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Advanced Structures and Composites Center CLT Lab Addition

Building Life-Cycle Carbon and Operational Energy Report

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INTRODUCTION

The premise of this report is to surmise the embodied carbon impact and anticipated operational energy use of the 57,995 sf cross-laminated timber (CLT) and glulam addition to the Advanced Structures and Composites Center (ASCC) on the University of Maine campus. The project will contain open lab space for the world's largest prototype polymer 3D printer, offices, and a presentation venue.

A life-cycle assessment is a methodology for quantifying environmental impacts at all stages of a building's life cycle. This is a cradle-to-grave assessment of the building, beginning from raw material extraction and sourcing, to manufacturing, transportation, construction, energy use, maintenance and building end-of-life recycling/disposal. Figure 1 notes the individual stages which comprise the whole building life cycle.

The intent of the life-cycle assessment (LCA) is to evaluate the embodied carbon impact of the timber design and identify opportunities for impact reductions. The primary goal of the engineering analysis is to understand and determine the feasibility of the project operational energy use to achieve Zero Net Energy (ZNE) for the new lab addition. Using the results from the LCA, low carbon benchmarks will be developed for major structural components, to inform future timber developments on the University campus and in the Northeast region at large.

This report has been broken down by the following life-cycle stages:

- A1-A3: Product Stage
- A4: Transportation
- A5: Waste
- B1-B5: Maintenance/ Material Replacement
- B6: Operational Energy Use
- C1-C4/D: End-of-Life/ Reuse, Recycling, Disposal

Operational Energy Definitions:

Zero Net Energy : A zero net energy (ZNE) building is an energy-efficient building that produces as much energy as it consumes over the course of a year, usually by incorporating renewable energy generation on-site (Credit-NBI).

Energy Use Intensity : An Energy Use Intensity (EUI) is the total building annual energy use divided by the gross floor area. EUI enables comparison of similar building types.

Funding for this report was provided by the Maine Mass Timber Commercialization Center, a U.S. Economic Development Administration (EDA) funded effort to promote mass timber production in the Northeast.

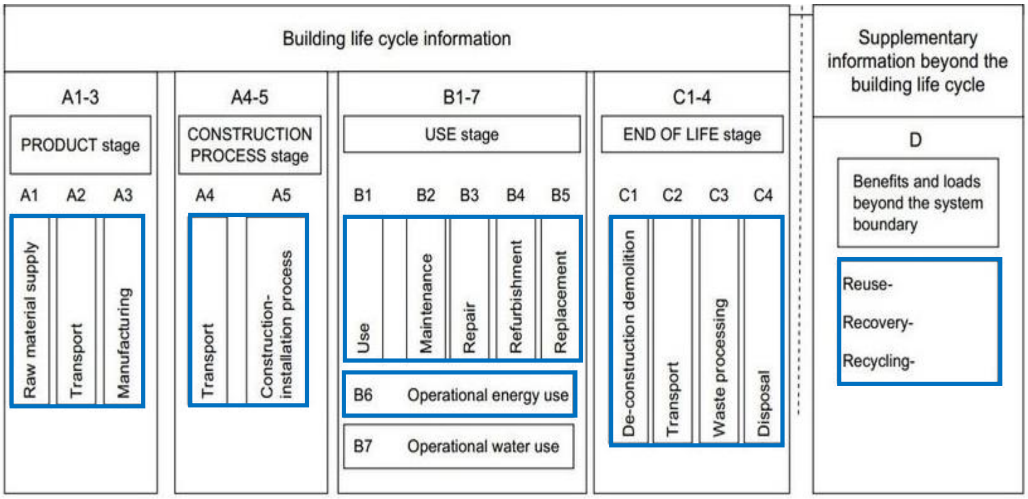


Figure 1: Stages of the whole building life cycle. Blue outline indicates stages incorporated into this assessment.

EXECUTIVE SUMMARY

A building's overall carbon emissions result from a combination of the carbon embedded in materials (embodied carbon) and the energy associated with maintaining building operations (operational carbon). As buildings have become more energy efficient over the last twenty years, research shows that the relative contribution of embodied carbon over the building lifecycle has become more significant (Architecture 2030). It is with this in mind that the University looks to build toward a sustainable future, taking advantage of the low carbon benefits offered by mass timber construction.

Life Cycle Assessment (LCA) Synopsis

To capture the full carbon picture of the Advanced Structures and Composites Center CLT Lab Addition, a preliminary cradle-to-grave whole building life cycle assessment was performed to examine the material carbon impact from major structural and architectural elements in the timber design.

The results demonstrate that the biggest stage contributor to the overall building embodied carbon footprint is the Product Stage carbon (1,397 tons CO2e). It accounts for approximately 82% of embodied carbon in the building. The Construction and Waste (181 tons CO2e), Maintenance and Replacement (60 tons CO2e) and End of Life (63 tons CO2e) stages have a minimal impact by comparison (Figure 2).

Operational energy is calculated separately but when factored in over the service life of the building, this energy use accounts for 86% of total carbon emissions. This includes all energy for lighting, HVAC and equipment plug loads in addition to a rooftop solar array.

Although wood is a renewable product that sequesters carbon during a tree's growth cycle, this carbon advantage is measured apart from the material life cycle stages. Following harvesting, a timber product's storage of carbon is highly dependent of the adaptive reuse or recycling strategies implemented at the end of the building's service life. Timber products should be repurposed whenever possible to keep the carbon they sequester within existing supply chains and prolonging the point at which they are landfilled or incinerated. Thus biogenic carbon is reported on in detail later in this report.

Overall, the life cycle stage that poses the greatest opportunity for embodied carbon reductions is the Product/material stage, which includes the selection, sourcing, and manufacturing of materials.

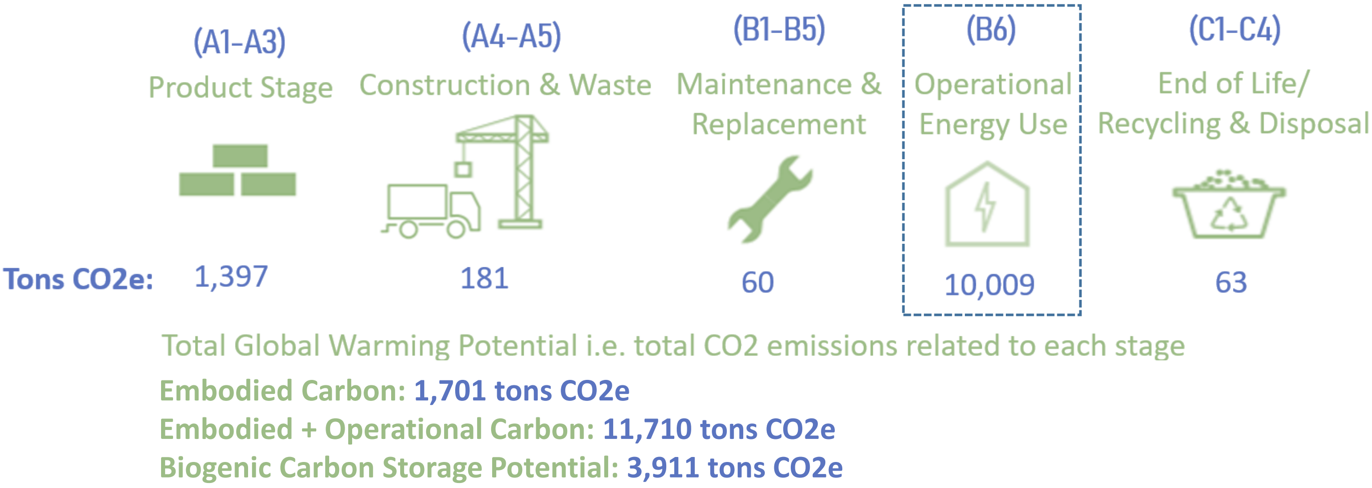


Figure 2: Total embodied and operational carbon emissions for the ASCC CLT Lab Addition.

EXECUTIVE SUMMARY

Operational Energy Analysis

Thornton Tomasetti (TT) facilitated discussions with the project architect and the owner to understand the nuances of the project design and operational schedules. Based on the information gathered, TT performed a preliminary energy analysis and estimated potential electric energy generation from Photovoltaic (PV) System.

TT's preliminary energy analysis indicates the project has an Energy Use Intensity (EUI) of 73 Kbtu/sf-yr. This metric normalizes the energy use of a building and allows comparison with typical building typologies in the same climate zone.

This provides a benchmark for the project to measure its performance against similar buildings. For the purposes of benchmarking, TT used CBECS database which indicates the design project performs roughly 47% better than a similar building in the same climate zone.

