



ACLT FORESTRY CASE STUDY

SUMMARY

Forestry and wood production have long been central to the Pacific Northwest's cultural and economic identity. However, as the climate and local communities evolve, the industry is undergoing significant changes. Over the past 40 years, Washington State's forest economy has shifted dramatically due to a variety of factors. Between 1980 and 2016, the number of mills in the state dropped from 687 to just 88, while annual production decreased from 5 billion board feet to 2 billion board feet in the same period.

Landownership trends have also changed. In 1980, large timber companies owned vast tracts of land, but today many of these companies have consolidated lands while also expanding into real estate, subdividing and selling less profitable commercial forestry parcels as residential lots -- a significant revenue stream for the industry. The consolidation of mills has made accessing them more difficult for small and mid-size landowners trying to manage forest lands. Smaller parcels have less merchantable timber and proportionally higher operating costs for logging, along with longer trucking routes for hauling timber to the nearest mills.

The Olympic Peninsula, a geographically isolated region in Washington State, has been particularly affected by these issues. While commercial forestry is still a vital industry in the region, there has also been a transition into higher densities of small forest landowners with very little mill access and less profitable markets for commonly harvested species. However, it also presents an opportunity for innovation and problem-solving. In this case study, we will explore how we at the Composite Recycling Technology Center (CRTC) are addressing these challenges in ways that benefit the environment, economy, and community.

We've worked with multiple community partners, including the Makah Tribe, to incentivize sustainable forest management and use Western hemlock, commercially considered a "low value" wood, to manufacture an advanced cross-laminated timber (ACLT) product and drive rural economic development on the Olympic Peninsula. By using a scaled approach, where wood products are designed around the local forestry and economic needs, our team at the CRTC has been able to use innovation to produce a viable building material and demonstrate how other communities can replicate this production model creating a truly sustainable product in their own communities.

This case study will discuss the current state of the Pacific Northwest wood economy and some of the challenges it has faced, and how the CRTC and Makah Tribe are addressing these on the northern Olympic Peninsula.

THE NEED FOR NEW FOREST ECONOMIES IN RURAL COMMUNITIES

The Olympic Peninsula is located in the northwestern corner of Washington State, characterized by an island of mountains disconnected from the rest of the state, surrounded by rugged coastline. In between the coast and mountains there is a ring of temperate rainforest, some of the last remaining old-growth protected rainforest in North America. This region has been characterized by its forests throughout time and has undergone a significant degree of change in the last 150+ years since colonists arrived. The region

is home to the Coast Salish people and many local tribes, and in this case study we will focus specifically on the Makah Tribe, located in the most Northwestern tip of Washington State, covering approximately 31,000 acres.

While the focus of this case study is on the Olympic Peninsula, it is not unlike many other rural communities in the Pacific Northwest facing very similar issues. Through this case study we will share the story of how we adapted to a changing forest economy and created a new solution to address local needs using a triple bottom line model, which focuses on finding solutions that prioritize the people, the landscape, and the economy equally. Ensuring that each of these factors was considered at each level ensures long term viability of the system, but also something that is truly sustainable.

The “Chain of Custody” is a forestry term representing the entire process of forest production, from forest management and growing trees all the way to the final product, in this case, a cross-laminated timber panel made of Western hemlock, one of the main timber producing trees of the Pacific Northwest.

The case study will be laid out in a way to show how forest ecology, forest management and policy, production, and waste reduction are all addressed using community based, innovative solutions, and how they can be applied to other rural communities.

CHANGING FOREST LANDOWNERSHIP IN WASHINGTON STATE

Forest landownership is changing across the state, and those trends impact forest management and how the industry is adapting. Washington State, officially the Evergreen State, is characterized by forest land. The state is approximately 45.6 million acres and in 2007 there were 19.64 million acres of forest in Washington State, which is roughly 43% of the state. By 2019, forest acres declined by 394,000 acres (or 2%).

At the same time, ownership of that forest land has been changing at a faster rate, especially in regards on small forest landowners (SFLO). In 2007 the forest distribution by owner class could be characterized as 42% managed by federal agencies, 39% privately owned, 10% managed by the state of Washington, 7% owned by tribes, and 2% managed by county and local municipalities. The most significant change to forest landownership is with the privately owned sector.

