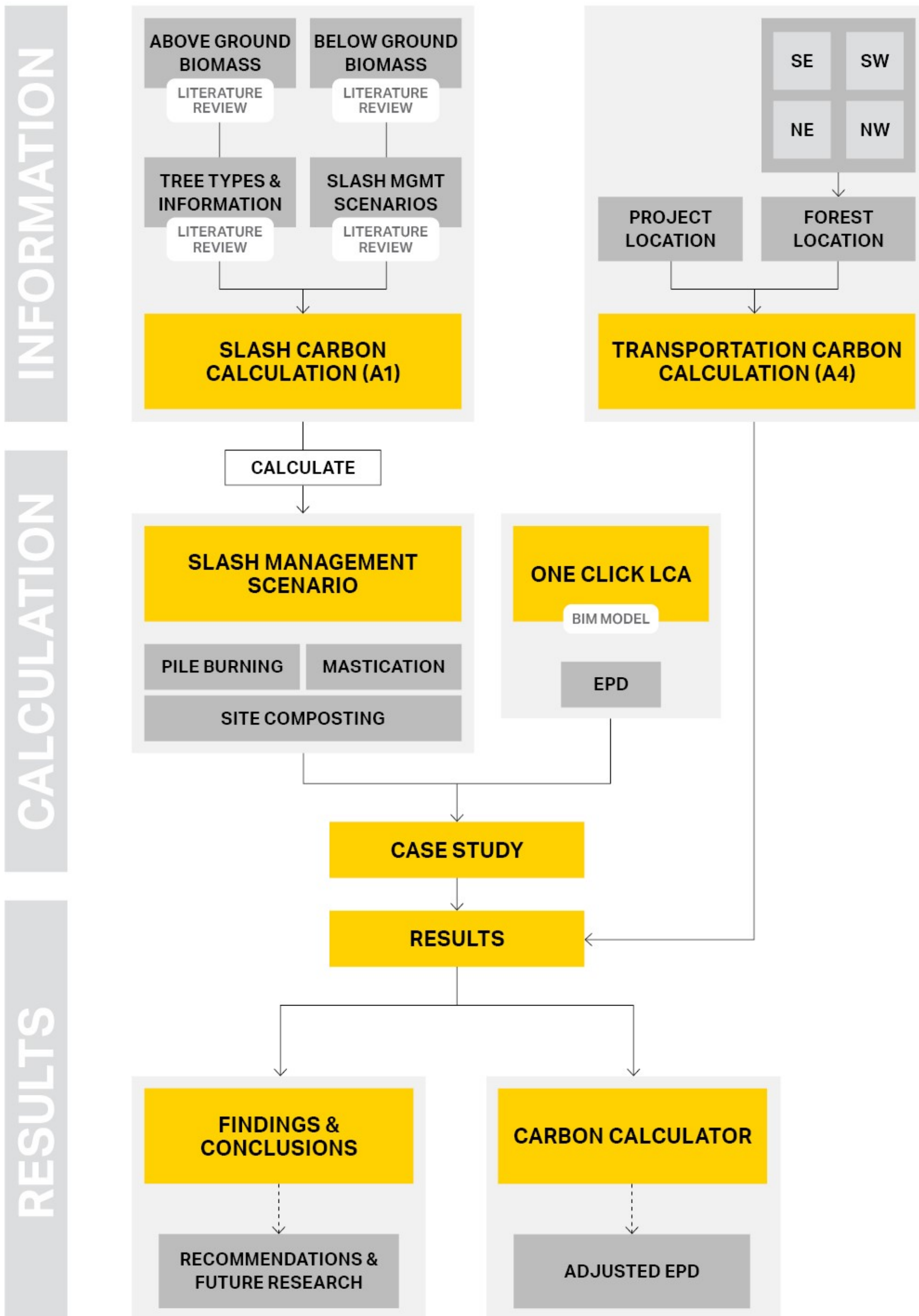

Figure 4. The study main methodology

Selection of an LCA Calculation Tool

To evaluate the embodied carbon of MT products from their cradle to site (A1–A4) life cycle, the researchers used OneClick LCA as the primary carbon accounting tool, focusing specifically on biogenic carbon.

OneClick LCA calculates the biogenic carbon stored in wood products but does not report biogenic carbon flows throughout the product's lifecycle or include biogenic carbon in the overall Global Warming Potential (GWP) assessment.

Due to its unique handling of biogenic carbon, OneClick LCA was selected for this analysis. It provides detailed biogenic carbon storage information and accommodates assumptions when biogenic carbon details are unavailable in EPDs.