This project type demands high power draw due to the lab equipment and its consistent use pattern. TT's preliminary energy analysis shows that the project cannot meet the Zero Net Energy (ZNE) status with solely an on-site PV system. To achieve ZNE status an EUI of 28 Kbtu/sf-yr must be achieved. The estimated equipment plug load alone has an EUI of 25.

TT recommends that the design team review the information in this report and provide feedback on any variations to operational use or proposed systems to reduce the EUI. However, to attain ZNE status the project must achieve 28 EUI or lower. This is assuming a PV system only on the roof. Different from a typical office building, this project type demands high power draw due to the lab equipment and its consistent use pattern. The equipment plug load alone uses 25 EUI while HVAC/Lighting/Hot Water use the remainder of the EUI (47).

PRODUCT STAGE (A1-A3)

The first stage of the life-cycle assessment considers solely the Product Stage embodied carbon. This is the carbon emitted through the raw material supply chain, the transportation of these materials to the factory, and the manufacture of these materials.

The information used to conduct this analysis was drawn from architectural and structural drawings, Revit models and obtained through discussions with Scott Simons Architects, the University and the structural engineer, Thornton Tomasetti. The OneClick LCA tool was used to perform the LCA.

When comparing the global warming potential of materials, the biggest element type contributors to the building's overall embodied carbon are the facade and foundations, accounting for 69% of the building's total embodied carbon emissions (Figure 3). The main carbon drivers of the façade include the metal panel siding and glulam curtain wall system, while the concrete comprising the slab on grade and footings represents the bulk of the carbon found in foundations.

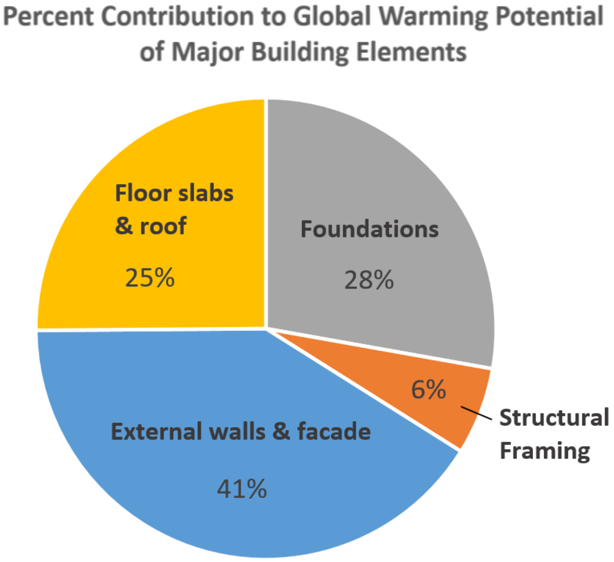


Figure 3: Percent contribution to embodied carbon by building element

To understand the impact of the major construction elements, which are the biggest contributors to the timber design, we have normalized the foundations, floors, and framing by floor area (57,995 sf), and the façade by vertical wall area (~83,176 sf), respectively.

When normalized by vertical wall area there is a significant carbon contribution from the façade (8.4 lbs CO2e/sf) which is due not to the intensity of the materials (glulam curtain wall and metal panel siding) but rather to the volume of material used to clad the structure. Foundations, however are materially heavy (8.1 lbs CO2e/sf) because of the carbon intensity of concrete. Floors (7.4 lbs CO2e/sf) and structural framing (1.8 lbs CO2e/sf) are comparatively smaller based on the volume of material (Figure 4).

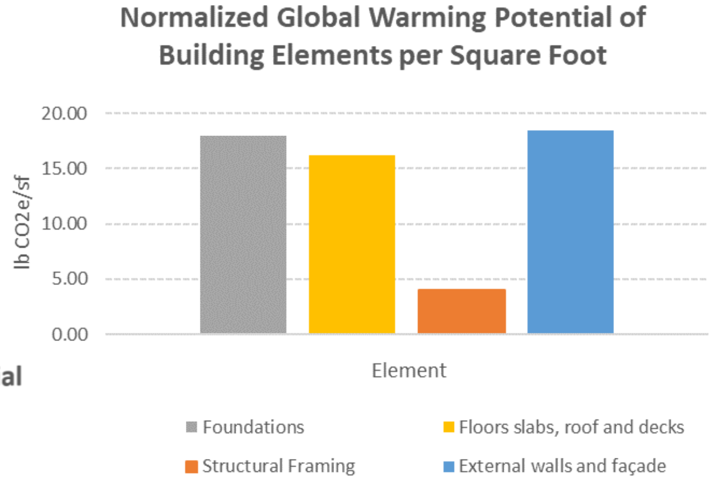


Figure 4: Embodied carbon normalized by square foot

This normalization further highlights opportunities for flexibility in making additional carbon reductions. The element currently exhibiting the highest efficiency is the structural framing.

A concrete mix with high cementitious material replacement value would positively impact the contribution of the foundations and floor slabs. Additionally, as the architectural walls do not require the added strength of 3 or 5 ply CLT, consideration should be given to selecting an alternative wood-based façade cladding material such as laminated veneer lumber or another panelized wood construction. This would reduce the quantity and cost of the material, thereby improving the carbon savings of the element category as a whole.

PRODUCT STAGE (A1-A3)

To further understand the carbon implications of specific materials, the life-cycle assessment data was parsed by individual materials. This again highlights the distinction between material quantity and carbon intensity, the two main factors that determine overall impact of a product on the building's embodied carbon emissions.

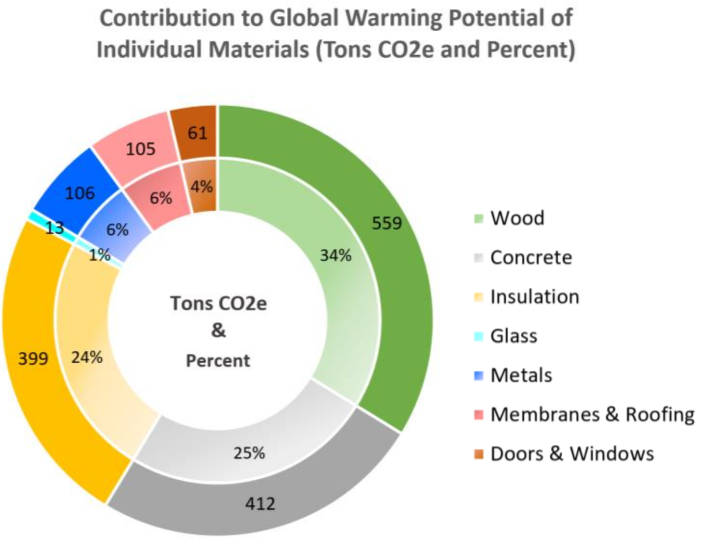


Figure 5: Embodied carbon and percent contribution of individual materials

The results demonstrate that the shear quantity of timber and insulation, including wood fiber, EPS, rock wool and sandwich panels, comprise 34% and 24% respectively, of the building's total embodied carbon.

Due to the energy intensive production process of cement, the concrete used in foundations and slab on grade, constitutes 25% of the overall material impact. The remaining 17% of carbon is associated with the glass, doors, windows, metal and membranes/roofing materials (Figure 5).

Although timber accounts for 34% of the building's total embodied carbon, when compared to traditional steel or concrete, wood is a highly efficient material choice.

When comparing the global warming potential of materials, Environmental Product Declarations (EPDs) provide product specific or industry average data on what a product is made of and how it impacts the environment across its life cycle.

To understand where the most effective material reductions can be made, the energy intensity of the production and manufacturing processes per material is important.

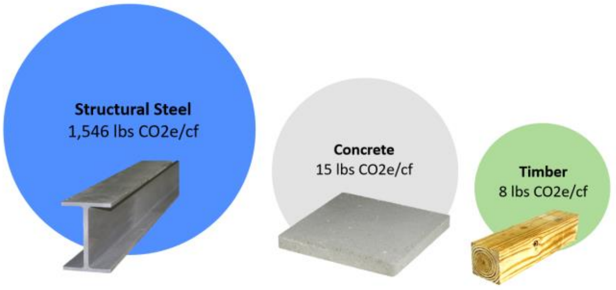


Figure 6: Industry average embodied carbon comparison of concrete, steel and timber per cubic foot of material

The manufacturing process of steel is roughly 100 times more carbon intensive than concrete, however in building construction a greater volume of concrete is used, which results in higher carbon emissions from concrete (Figure 6). For example, where 1,000 cubic feet of steel might be used, 150,000 cubic feet of concrete may be needed, resulting in a difference in emissions of more than 600,000 lbs CO2e. This highlights the material areas with the greatest potential for meaningful impact reductions.