A subset of privately owned forests are small forest landowners, which account for about 15% of forest land. SFLO forest acres declined from 2.99 million acres in 2007 to 2.88 million acres in 2019 (a 3.7% decline). Total parcel acreage owned by SFLO declined from 5.04 million acres to 4.84 million acres (a 4% decline). However, the number of small forest landowners increased from 201,000 in 2007 to 218,000 in 2019 (or 8.5%). The number of SFLO parcels increased from 256,500 to 261,800 (or 2.1%). These statistics demonstrate a trend of shrinking overall SFLO forest land and parcel size, but an increase in number of parcels and landowners. Perhaps a better term for this emerging land base is “micro-forest landowners.”

Often, setup costs are disproportionately higher for micro-forest landowners. There are several fixed costs associated with any given harvest, including permitting and the cost associated with transferring logging equipment from site to site. Smaller acre parcels don’t produce as much revenue and these setup fees have a higher impact on the profitability of the harvest.





These numbers are important to understand for the future of forest management. The increasing number of small forest landowners means there is further need for forest management services tailored to small forest landowners despite the fact the forest industry has shifted away from these needs. Logging operations, mills, and forest management have adapted to consolidation and meeting the needs of the larger industrial timber industry. This has created a large gap in the equipment, infrastructure and management for small, local forests.

DECREASING TIMBER PRODUCTION

The number of mills in the state dropped from 687 in 1980 to just 88 by 2016, while annual production decreased from 5 billion board feet to 2 billion board feet in the same period. Why has this happened? The answer is multilayered and complex, but there are a few key points to tease out.

Policy Change and Conservation

Concerns of overharvesting are not new and have been affecting policy since the 1880's. Perhaps the two most impactful policies that enhanced protection of forests and reduced logging are the Wilderness Act of 1964 which set aside almost 2 million acres protected wilderness, and the US Fish and Wildlife service's 1990 declaration of the Spotted Owl as an endangered species and set aside 11.6 million acres of old growth forest for Spotted Owl habitat. Additionally, the Washington Forest Practices Act in 1974 set significant standards for conservation across the state, and some of the highest standards in the country for forest protection.

Shorter Rotations, Smaller Trees

Forest land has become increasingly consolidated into large landownerships by industrial companies. Although there is an increase in SFLO as discussed previously, the impact on timber production by this consolidation is a forest management approach suited for industrial forests, or tree farms. Since so much of the older timber has been cut, and the industry has become highly efficient at growing young trees faster, the average rotation age (or age of trees when they are harvested) has declined. This has boosted timber production to meet the needs of large production mills, but there are significant drawbacks. Longer harvest rotations allow the forest to reach ecological maturity which in turn yields larger trees and provides greater carbon sequestration, healthier forests and ecosystems, and in some cases if managed correctly, higher production yields.

An industry indicator of this trend in favor of younger smaller trees, is that most commercial mills no longer accept trees over 32" in diameter, a size which used to be commonplace. Now, average tree diameters are smaller and only specialty mills can handle the relatively small percentage of large diameter logs. Historically trees were cut at 60-80 years (or older), but the industry standard has pushed those rotation ages to 30-50 years for the main commercial species, namely Douglas-fir and Western hemlock.

Fewer Mills

As noted above, the number of mills in Washington dropped by 87% between 1980 to 2016. Small to mid-size mills were unable to compete in the industry and have slowly closed over time. Mills have become larger, and many are also owned by the larger industrial timber companies, making them vertically integrated.

In Washington, many of the larger mills are consolidated along the main transportation routes, which is the I5 corridor, which runs north/south from Vancouver, BC, to Portland, OR. The Olympic Peninsula, which is one of the highest timber producing areas of the state, has fewer than 7 operating commercial mills covering an area of roughly 1.5 million acres. This adds further strain and profitability challenges for landowners and forest managers who don't have direct access to mills, such as tribal and small forest landowners.

Trucking Rates

Trucking rates have increased significantly over time as have hauling distances. A gallon of diesel on the West Coast cost \$1.20 in 1995, and has risen to \$4.24 in 2025, a 71% increase. During the pandemic it peaked at \$6.45 per gallon, the highest rate in trucking history. As a generally accepted rule in the industry, trucking rates were expected to be 20% or less of the overall costs of a harvest, but in rural areas with fewer mills like the Olympic Peninsula, trucking rates can run as high as 40% of harvest costs. In some cases, depending on the commercial value of the timber, rates can exceed 40% of harvest costs. Higher trucking fees impact the cost to set up equipment at a harvest, which also affects the bottom line. The combination of lower harvest volumes, longer trucking routes, and rising trucking costs are especially impactful on smaller forests in rural areas like the Olympic Peninsula.

WHAT IS CLT AND IS IT SUSTAINABLE?