Tree Species Studied

In this study, we analyzed seven different trees species that are the most frequently used in MT production for use in building construction, according to Corgan's 2023 Mass Timber report [16]. These tree species include:

1. Alaska Yellow Cedar

2. Douglas Fir

3. Hemlock Fir

4. Ponderosa Pine

5. Southern Yellow Pine

6. Spruce Pine Fir

7. Western Red Cedar

These species were selected due to their prevalent use in construction and availability in MT applications.

Dynamic Carbon Accounting Model

To accurately determine the amount of modified biogenic carbon in the final product based on building specifications, Corgan developed a dynamic formula accounting model. This model considers several key factors.

1. **Below-Ground Biomass Carbon Stock**: The carbon stored in the roots and soil of trees.
2. **Carbon Emissions from Slash**: The residual biomass left after logging contributes to carbon emissions as it decays.
3. **Decay of CO_2e Over Time**: The gradual release of CO_2e into the atmosphere as organic materials decompose.

Using Autodesk Revit to quantify the wood in the building, the number of trees harvested to produce Cross-Laminated Timber (CLT) and Glue-Laminated Timber (GLT) products was calculated. This calculation takes into account all the material losses that occur during the processing of trees from the forest, including losses at sawmills and timber factories, which account for approximately 65%, as discussed earlier in the study in Figure 1.

Carbon Sequestration & Release Calculations

In the AEC domain, accurate calculation of carbon storage is critical for understanding the environmental impact of various materials and processes. This section delves into the methodologies used to calculate the amount of CO_2e biologically sequestered in the tree and then released from slash during harvesting activities, using established models and empirical data.

Sequestered Biogenic Carbon

ABOVE-GROUND BIOMASS (AGB) CALCULATION

The Chave model[17] is employed to estimate the above-ground biomass (AGB) of trees, which is fundamental to determining carbon storage. The formula used is:

$$AGB = 0.673\,.\,(\rho.\,DBH^2.\,H)^{0.976}$$

Where:

AGB: Above-ground Biomass (pounds)

DBH: Diameter at breast height, measured at 1.35 meters above the ground.

H: Tree height (feet)

ρ: Wood density

The tree-specific values such as DBH, H, and ρ were taken from the wood database website for each of the tree species that are used to fabricate MT[18].

BELOW-GROUND BIOMASS (BGB) CALCULATION

Below-ground biomass (BGB), representing the root system, is approximated as 26% of the AGB[19]. The calculation is:

BGB = 0.26* AGB

TOTAL BIOMASS (TB) CALCULATION

Combining AGB and BGB gives the total biomass (TB) of a tree:
TB = AGB + BGB = AGB + 0.26 x AGB = 1.26 * AGB

DRY WEIGHT AND CARBON CONTENT

A tree typically consists of 72.5% dry matter[20]. Thus, the total dry weight (TDW) is calculated as:
TDW = TB x 0.725
Since carbon constitutes 50% of the dry weight:
Total Carbon (TC) = TDW * 0.5

CO2 EQUIVALENT SEQUESTRATION

The CO_2 equivalent is derived from the carbon content. Given the molecular weight ratio of CO_2 to carbon is 44/12 (or 3.67):
CO_2 equivalent weight = TC * 3.67

CO_2e Release from Slash Decomposition

The calculated value above represents the total CO_2e sequestered over the whole tree's lifetime[21]. However, the carbon release in decomposition scenario happens gradually. To model CO_2e release from decomposing slash, an exponential decay model as used:

$$M(t) = M(0).e^{-kt}$$

Where:

M (t): Mass at time T

M (0): Initial mass

K: Decay Constant

Results

Corgan Mass Timber Carbon Calculator

To help designers estimate and account for the effect of slash on the amount of biogenic carbon, using the formula above, the Corgan Hugo-Echo team developed a tool that calculates the CO_2e released from the slash for two variables, 1) varying tree species and 2) in different scenarios the slash end life. The intent of this exercise is to modify the amount of biogenic carbon that is featured in EPDs (stage A1) by applying additional carbon emissions calculated. Using the data collected from different tree species from USDA[22] and wood database[12], (Table 1) four different scenarios were created for wood slash as discussed earlier in the paper.

Table 1. Tree species characteristics.