With respect to timber, while the carbon emitted during the felling and processing of timber in the product stage is low relative to other materials, harvesting from sustainably managed forests and incorporating adaptive reuse of materials at end of life will ensure the project can take full advantage of the timber's low carbon properties. Refer to section on Timber Sourcing on page 9 and Adaptive Reuse on page 18 for more.

BIOGENIC CARBON

Timber sequesters carbon during a tree's growing life and this is known as biogenic carbon. While age and tree species determine exactly how much carbon is stored by a particular specimen, research indicates that a single timber product stores on average 1 ton of CO2 per 1.3 cubic yards of wood.

This carbon storage is not accounted for in the product stage of the life cycle (A1-A3), if it were timber would have a far lower product stage embodied carbon emissions. Instead biogenic carbon is reported separately.

To fully utilize the advantages of carbon sequestration potential, timber will be procured from suppliers that adhere to sustainable forestry practices which ensure that harvesting does not outpace the rate of tree regrowth. In addition, the building design will consider the value, both in reduced material costs and carbon emission, of maintaining products within a circular economy.

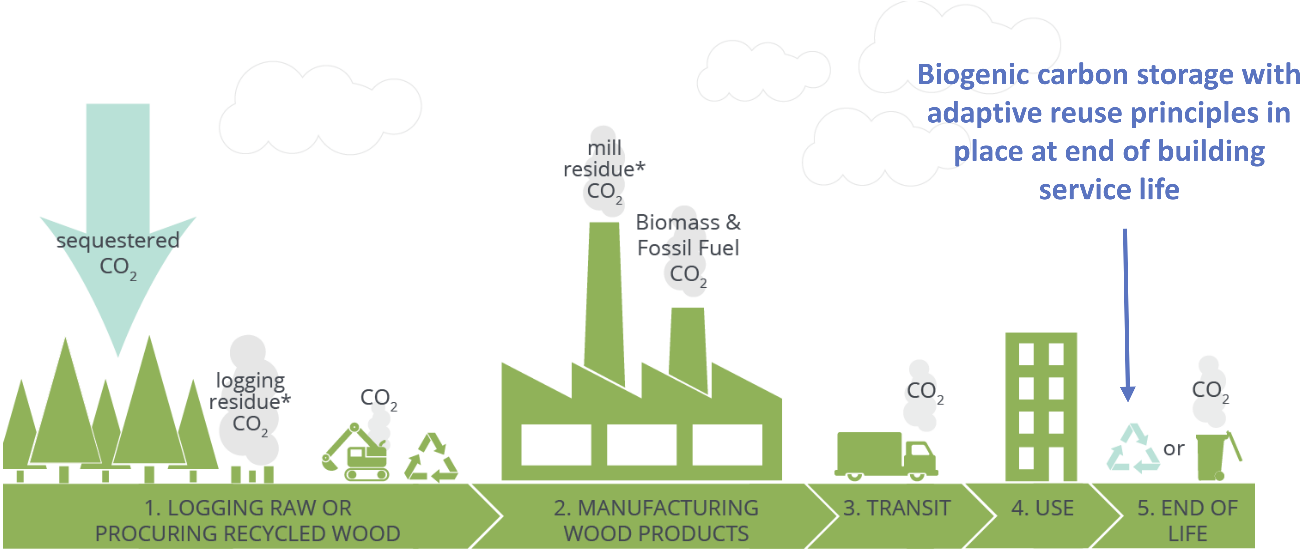
This adaptive reuse of materials can be achieved through good administration of documentation including drawings and models, which may be used to determine the structural integrity of materials for future reuse. Refer to section on Adaptive Reuse page 16 for more.

The LCA for the CLT Lab Addition revealed a biogenic carbon storage potential of 3,911 tons CO2e (Figure 7). This project will integrate a strong end-of-life narrative to ensure the carbon storage potential in TT's calculations is realized.

Timber cannot be assumed to be a carbon positive until proper end-of-life stage principles like adaptive reuse are executed upon. Therefore, the benefit of this carbon storage is kept separate from the overall assessment of the building's fossil related embodied carbon emissions.

Total Embodied + Operational Carbon:
11,710 tons CO2e

Biogenic carbon storage potential:
3,911 tons CO2e



*logging and mill residue: including branches, stumps and bark left behind in processing logs into lumber, releasing CO2

Figure 7: Life-cycle of timber, including carbon sequestration during growth, carbon emissions of manufacturing and end of life landfilled or incineration emissions, and biogenic carbon storage with adoption of circular economy strategies for materials used in built design. Credit – Architecture 2030.

MATERIAL SELECTION AND OPTIMIZATION

Assumptions

The LCA results represent the total life cycle impact of the building over a 60 year service life. The facades modeled in the LCA are assumed to have a service life matching the building.

Product specific Environmental Product Declarations (EPDs) were used whenever possible to accurately capture the carbon impact of specific material quantities. Where product specific EPDs were not available, industry averages have been used.

Wood

In the case of the cross laminated timber (CLT) panels, which have been priced by SmartLam, precise quantities have been used to reflect the amount of timber to be utilized on the project. A comparable EPD for North American CLT was used to ascertain the carbon impact of the material. Similarly, an industry average North American EPD was selected to capture the carbon impact of glue laminated timber (GLT) on the project.

Concrete

Based on TT's design expertise with mass timber in the Northeast and in consultation with the structural engineer, the LCA assumes a 20% cementitious material replacement for all concrete. Concrete mix designs which utilize between 20% and 40% cementitious material replacement are widely achievable. On occasion, the availability of a specific cement replacement material such as slag, fly ash or pozzolan, may vary regionally, but all are capable of achieving similar carbon reductions. Winter conditions and the heat hydration necessary to obtain proper curing and strength will impact the exact percentages. Coordination with local suppliers is necessary to achieve the maximum carbon savings from concrete. TT has assumed a medium level cement replacement of 20% for all concrete in this analysis and a transport distance of 130 miles, based on regional typical values from manufacturing to construction site.

Transport impacts are accounted for in A4 of the life cycle. Dependent on the right conditions, proper equipment and the compressive strength desired, increased carbon savings can be attained with a higher degree of cement replacement in concrete Figures 8 & 9 serve as blueprints for future projects of what is currently achievable.

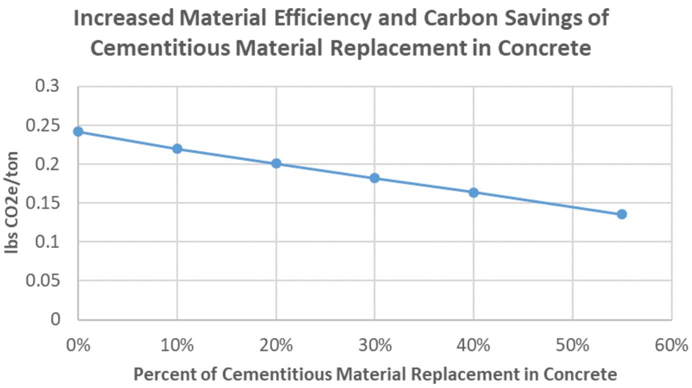


Figure 8

Steel

A high degree of recycled content is common for all structural steel (80-100%) and reinforcement steel (90-100%). For structural steel profiles this LCA assumes a recycled content 90% and 97% for reinforcement steel (rebar). The exact percentages achievable are dependent on individual manufacturers and locations; these thresholds were selected due to their wide acceptance and availability across industry.

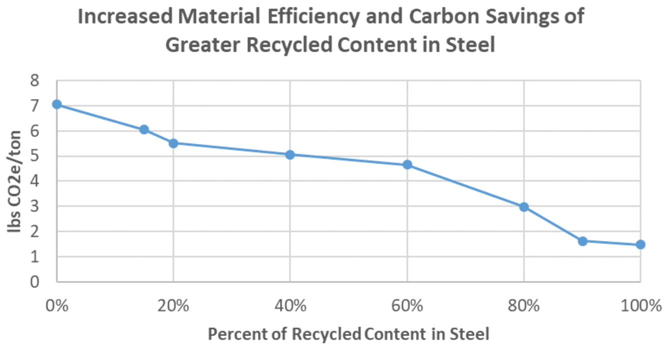


Figure 9

TIMBER SOURCING

The second stage of the life-cycle evaluates the transportation of the building materials to the site, and any waste associated with the installation of those materials. This covers impacts of product transport from factory to the construction site.

Timber Sourcing

In order to maintain a balanced ecosystem, where the use of mass timber for construction does not outpace the growth of new trees, it is imperative that projects specify and source timber from sustainably managed forests. Forest regrowth in Maine takes between 40 and 60 years depending on the location and tree species.

A sustainably managed forest ensures that only select trees are cut, allowing a subset to grow uninhibited and replenish those that have been harvested. This maintains a carbon balance by not harvesting more than can be regrown. Sustainable forestry is key to ensure projects are not doing more harm than good by contributing to deforestation or supporting illegal logging.

Forest management schemes curb illegal forestry practices and Chain-of-Custody (COC) certification tracks wood products from certified forests to the point of sale to ensure that certified material is kept separate from non-certified material throughout the supply chain.

Certification schemes which should be sought out are Forest Stewardship Council (FSC), Programme for the Endorsement of Forest Certification (PEFC) and Sustainable Forestry Initiative (SFI) (Figure 10). It is important to note that not all schemes are created equal, though taking a conservation based approach to managing forests is crucial.

Figure 10: Sustainable forestry labels denote environmentally responsible forest practices and prevent over-harvesting.

Adhesives

When sourcing timber attention should be paid to the particular glues or adhesives used to bond wood laminations, many contain formaldehyde which is a known volatile organic compound (VOC) and off-gasses into the atmosphere and indoor environment. The current industry standard for CLT is to use a formaldehyde-free polyurethane (PUR) adhesive, though some manufacturers use Melamine- Urea Formaldehyde. PUR is the only adhesive that is classified as Red List Free by the International Living Future Institute (ILFI) and the Living Building Challenge (LBC) – the most stringent green building rating system available at present. Red List Free materials are absent from the worst in class chemicals that negatively impact human and environmental health (Figure 11).

Emissions from engineered wood products, like CLT are widely recognized as being much lower than emissions from traditional particleboards, primarily because the adhesive in CLT comprises only a small percent of the overall volume. Glulam production, however, may involve formaldehyde based adhesives such as Phenol Formaldehyde (PF) and Phenol Resorcinol Formaldehyde (PRF). Careful consideration should be given to the end of life for wood products which include formaldehyde based adhesives, as they will need to be properly treated ahead of being repurposed or biodegraded, such that chemicals with not leach into the environment or hinder the natural carbon cycle.

Figure 11: Typical glue lamination process for wood and the Red List Free label which designates a product as being free from chemicals with the greatest adverse effects on human and environmental health.

TRANSPORTATION (A4)

Material sourcing is a key driver of embodied carbon in the life-cycle assessment due to the carbon intensity of placing timber on a truck or train and bringing it to Orono, Maine. TT evaluated the carbon intensity of steel, CLT and glulam transportation from domestic, local and international suppliers to illustrate the carbon impact of regional sourcing.

The tons of CO2e emitted in delivering 1,000 cubic feet of material to the project site is five times greater for steel from Pennsylvania than from Canada, a difference of 5.8 tons CO2e. Both mills manufacture steel via electric-arc furnaces (EAF), which involve a greater power consumption but overall use less raw material than a blast oxygen furnace, relying instead on recycled steel scrap. In EAF steelmaking the primary source of emissions is indirect from electricity usage (approx. 50%), natural gas combustion (40%) and actual steel production accounts for roughly 10% (Credit- EPA).

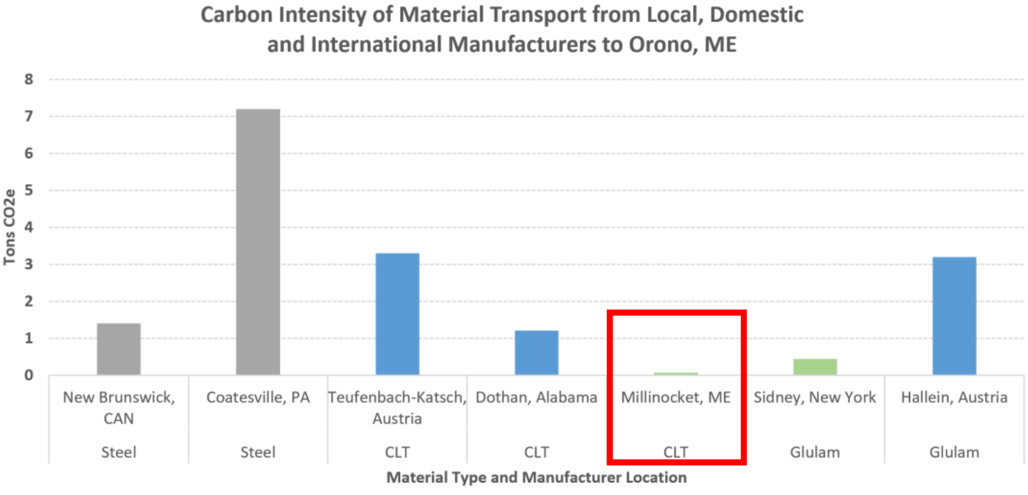
For CLT, the choice to source from SmartLam in Alabama as opposed to the international market results in a carbon savings of just 2.1 tons CO2e. Whereas trucking emits approximately sixty times more carbon than an ocean liner, a larger quantity of material can be accommodated on a container vessel than on a flatbed truck, thus reducing the number of overall trips necessary and the carbon emitted. If CLT was sourced from a future plant in Maine, the impact of transportation emissions would be almost negligible at 0.1 tons CO2e.* Sourcing CLT within the state of Maine results in a 1.1 tons CO2e reduction from domestic sourcing and a 3.2 tons CO2 reduction from the international market.

In the case of glulam, the proximity of New York to the site makes the international market a less effective carbon choice, with a savings of 2.8 tons of CO2 for selecting the domestic sourcing option (Figure 12).

The results demonstrate the competitiveness of a local sourcing option not only from a carbon emissions perspective but also in terms of shipping costs. For materials with energy intensive production processes, like steel, source location can significantly impede the carbon efficiency of a project (Table 1). Overall the project team's choice to source material locally wherever possible has resulted in the relatively low 181 tons of CO2 for life-cycle stage A4-A5, while also having the dual benefit of supporting the local economy.

Table 1: Tons of CO2 Emitted by Material based on Location

Material	Manufacturer/ Location	Mileage to Orono, ME	Transport Ton CO2e
Steel	Ocean Steel / New Brunswick, CAN	116 mi	1.4
Steel	ArcelorMittal/ Coatesville, PA	578 mi	7.2
CLT	KLH/ Teufenbach-Katsch, Austria	3,790 mi	3.3
CLT	SmartLam/ Dothan, Alabama	1,525 mi	1.2
CLT	Future Manufacturer/ Millinocket, ME	67 mi	0.1
Glulam	Unalam/ Sidney, NY	506 mi	0.4
Glulam	Binderholz/ Hallein, Austria	3,720 mi	3.2



*Note:

For the purpose of this study a CLT plant was assumed in Millinocket as it is central to spruce, pine and fir forest resources and is close to a main highway for ease of goods transportation.

Figure 12: Carbon Impact of Material Transport based on Manufacturer Location

WASTE (A5)

To account for the waste of materials associated with their installation on the project, TT has incorporated predicted waste rates into the life cycle assessment for the CLT Lab Addition. These waste rates are industry average assumptions for major building materials, and exact rates will depend on the materials, products and installation approach taken therein.

For all materials, including insulation, membranes, roofing and others not listed in Table 2, every attempt should be made to recycle products or component parts via manufacturer recycling programs or repurpose materials on other projects or via alternative applications.

These waste rates were combined with the transportation to site and construction for a total of carbon emissions from the A4-A5 Construction and Waste stage.

Transportation to Site: 135.0 tons CO2e

Waste Contribution: 46.0 tons CO2e

Total stage emissions: 181 tons CO2e

Table 2: Estimated Waste Rates for Major Building Materials

Material	Waste Rate (WR)	Global Warming Potential (GWP Ton CO2e)	Total Waste Contribution (Ton CO2e)
Concrete	5%	412.1	20.6
Steel reinforcement	5%	63.6	3.2
Steel frames (beams, columns, braces)	1%	42.3	0.423
Timber frames (beams, columns, braces, walls)	1%	109.9	1.1
Timber floors	10%	49.5	5.0
Timber roof	10%	144.6	14.5
Aluminum frames	1%	60.9	0.609
Glass	5%	13.2	0.660
TOTAL	-	-	**46.0**

MAINTENANCE/ MATERIAL REPLACEMENT (B1-B5)

This life-cycle stage includes environmental impacts from replacing building products after they reach the end of their service life. The emissions cover impacts from raw material supply, transportation, and production of the replacement material, as well as impacts from manufacturing the new material and handling waste generated during that production process.