	Species	Height (ft)	Diameter(ft)	Slash Generated	Dried Weight (lb/Ft3)	Decomposition Rate [Per Year]
	Alaska Yellow Cedar	100-120	4_6	25-30%	31	0.05 - 0.1
	Douglas Fir	200-250	5_6	20-25%	32	0.1-0.15
	Hemlock Fir	65-100	2_3	20-25%	28	0.1-0.2
	Ponderosa Pine	100-165	2_4	15-20%	28	0.1-0.2
	Southern Yellow Pine	65-100	2_3	20-30%	35	0.15-0.25
	Spruce Pine Fir	65-100	2_3	20-25%	33	0.1-0.2
	Western Red Cedar	165-200	7_13	25-30%	23	0.05-0.1

Next, the AGB and BGB calculations were done for each scenario accordingly. For example, in the site composting scenario, the tree slashes decay over a long time, whereas in the pile burning scenario, most of the slash mass burns and is released into the atmosphere in a short period.

As the study covers cradle to site (A1–A4) life cycle stages of the material life cycle, it first calculates the CO_2e emissions for the A1 stage and then assesses the emissions from the shipping process of the raw material. It is important to note that the A2 and A3 stages have been considered constant and have not been omitted, as discussed in the assumptions. This approach ensures a comprehensive analysis of emissions throughout the entire supply chain.

The distance between the manufacturing plant (Point A) and the construction site (Point B) was calculated using their respective geographic coordinates (latitude and longitude) in miles, using the haversine formula[23] (Kettle, 2021) adjusted for the earth's curvature and converting degrees to miles.

$$Distance = SQRT((\Delta X * 69)^2 + \left(\Delta Y * 69 * \frac{COS(RADIANS((\sum X))^2}{2}\right)^2)$$

X1 = Point A Latitude

Y1 = Point A Longitude

X2 = Point B Latitude

Y2 = Point B Longitude

The study assumes the use of 40-ton heavy trucks for material shipment. First, the number of trucks required was determined by dividing the total material quantity, derived from the quantity takeoff in Autodesk Revit, by the truck capacity. To calculate the CO_2e emissions from material transport, the emission factor for a 40-ton heavy truck (according to the EPA) was multiplied by the distance and the truck's tonnage[24]. This emission value was then doubled to account for the round trip, as each truck returned to the origin.

$$GHG_T = D * W * EF * 2$$

Where:

D: Distance, mile

W: Weight of the shipment, ton

EF: Emission Factor, Kg CO_2e/ton-mile

Case Study: Office Building with MT Structural Elements

To illustrate the practical application of these calculations, a case study of a theoretical 216,000-square-foot, six-story office building office building with MT structural elements was conducted (Figure 5). The building, which uses Douglas Fir and Spruce for its primary structural components, was analyzed for its CO_2 emissions from the slash.

The total volume of wood used in the building was estimated to be 115,2501 cubic feet, with Douglas Fir used in flooring and structural columns and Spruce used in framing. The biomass for each tree species was calculated based on the volume of wood used, and the corresponding carbon content was determined. The CO_2 emissions were then calculated using the formula previously mentioned.

An Autodesk Revit model is used to help quantify the amount of wood used in the project. The breakdown of the building elements is shown below.

Figure 5. Case study illustrating timber volume in square feet for structural columns, framing, and flooring

As discussed earlier, the study calculated the adjusted value of biogenic carbon in the A1 stage under different scenarios of slash management. Figure 6 shows the comparison of the current industry average biogenic carbon for each subassembly element of the building vs. the different slash management scenarios. This approach ensures a consistent basis for assessing the impact of different slash management strategies on biogenic carbon levels.