For the purposes of the life-cycle assessment, a typical 60 year building service life has been assumed. The building service life defined as the period of time which the building is in use, prior to the need for significant renovation or refurbishment.

Materials modeled in the LCA are anticipated to have a service life on par with that of the building. However, product service life can vary depending on material selection, product maintenance needs or potential replacement. Material replacement cycles that are less than the service life of the building will inject additional carbon into the overall footprint of the building.

Table 3 identifies the service life to assigned materials included in the life cycle assessment. Overall embodied carbon associated with this stage will fluctuate based on anticipated product replacement needs.

Table 3: Service Life Assumptions for Building Elements

Building Element Type	Service Life
Substructure	
Foundations	Permanent
Lowest Floor Slab	Permanent
Superstructure	
Frame	As building, 60 years
Upper Floors	As building, 60 years
Roof	As building, 60 years
Membrane roofing	30 years
Internal Finishes	
Internal Curtain Walls	As building, 60 years
Insulation	As building, 60 years
External Envelope/ Facade	
External walls/ cladding	As building, 60 years
Curtain walls	As building, 60 years
Windows	As building, 60 years
External Doors	30 years
Glazing	30 years
Photovoltaic System	30 years

OPERATIONAL ENERGY (B6)

Design Narratives

Architectural

The building's program includes a 3D printer lab, office spaces and other ancillary spaces (Figure 13). The design team has chosen a mass timber construction with the goal of creating a low embodied carbon structure.

The proposed building is connected to an existing building on the east wall.

The envelope will be insulated metal panels and wood fiber insulation with an effective assembly U-factor of U-0.049 and a roof assembly of U-0.014. The windows will be high-efficiency thermally broken window frames with a center of glass U-0.26 and argon filled double pane glazing. Slab on grade will be fully insulated with R-10 EPS insulation.

Lighting

Daylighting is achieved through a combination of optimal window sizes, skylights and Kalwall (in the main lab). The spaces with daylight will be provided with daylighting controls to minimize usage of artificial lighting. Emergency lighting will not be controlled by daylighting sensors.

LED fixtures are considered in the basis of design for all lighting needs which provide lighting efficiently while significantly reducing the heat load from the fixtures.

A 40% reduction from ASHRAE 90.1-2016 lighting power is assumed in the analysis as a place holder until lighting design is fully developed. This estimate is based on TT's experience with other projects.

HVAC

Three options have been discussed with the design team. In future updates, TT will evaluate these systems based on the feedback from the design team and the owner. The option that could enable the project to go carbon neutral in phases, is used for this analysis as described in the following sections.

<u>Plant</u>:

A chiller heater can produce hot water and chilled water and take advantage of simultaneous heating and cooling loads by simply transferring energy from one side to the other side. The offices are equally spread between perimeter and core of the footprint which results in simultaneous heating and cooling. This plant could tie into the campus steam or have a stand-alone boiler (electric or natural gas). It provides flexibility to make the building all-electric, if desired. A cooling tower may be necessary depending on the MEP's load calculations.

<u>Air Distribution</u>:

A displacement ventilation system, where the air is delivered within occupied zones (6-8 ft. from the finished floor) is very efficient for large volume spaces. It conditions just the volume where occupants are. The cold air stays where occupants are (cooling mode). The diffusers (supply and return) can be located appropriately to help with destratification. Where height restrictions allow (opposite side of the 3D printer bay), a large fan (Big Ass Fans) can gently move the air during heating mode. Offices can be served with fan coil units (four-pipes on the perimeter and two-pipes in the core zones). A 100% outside air system with high-efficiency heat recovery can provide needed ventilation. A Demand Control Ventilation strategy will help to dial down the ventilation as occupant density varies and minimize waste of energy for cooling, heating and dehumidification.

Figure 13: A rendering of the CLT lab addition to the Advanced Composites Center, courtesy of Scott Simons Architects

OPERATIONAL ENERGY (B6)

Energy Analysis

TT performed a schematic whole building energy analysis to understand the operational use and potential for achieving Zero Net Energy (ZNE). As designed, the project is estimated to use 73 Kbtu/sf-yr. This is a reduction of nearly 50% from a typical building of similar use type.

Current estimate for equipment plug loads, defined as energy used by equipment that is plugged into an outlet in the project's labs (28%) and offices (5%), is alone approximately 25 Kbtu/sf-yr based on the information provided by the University. The rest of the energy use is from lighting and HVAC (Figure 14). As such, equipment plug loads present the greatest opportunity for efficiency improvements.

If the building were to pursue ZNE status, the project Site EUI could not exceed 28 Kbtu/sf-yr. TT recommends that the design team carefully review the equipment plug loads and use schedules to discuss opportunities to conserve plug load energy. Further opportunities for energy conservation in HVAC system can be explored as the design develops.

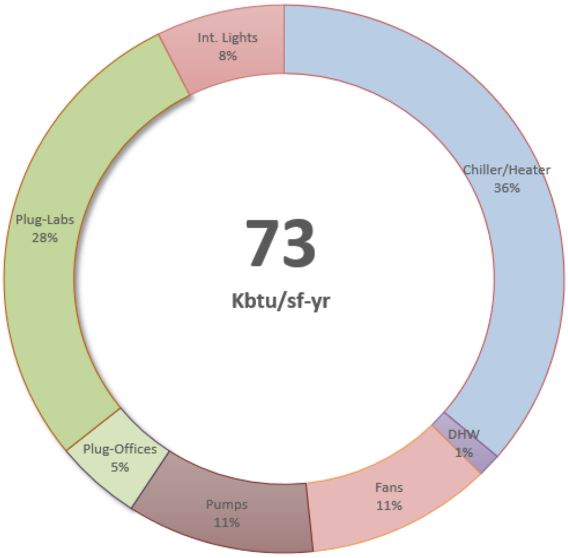


Figure 14: Breakdown of estimated energy end uses and EUIs

Building EUI: 73 **Equipment Plug Load EUI:** 25

Energy conservation strategies for reducing equipment plug loads will also reduce the HVAC energy associated with heat generated by all lab equipment. However, achieving ZNE will pose a challenge for this building due to the heavy energy consumption of the lab and large plug loads for industrial equipment.

This said, the project has several load sharing opportunities due to simultaneous heating and cooling load as a result of high internal loads and core versus perimeter zones. Strategies that help to further enable load sharing could reduce the HVAC energy by 15-20% (Figure 15).

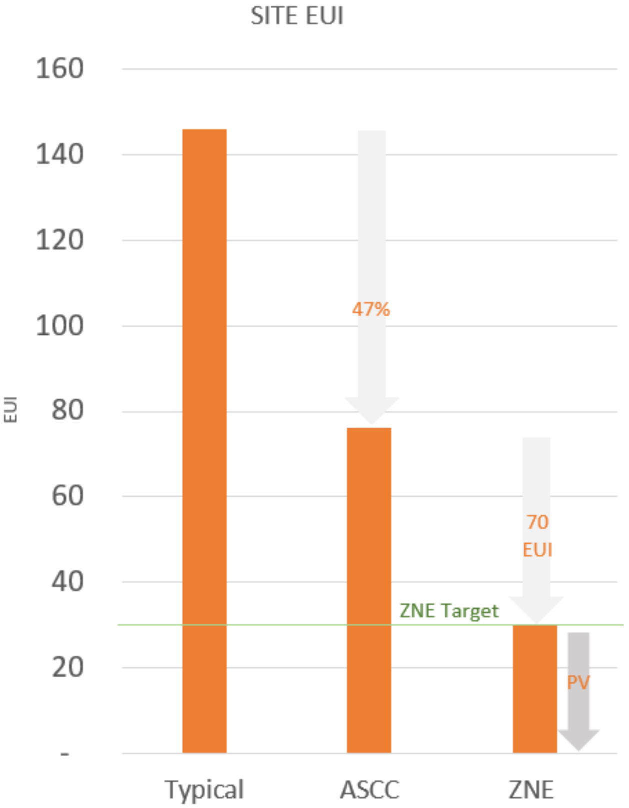


Figure 15: Comparison of site EUI reduction for a typical building vs the ASCC lab addition as a standard and zero net energy building

OPERATIONAL ENERGY (B6)

CHP Biomass System

A Combined Heat and Power (CHP) system is an integrated energy technology that when designed well provides the best fuel efficiency to generate electricity and utilizes the waste heat generated in the process (Figure 16). A biomass source such as wood residues from forests and mills, which are plentiful in Maine, can be a reliable and renewable resource for minimizing the carbon footprint of a building.