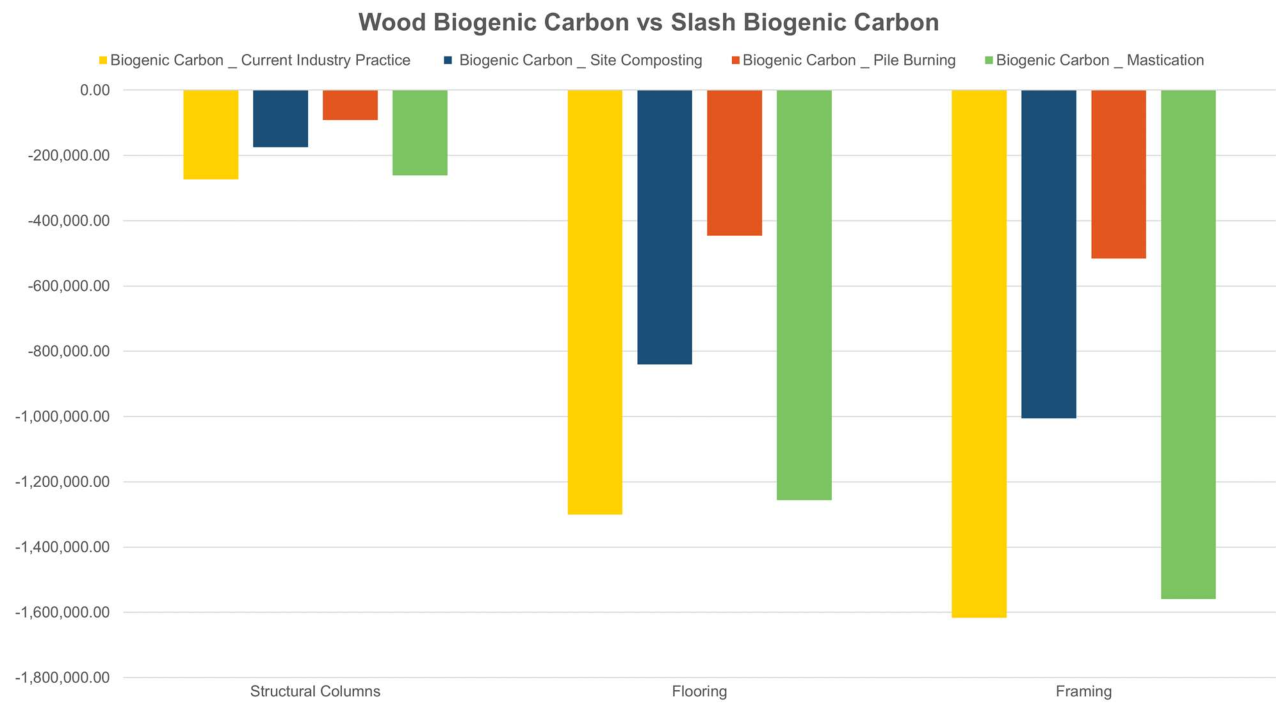

Figure 6: Comparison of the ~~I~~industry biogenic carbon for each subassembly element of the building with different slash management scenarios

The charts illustrate that the method of slash management significantly impacts the overall biogenic carbon balance of wood subassemblies. The pile burning scenario consistently shows the highest carbon release, indicating it has the most detrimental impact on the environment. In contrast, the mastication scenario shows minimal carbon release, suggesting it is the most environmentally friendly option for managing slash. When compared to pile composting or site composting, mastication releases less CO_2e in the environment as the materials are spread thinly over a large area, providing soil protection and nutrients[25].

Effective slash management is crucial for maintaining the carbon sequestration benefits of wood products. These insights can help guide decisions in sustainable forestry and construction practices.

In addition, it is important to note that in the site composting scenario, the CO_2e release happens gradually over a long period. In contrast, the CO_2e release of the pile burning, and mastication scenarios happens in a short period of time. For this study, Corgan selected a time horizon of 1 to 10 years for the decomposition calculations as most of the decomposition happens in the first decade.

Over a decade, approximately

80-90%

of the carbon in the slash is released as CO_2.

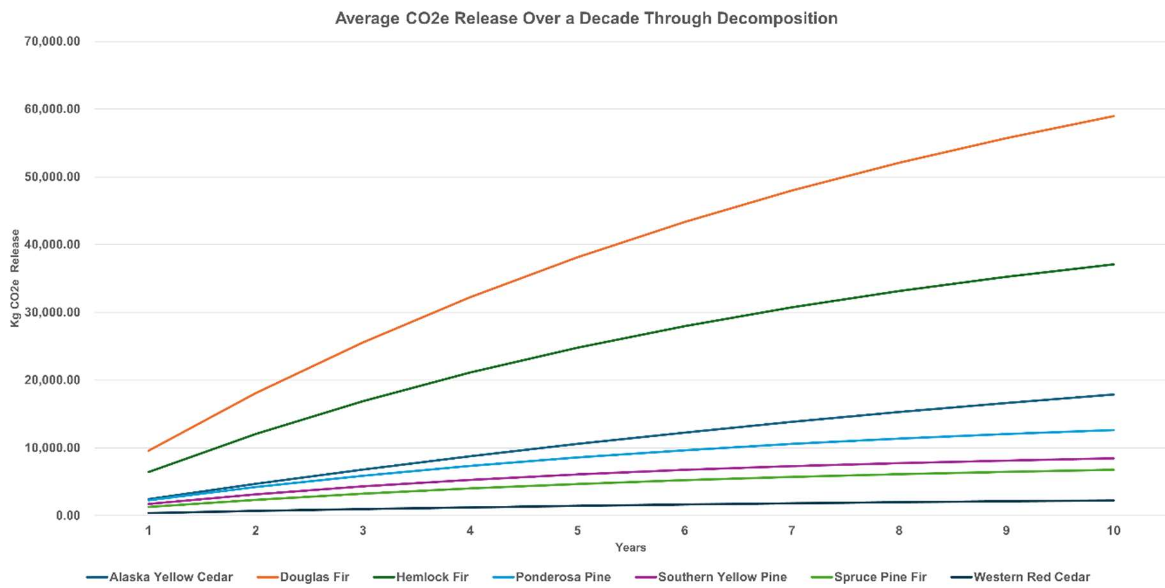

Figure 7. The average CO_2e released over a decade through the decomposition of different tree types

While the decomposition rate is a strong indicator of which wood type is optimal for use in buildings, designers and their clients take into consideration several other important factors in the material selection process. Elements like cost, transport, aesthetic, and density, may be more integral to certain project types to optimize the performance of the structure. A basic example of this would be if a client is in the Pacific Northwest region, building a data center, notoriously heavy and structurally demanding, it is more opportune to use Southern Yellow Pine, to achieve the highest density value, over the choice of Douglas Fir, which requires less transport and has a better decomposition rate. Using this tool can help designers to find suitable alternatives that are more local and thus generate less GHG emission from transportation.

Figure 8 illustrates the differences between the current biogenic carbon, the slash-released carbon, and the adjusted biogenic carbon for the three building components considered in the study: structural columns, flooring, and framing. The differences between the current biogenic carbon and the slash-released carbon were 35.15% for structural columns, 35.41% for flooring, and 37.78% for framing.

Figure 8. The differences between the current biogenic carbon (in kg CO_2e), the slash-released carbon (in kg CO_2e), and the adjusted biogenic carbon (in kg CO_2e) for the three building components considered in the study in the A1 scope

Biogenic EPDs

The study compares the current global warming potential value in the A1 stage for 1 cubic feet of timber from six different wood manufacturing companies [26,27,28,29], used for calculating the biogenic carbon of MT projects, with the adjusted calculated biogenic carbon EPDs when slash is considered. The following image shows this comparison for the site composting scenario.

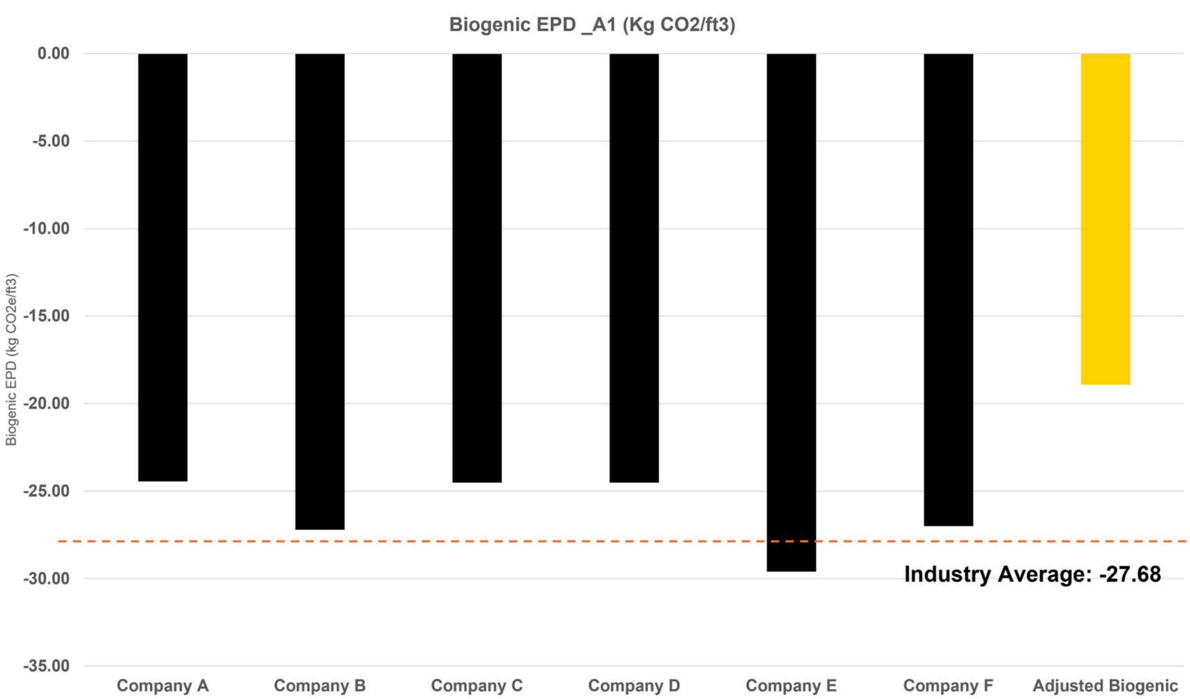

Figure 9. Biogenic carbon EPD comparison: six wood companies vs. adjusted biogenic carbon with slash

The comparison shows that when slash is considered, the biogenic carbon sequestration potential decreases, as evidenced by the higher (less negative) value of the adjusted biogenic carbon compared to the individual company values. This highlights the importance of effective slash management in maintaining the carbon sequestration benefits of wood manufacturing processes.