CHP can reduce greenhouse gas emissions by burning less fuel to produce each unit of energy output and by avoiding transmission and distribution losses of electricity.

For CHP to run at a higher efficiency, a continuous heat load is necessary throughout the year or the system should be operated only when there is a consistent heat load. A CHP system at the campus level could run more efficiently by aggregating campus wide diverse loads and running at its peak efficiency.

Typically, the combined source energy efficiency (electricity and heating) compared to the current system at the campus plant can be improved up to 40-50%. Additionally, if biomass is used as the fuel source there may be reasonable cost benefit.

The information provided here is for conceptual understanding of the impact of a Biomass CHP system on carbon emissions and has not been quantified through analysis.

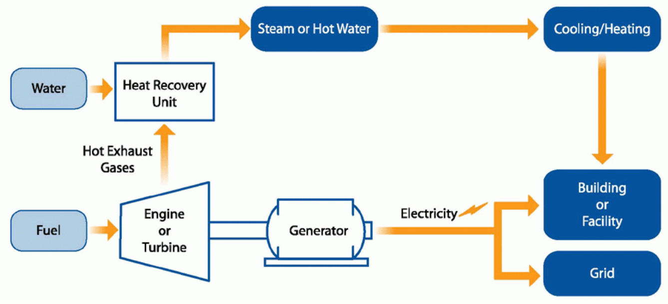


Figure 16: Schematic layout of CHP

(Image credit: https://www.epa.gov/chp/what-chp)

Wood sequesters carbon during a tree's growing period (refer to Biogenic Carbon section page 7 for more) however, combustion of wood scraps to produce energy releases the CO2 stored in these materials.

While a CHP biomass system does use up available and renewable forest byproducts, the project must also consider the carbon emissions released with the burning of wood biomass. This amount of carbon emitted will be based on the size of the biomass system, rate of energy consumption and type of tree species incinerated.

OPERATIONAL ENERGY (B6)

Photovoltaic (PV) System Analysis

Operational Energy

Based on the roof area, TT estimates that an approximately 500 KW PV system is feasible to install after accounting for equipment on the roof. No other areas have been explored for a PV system.

TT recommends that the project strive to bring the EUI to the lowest possible number before exploring PV opportunities. This exercise is meant to show potential for PV generation and as a result determine the feasibility of Zero Net energy (ZNE) for the project.

There are several high efficiency panels, Tesla being one of them. Assuming Tesla's efficiency, we estimate an approximate 500 KW DC PV peak production which translates into an EUI of 28 for the project. A monthly breakdown for the electricity generation for the 500KW system is shown in Table 4.

Table 4: Operational Carbon Contribution of PV System

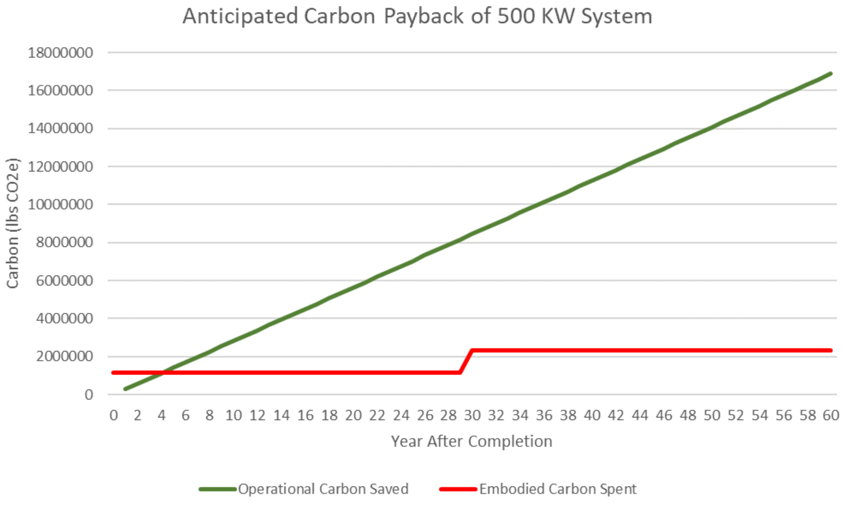
Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	2.87	38,338
February	3.88	46,212
March	4.82	62,088
April	5.40	64,936
May	5.72	70,616
June	5.89	68,738
July	6.18	73,477
August	5.91	70,176
September	5.03	59,198
October	3.39	42,466
November	2.57	31,985
December	2.16	28,636
Annual	**4.49**	**656,866**

Embodied Carbon

Assuming a high efficiency yield from monocrystalline panels, TT evaluated the embodied carbon payback contribution of the PV system (Table 4). Based on an anticipated system generation of 500 KW DC PV, a carbon factor of 429 lbs/MWH was assumed for Maine generated energy and using an average carbon coefficient for monocrystalline panels, the PV system is predicted to save 281,424 lbs CO2/yr.

The embodied carbon associated with the installation of the PV is 1,158,345 lbs CO2. This equates to an upfront payback of 4.1 years, however we anticipate the array will need to be replaced following a 30 year service life and this will re-inject carbon into the building's overall carbon budget, see Figure 17.

Figure 17 : Carbon Payback of PV System



OPERATIONAL ENERGY (B6)

Operational Carbon Contribution

The total life cycle carbon of the building includes both embodied and operational energy, used during building occupancy. The estimated energy use of 73 EUI for the lab addition is comprised of HVAC, which includes heating, cooling, fans and pumps, plug loads and the remainder of the energy use intensity is for hot water and lighting. This does not include the PV system, which alone can generate 28 EUI, equating to an overall EUI of 45 (Table 5).

The carbon contribution of these systems to the building's overall carbon budget weighs heavily on equipment efficiency and the source of energy generation. Maine has a cleaner energy grid compared to other states due to Hydro-Québec, which supplies energy to the cities of Bangor and Orono. Much of the other electricity generation comes from non-hydroelectric renewables, such as wind power and biomass from wood waste, a small amount is from natural-gas fired power plants (EIA, See Appendix A).

The low emissions generated by the hydroelectric dam result in a lower than US average, annual CO2 emissions for the Maine grid (429 lbs CO2/MWH). Assuming PV is incorporated on the project, an EUI of 45 emits 166,810 kg CO2/yr. Given this, the lab addition will contribute 10,008,593 tons of CO2e over its 60 year building service life.

Energy Use Conclusion

The proposed project has a high performance envelope and HVAC systems. TT's estimated energy use of 73 EUI performs approximately 47% better than a typical building type in the same climate zone. This is a significant improvement in performance compared to a similar building type.

However, to attain ZNE status the project must achieve 28 EUI or lower. This is assuming a PV system only on the roof. Different from a typical office building, this project type demands high power draw due to the lab equipment and its consistent use pattern. The equipment plug loads use 25 EUI while HVAC/Lighting/Hot Water use the remainder of the EUI (48).

TT recommends the following:

- Explore further opportunities to optimize equipment plug loads use such as occupancy sensor based receptacles and/or smart power strips in non-lab spaces, power management software for lab areas that do not disrupt the research activities
- Explore load sharing opportunities (passive or active) during simultaneous heating and cooling loads
- Consider, only after all conservation measures have been explored, on-site PV (non-roof), off-site PVs or Renewable Energy Credits (RECs) to achieve zero operational energy use

Table 5: Energy Use Intensity Breakdown and Carbon Emissions By System Type (Kbtu/sf/yr)

System	EUI (Kbtu/sf/yr)	KBTUs	MWH	CO2 (lbs)	CO2 (US tons)
HVAC	41	2,665,000	781	335,078	168
Plugs	25.55	1,660,750	487	208,811	104
DHW + Light	6.45	419,250	123	52,713	26
TOTAL	**73**	**4,745,000**	**1,391**	**596,602**	**298**

END-OF-LIFE/REUSE, RECYCLING & DISPOSAL (C1-C4 / D)

The end-of-life cycle stage includes impacts for processing recyclable construction waste flows for recycling (C3) through to the end-of-waste stage, where the impacts of processing and landfilling materials which cannot be recycled (C4) are captured. The impacts associated with building deconstruction are also included in this stage as emissions from waste energy recovery.

Life cycle stage D, Reuse, Recovery and Recycling accounts for the benefits of keeping existing materials within the production-supply chain. This has significant economic, social and environmental benefits, all dependent upon keeping climate change and carbon emissions from buildings and industry, in check to maintain ecological system balance (Figure 18).