Tree Species

The chart highlights the impact of different tree species on biogenic carbon sequestration under three slash management scenarios: site composting, pile burning, and mastication. The biogenic carbon EPDs is measured in $kgCO_2e/ft^3$.

Figure 10. Adjusted biogenic carbon comparison by tree species and slash management scenarios

Figure 10~~Figure 10~~ shows how different tree species inherently have varying capacities for carbon sequestration.

Hemlock Fir and Southern Yellow Pine show significant variations in sequestration potential depending on the slash management scenario applied.

Alaska Yellow Cedar, Douglas Fir, and Western Red Cedar consistently show high sequestration potential, especially under mastication. These species can be prioritized in reforestation and timber production projects to maximize carbon sequestration benefits.

The mastication scenario universally enhances biogenic carbon sequestration across all species, making it the most effective method.

Pile burning significantly reduces the sequestration potential of all species, suggesting it should be avoided to maintain high carbon storage levels.

In conclusion, the selection of tree species plays a crucial role in the biogenic carbon sequestration potential of wood products. Species like **Douglas Fir**, **Alaska Yellow Cedar**, and **Western Red Cedar** show high sequestration capabilities, especially when combined with effective slash management methods like **mastication**. Understanding the interplay between tree species and slash management scenarios can guide forestry practices toward maximizing environmental benefits and enhancing the carbon sequestration capacity of forests.

Table 2 shows the matrix of scenarios for all species and resulting additional CO_2e emissions increase as percentage compared to the current industry average EPDs.

Table 2: Percentage increase of CO2e release of slash management scenarios compared to industry average EPDs

Timber Species	Percentage Increase_ Site Composting	Percentage Increase _ Pile Burning	Percentage Increase _ Mastication
Alaska Yellow Cedar	44.70%	79.56%	5.12%
Douglas Fir	36.04%	66.54%	4.32%
Hemlock Fir	33.54%	60.89%	3.94%
Ponderosa Pine	25.99%	46.07%	2.96%
Southern Yellow Pine	46.97%	83.34%	5.36%
Spruce Pine Fir	39.01%	69.11%	4.44%
Western Red Cedar	1.28%	49.13%	3.83%

Transport

Long transport distances from manufacture to the building site can have a considerable effect on the final embodied carbon of the building material. To demonstrate the effect of transport emissions on the sustainability level and embodied carbon of MT projects, four scenarios were created, each representing a different forest type: Northwest (NW), Southeast (SE), Southwest (SW), and Northeast (NE). For each U.S. region, a manufacturer was selected as the supply location, and specific project locations were identified.

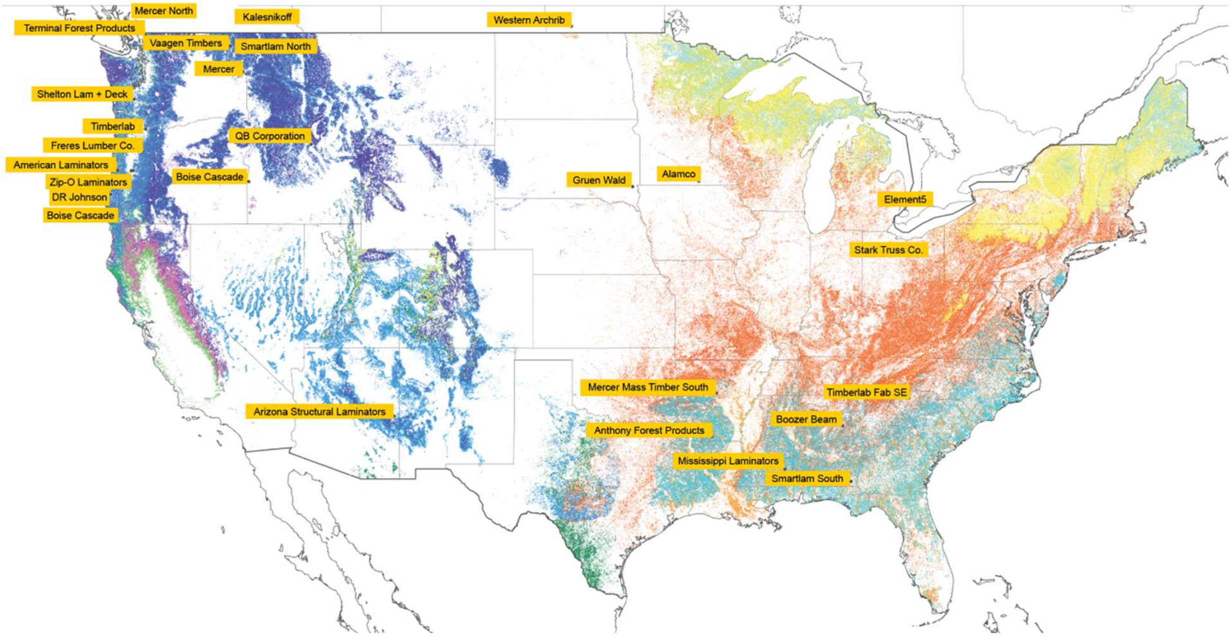

Figure 11. Locations of mass timber manufacturers in the U.S.

This approach allows us to analyze and compare the impact of transport emissions across various regions, providing valuable insights into how transportation distances and regional characteristics influence the overall environmental footprint of MT projects. By understanding these dynamics, AEC professionals can make informed decisions to optimize supply chains and enhance the sustainability of MT construction.

Table 3. The selected manufacturers for different study scenarios.

Scenario	Timber Sourcing Region	Manufacturer Location	Project Location	Transport Emission KgCO_2e	Difference Magnitude of Current A1 EPD
A	SE	El Dorado, AR	Dallas, TX	130,493.31	4.09%
B	NW	Spokane, WA	Dallas, TX	808,082.76	25.34%
C	SW	Eagar, AZ	Dallas, TX	395,753.55	12.41%
D	NE	Canton, OH	Dallas, TX	550,663.02	17.27%

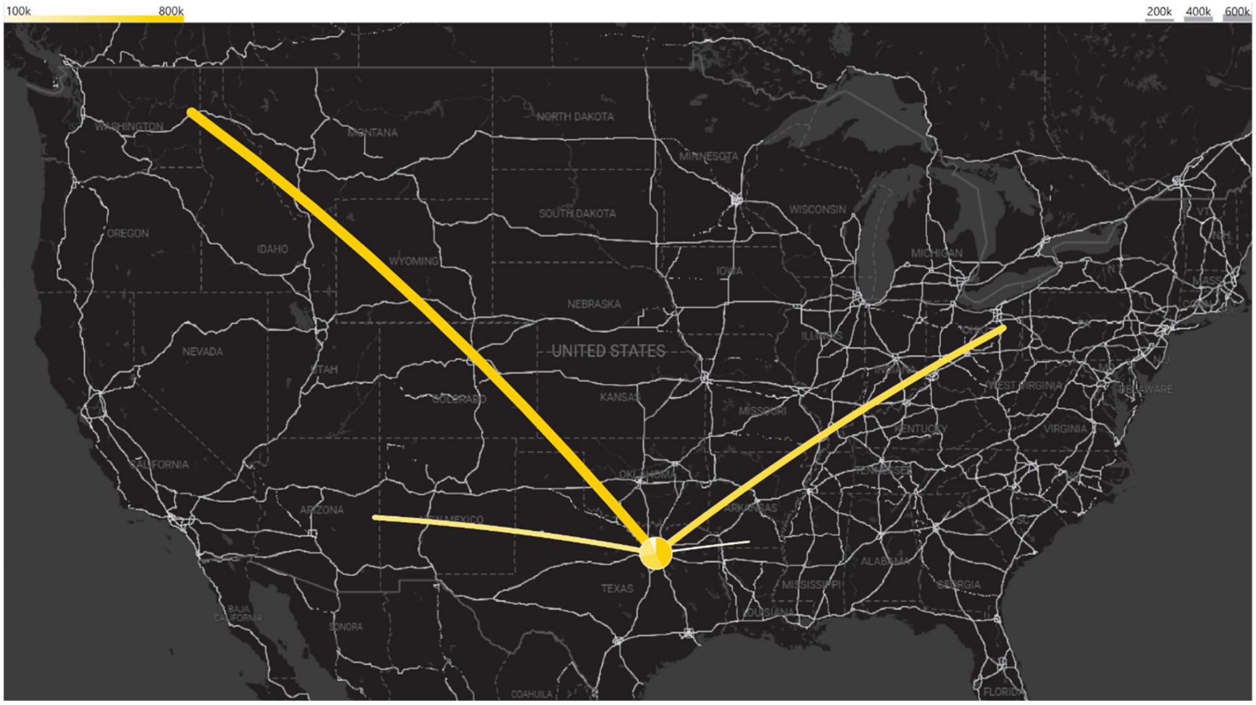

Figure 12. Amount of transport CO_2 to the construction site based on the distance of manufacture

Figure 12 illustrates the CO_2e emissions generated from transporting materials from each manufacturer location to a construction site in Texas. The line width and color range both indicate the amount of CO_2 emissions, with thicker lines and darker colors representing higher emissions.