This circular economy approach eliminates new waste generation by continually re-using resources. Steel, for example, can be recycled continuously without any impact to its tensile strength and steel which contains higher recycled content has a lower embodied carbon impact. Reusing materials reduces the need to inject new carbon into a building's carbon budget, allowing projects to take full advantage of the carbon savings of material reuse.

Deconstruction & Recycling

Consideration for where materials end up after leaving the project site or serving their use to the building is tantamount to balancing both building and ecosystem carbon. Designing for eventual deconstruction and dismantling is a critical component of sustainable design and especially relevant to timber due to its carbon sequestration properties.

Though wood is a carbon sink, at the end of the typical building's 60 year service life, the majority of timber products are discarded, select members may be recycled but more often are landfilled or incinerated. It is at this point in the end-of-life cycle stage that the biogenic CO2 stored in timber is released through combustion or decomposition. (Refer to Product Stage section page 5 for early stage emissions.)

The end-of-life for timber used in the lab addition should be taken into account in the early design stage, to preserve the carbon savings achieved with wood construction and promote sustainable use of this natural resource.

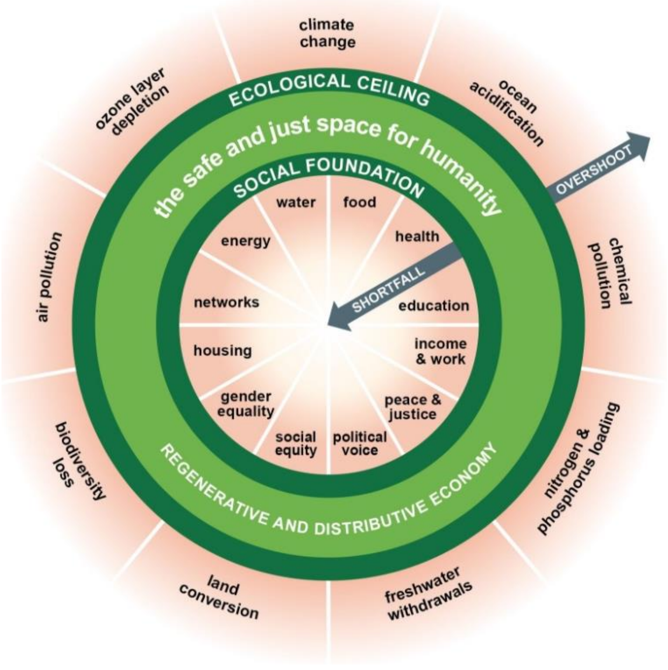


Figure 18 : The doughnut of social and planetary boundaries (Credit Kate Raworth)

Adaptive Reuse

Opportunities for elongating the building's service life should be discussed early on. A choice between bolted or welded connections will impact the dismantling and recycling potential of the structure. Whenever possible, bolted connections, which can be removed at the end of the building's service life, should be specified.

The CLT lab addition to the Advanced Structures and Composites Center is anticipated to serve students, staff, and faculty for 60+ years, however its service to the community will grow and change based on student learning needs and those of the University at large.

As such, these predicted use changes should be accounted for. The design team should utilize the intelligence capacity of their BIM environments so that data, such as the structural capacity of structural elements, façade material breakdowns, etc., are well documented. This will allow future design teams to be able to quickly assess material re-use and repurpose potential building elements.

LOW CARBON BENCHMARKS

In recognition that climate change is affecting every country on every continent, Goal 13 of the *United Nations Sustainable Development Goals* challenges countries, institutions and individuals to “take urgent action to combat climate change and its impacts.” The UN has set forth an ambitious target of cutting global emissions by 45% by the year 2030. With 11% of global greenhouse gas emissions attributable to the building and construction industry alone, it is critical to understand how new construction aligns with the design targets of future sustainable construction.

Using industry accepted breakdowns for a typical comparable building, and TT’s own internal studies, we have developed carbon benchmarks for each of the major carbon driving elements of the CLT lab addition which include foundations, floors, framing, and façade.

The carbon contribution of each of these building elements were compared to carbon targets for similar facilities, in order to benchmark the lab’s overall progress in aligning with the goals for 25% reduction in CO2 by 2025, 45% reduction by 2030, 68% reduction by 2040 and zero carbon emissions by 2050.

The results demonstrate that the CLT lab addition is performing above the industry carbon benchmarks and is on target to meet the carbon reduction goals outlined for next 10 years (Figure 19).

This said, several elements will need to be considered for greater efficiency to remain aligned with these targets. The foundation embodied carbon will only meet target until 2028, at which point slab design efficiencies will need to be considered.

Facades currently meet the targets through 2025, but in 2027 they will fall short and similarly floors will fall away from the embodied carbon target beginning in 2042. Framing will meet the carbon target by 2042 and thereafter exceed it until 2050, when emissions from all buildings must be zero (See Appendix B).

The degree of performance for each element category is dependent on various factors including material type, quantity used, and carbon intensity inherent in manufacturing. These carbon benchmarks are meant to be a model for future buildings.

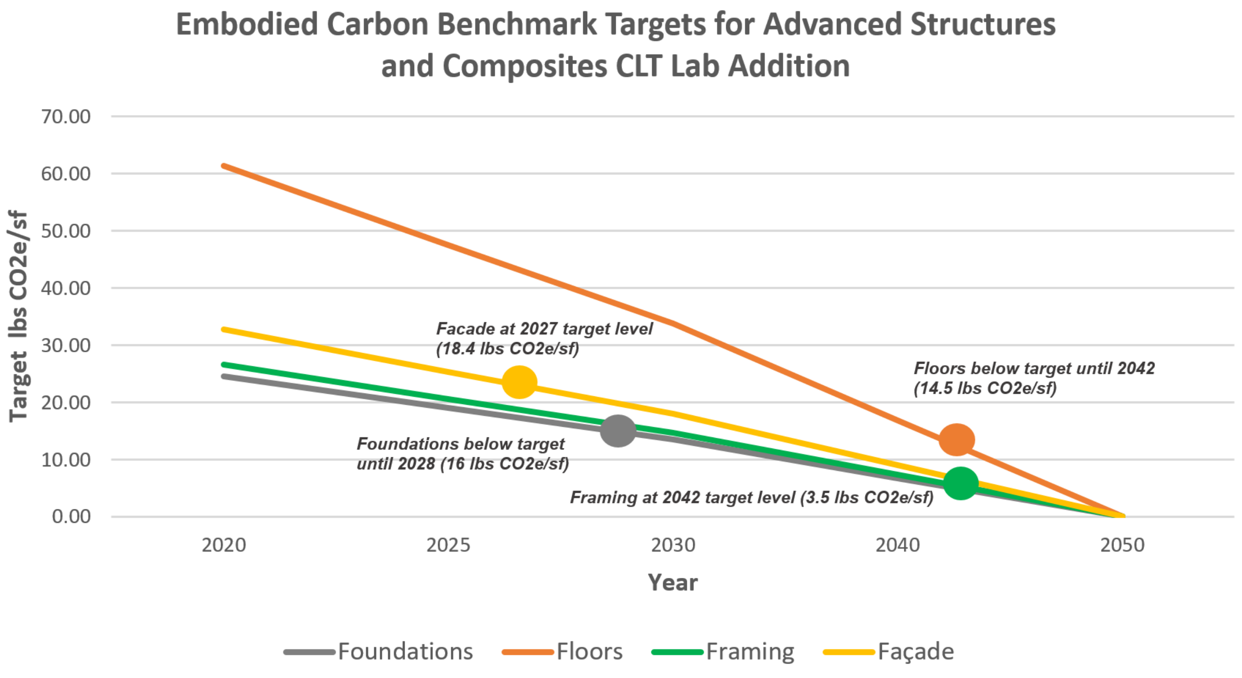


Figure 19: Embodied carbon emissions associated with major building elements in relation to UN climate reduction targets.

CARBON REDUCTION OPPORTUNITIES

Recommendations

In order to continue making progress towards these low embodied carbon benchmarks, strategies for optimizing building and material efficiency will need to evolve. The reduction targets currently set for 2040 and 2050 may indeed change based on global advancement and achievement in carbon reductions over the next 10 to 15 years. To ensure that the carbon emissions from new construction are properly curtailed, in order to maintain ecosystem balance and remain within our planetary resource boundaries, it is necessary to think broadly about a strategic approach to reducing carbon beyond just major building materials.

This can be done in a number of ways including development of a campus wide carbon strategy. This may take the shape of a low carbon procurement policy or a list of manufacturers whose products have been pre-approved as being low embodied carbon alternatives to typical building materials. Using the influence of the institution can drive change in the industry by putting pressure on manufacturers and the wider supply chain, ensuring continued advancement in low carbon design material options.