Routes with thinner and lighter lines are more efficient in terms of emissions. This map helps us understand the emission impact of each route, enabling informed decisions about material sourcing. Clients often insist on specific types of wood that are native to certain forest types or are more cost effective. Therefore, as designers, it is crucial to consider which wood is used in the project and, if possible, choose alternative local options that are closer to the project site.

Given the considerable amount of CO_2e emissions associated with transporting materials, future research could investigate the potential of renewable energy sources to reduce overall emissions during transport.

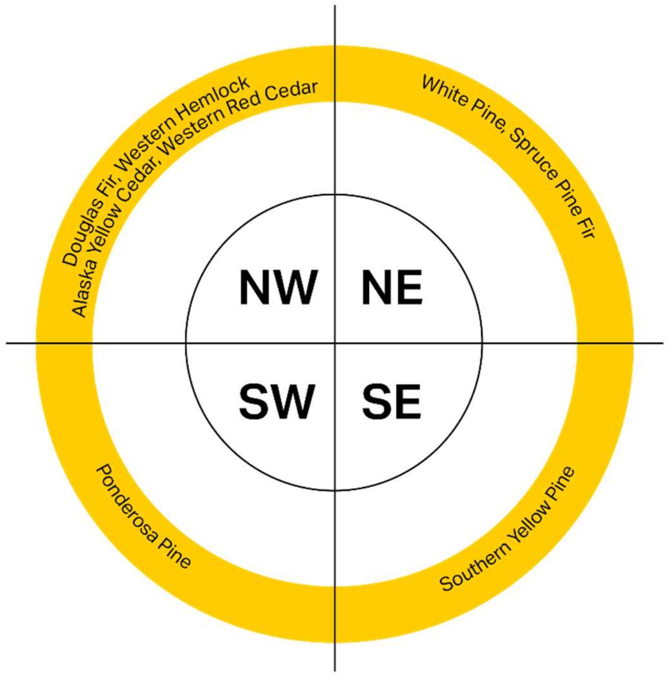

Figure 13. Tree species for each U.S. national quadrant

Figure 13 shows the tree species diversity based on the forest types. As shown in the image, NW forest has the highest tree diversity, making it an ideal supplier for designers. However, by understanding the carbon footprint associated with different transportation methods and distances, designers can make informed decisions to minimize environmental impact. Additionally, the study suggests strategies such as sourcing materials locally, optimizing transportation routes, and selecting low-emission vehicles to further reduce the embodied carbon in construction projects.

Insight & Future Work

- **Corgan Mass Timber Carbon Calculator:** Creating a dynamic biogenic EPD calculator for designers allows them to see the impact of slash management scenarios for different tree species, leading to more sustainable project outcomes. The calculator enables near real-time decision-making for selecting lower carbon-intensive timber types at every project phase, facilitating discussions with contractors and engineers.
- **Transparency in Slash Management:** Encourage designers to be vigilant about slash management by requesting information from manufacturing plants and material vendors. This promotes transparency and positive change across the supply chain.
- **Slash Pile Scenarios:** Highlight the difference between the long-term decomposition of slash piles and the rapid CO_2 release from burning, as well as mulching.
- **Local Material Sourcing:** Encourage architects to prioritize sourcing local materials to reduce embodied carbon.
- **Maximizing Carbon Storage:** Design to maximize the amount of carbon stored in timber during its use phase, using larger timber sections or tree species with the lowest CO_2e emissions from slash without compromising safety or performance.
- **Stakeholder Engagement:** Engage with stakeholders — including clients, contractors, and suppliers — to educate them about the importance of reducing hidden embodied carbon and foster collaboration to implement best practices throughout the project lifecycle.
- **Low-Carbon Tree Species:** Prioritize the use of low-carbon tree species for MT projects using data-driven decision-making tools.
- **Future Endeavors in Carbon Reduction:** Explore biogenic carbon reduction strategies for other building subassemblies such as curtain panels and stairs.

Advancing Industry Collaboration on Slash Transparency

The next step involves fostering industry collaboration and transparency about the slash created in the A1 stage. By sharing data and methodologies for managing slash, the industry can better understand its impact on carbon emissions. This collective effort will improve carbon accounting practices and promote more sustainable construction processes, ensuring all aspects of MT production are comprehensively evaluated and optimized for minimal environmental impact.

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