A low carbon strategy should also focus on transitioning the University's operational energy to more efficient, renewable fuel sources. The state of Maine grid mix is transitioning away from fossil fuels and towards renewables, like PV and hydropower. To further drive down building EUI an energy mix that takes advantage of this renewable energy should be evaluated, along with the potential to build up off and on-site renewables like solar or wind power.

In addition to the efficiency measures and reduction strategies outlined in the body of this report, TT recommends the project incorporate the following:

- Request Environmental Product Declarations (EPDs) for all building materials, not only to accurately capture the impact of product use but also as a means of driving the industry towards transparency around the carbon impact of their products
- Request supplier information to understand where materials and their component parts are being sourced. Consider local suppliers for the main carbon driving elements on the project:

Concrete: A local concrete supplier on previous Maine projects has been Dragon Concrete in Thomaston, ME. If sourcing is within a closer radius to the site carbon emissions from the A4 transport stage can be reduced.

Steel: Previous University project's have sourced steel from Ocean Steel in Canada, proximity to the project makes the international market a better option compared with domestic sourcing out of Pennsylvania.

CLT + Glulam: While SmartLam's CLT production facility in Alabama is expected to come online in time for the construction of this project, a future CLT manufacturing plant in Maine would provide significant transportation cost and carbon savings while making use of the state's plentiful varieties of sustainable forested timber and supporting the local economy

Where these large quantity and carbon driving materials are procured will impact the embodied carbon results outlined in this study.

Impact

The CLT lab addition life-cycle assessment and carbon benchmarking study demonstrates that the building is well designed and on target to meet the carbon reduction goals outlined for 2030 and beyond. Despite being a high energy powder draw space due to much heavy lab equipment, the building is able to demonstrate an EUI of 73, 47% less than an typical building of similar use type. This is substantial and further reductions are still possible through equipment plug load efficiencies or PV generation on or off-site.

The project attributes a high degree of consideration towards the sourcing location of key carbon driving materials. Although transportation is only a small percentage of carbon emissions, product stage material carbon accounts for the majority of life cycle stage emissions. It is at this early point of timber sourcing where the availability of a Maine-based CLT manufacturer would make transportation emissions nearly negligible (0.1 tons CO2e), while supporting continued sustainable management of Maine forests and the economic benefit of lower material costs, as well as overall benefit to the local economy.

This project seeks to bring awareness to mass timber constructability and serve as a case study for timber design. The life-cycle assessment results and low carbon benchmarks provided in this study are intended to be utilized by design teams to influence future designs.

APPENDIX A – ENERGY INPUT ASSUMPTIONS

GENERAL	
Steam rate	$20/MMBTU
Electricity rate (if known)	$0.14/KWH
Natural Gas rate (if known)	$0.9/Therm
Ventilation	30% greater than ASHRAE 62.1 ventilation rates.
Setpoints Summer (Occ / Unocc)	Offices : 72/75 Lab: 75/80 F
Setpoints Winter (Occ / Unocc)	Offices : 70/68 Lab: 60/55 F

OCCUPANCY	
Occupancy schedule	Offices: Typical office schedule (8-6P- Weekdays; Closed on Weekends & Holidays) Lab: School year (8A-8P); Summer- 50% of typical school year)
Total Occupancy	Offices: 150 SF/Person; Lab: 500 SF/Person

BUILDING ENVELOPE (CONSTRUCTION ASSEMBLIES)	
Roofs	U-0.014
Walls - Above Grade	U-0.049
Slab on Grade	2” EPS below entire slab
Vertical Glazing Description (storefront)	Aluminum Clad wood window Sierra Pacific - Aspen window - Basis of Design
Vertical Glazing U-factor, SHGC, VT	U-Value 0.24, SHGC 0.27, VT .64
Vertical Glazing Description (window units)	Timber Curtain wall Sierra Pacific - Architectural wall system - Basis of Design
Vertical Glazing U-factor, SHGC, VT	U-Factor 0.25, SHGC 0.19, VT .43
Shading Devices	Assume at storefront only SC-.30
Skylight Description Unitary (Lab space)	Wasco Ecosky CLC3
Skylight U-factor, SHGC, VT	U-Factor 0.33, SHGC 0.31, VT .40
Skylight Description Framed Pyramidal	Wasco (87 triple glazed)
Skylight U-factor, SHGC, VT	U-Factor 0.19, SHGC 0.14, VT .17
Translucent Panel Description	Kalwall - 4" K100, white - white, 2" thermally broken, fiberglass insulation - Basis of Design
Translucent Panel U-Factor	U-Value 0.08, SHGC 0.04, VT - .04

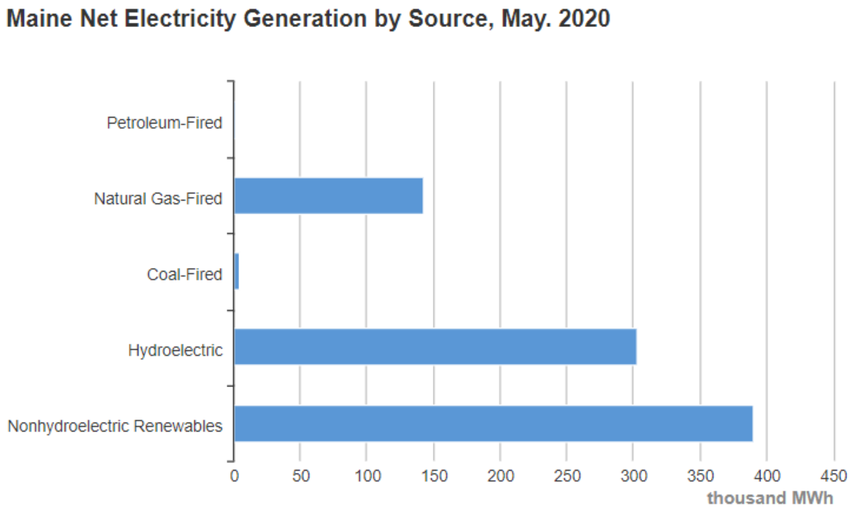
LIGHTING	
Lighting Power Density (W/sf)	Assuming LED - 0.55 w/sf (offices) ; Lab- 0.75 w/sf
Daylight Dimming Controls	Perimeter office spaces with continuous dimming controls; Lab- stepped switches

APPENDIX A – ENERGY INPUT ASSUMPTIONS

HVAC SYSTEM	
	Chiller/Heater
Plant	A chiller heater produces hot water and chilled water and takes advantage of simultaneous heating and cooling loads by simply transferring energy from one side to the other side. The offices are equally spread between perimeter and core of the footprint which results in simultaneous heating and cooling. This plant has been modeled with a stand-alone boiler (electric). A cooling tower is modeled for rejection of excess heat in the system.
Air Distribution	Displacement ventilation system: Air is delivered within occupied zone (6-8 ft from the finished floor) for large volume spaces. It conditions just the volume where occupants are. Offices served by fan coil units (four-pipe on the perimeter and 2 pipe in the core zones). A 100% outside air system with high-efficiency heat recovery system provides ventilation. A Demand Control Ventilation strategy will help to dial down the ventilation as occupant density varies and minimizes wastage of energy for cooling, heating and dehumidification.

SERVICE HOT WATER	
Water Heater type	Electric heat pump serving the bathrooms.
System efficiency	2 COP
Low Flow Fixtures	Low flow lavatories

Maine electricity generation breakdown by source fuel



Maine Net Electricity Generation by Source, May. 2020

eia Source: Energy Information Administration, Electric Power Monthly

APPENDIX B – LOW CARBON BENCHMARKS

Building Element Type	Industry Target – 2020 lbCO2e/sf	Industry Target – 2025 lbCO2e/sf	Industry Target – 2030 lbCO2e/sf	Industry Target – 2040 lbCO2e/sf	Industry Target – 2050 lbCO2e/sf	Lab Addition As Design – 2020 lbCO2e/sf
Substructure						
Foundations / Lowest Floor Slab	24.53	19.01	13.49	6.75	0	16.06
Superstructure						
Frame	26.58	20.6	14.61	7.3	0	3.52
Upper Floors	61.31	47.52	33.73	16.85	0	14.52
External Envelope/ Facade						
External walls/ cladding	32.7	25.34	18.0	9.0	0	18.48

Note: *The above building elements were included in the scope of the life-cycle assessment for the lab addition. External site works, fittings, furnishings are excluded. Operational carbon from building services, including MEP, has been assessed separately in the Operational Energy B6 stage of this report.*