"Forests defined by what is left behind rather than what is taken." - Ryan Temple, Sustainable Northwest Wood

Cross-laminated timber has gained significant popularity in recent years as a sustainable building solution. There are questions about the blanket statements about the sustainability of the product, many of which lie in forest management and supply chain.

Mass timber is a broad class of engineered wood products that have been a part of construction for years. Most simply put, mass timber products are formed by mechanically or adhesively bonding smaller wood components to produce large wood structural elements. Most common mass timber products are glue-laminated beams (glulam) and cross-laminated timber (CLT). These products are used primarily in commercial and multi-family construction projects but see some use in residential applications. CLT and glulam mass timber construction are often seen as a more sustainable alternative for steel beam and concrete slab construction methods.

CLT is produced by laminating lumber boards into layers set at perpendicular orientations, with a structural adhesive to make solid wood panels. These panels have excellent structural properties, fire resistance, dimensional stability, and can be machined with any number of details for connections, wiring, and cutouts for doors and windows. Traditional CLT panels are large format (12' x 60' for example) and are produced in large highly automated facilities. In North America, the majority of CLT panels are produced from Douglas Fir and more recently, Southern Yellow Pine. These species are readily available at sawmills and produce a high grade CLT, due to the excellent stiffness and strength of the lumber.



Mass timber and CLT has gained popularity in forestry, as it provides a market for sustainably harvested lumber. Sustainable timber production is important for the long-term health of the forest and key for continued production. Forest management varies regionally depending on forest ecology, landowner objectives, timber markets, and the logging operations available in the region. It is a nuanced and complex subject that should be customized region by region, and forest by forest. Lumber harvesting for CLT production can support sustainable forest practices as a market for small diameter trees and to ensure a high volume of lumber demand. Trees can be grown on shorter rotations of 20-30 years or support commercial thinning operations. While this is beneficial for production and can support sustainability goals, it does raise questions about forest management and environmental concerns, especially considering the ecological benefits of longer harvest rotations. The ecological diversity and complex supply chain dynamics of forests make blanket statements of sustainability troublesome.

As a consumer, architect, or wood product manufacturer one of the most powerful tools at your disposal for ensuring healthy forestry practices and sustainable wood products is knowing where your wood comes from, how the forest is being managed, and who is benefiting from creating this product throughout the entire chain of custody. Each region, forest, and chain of custody is unique and must be considered on a case-by-case basis. Below are some of the considerations to keep in mind when sourcing CLT or any wood products:

AGE OF TIMBER: Timber rotations lengths, or the age of trees when they are cut. As the pressure increases in the forest industry, the trend is to cut trees younger and smaller. According to latest research, 60 years rotation is the target for maximizing tree growth and production while also maintaining consistent forest health.

TIMBER HARVESTING METHODS: There are a variety of timber harvesting methods, including hand-felling, cut-to-length, shovel logging, tower logging, horse logging, and the list goes on. Speak with local county conservation districts, county extension cooperatives, or state or county forestry services to find out which are available.

TIMBER SPECIES: Species will change with location. Ensuring that a mix of species that are native to the landscape are replanted or left behind is key for ensuring the long-term resiliency of the landscape, and for mitigating risk with issues caused by climate change.

TRUCKING: As mills close down across the region, trucking has increased to reach the nearest mill. Fuel rates have increased over time as well, and commercial log values typically have not kept up. Trucking rates can be a barrier to timber harvesting and can eat up 30-40% of revenue depending on variables.

MILL RATES: While trucking rates and logging costs have increased over time, commercial rates for timber have not matched this trend. The need for finding local buyers and re-evaluating the value of wood based on the costs for production is an important step in creating equitable forest economies.

WOOD SUSTAINABILITY CERTIFICATIONS

Sustainability certifications are a well-established methodology for ensuring healthy forest management practices and equitable chain of custody. These are internationally recognized certifications which provide some baseline protection around forest management, labor laws, and human rights. This is a “blanket” approach that allows manufacturers and consumers to meet sustainability goals without knowing the exact origin of the wood. The primary sustainability certifications are FSC, SFI, and PEFC.

FOREST STEWARDSHIP COUNCIL (FSC): International gold standard in sustainability certifications. Requires the highest levels of environmental, social, and economic responsibility and monitoring.

SUSTAINABLE FOREST INITIATIVE (SFI): North American sustainability standard, less rigorous sustainability certifications than FSC.

PROGRAM FOR THE ENDORSEMENT OF FOREST CERTIFICATION (PEFC): Another global forestry sustainability certification, more common in Canada and outside of US.

This is a good approach for large manufacturers or consumers buying products from distributors who’ve sourced lumber from numerous locations. The downside of these certifications is they can be costly for all stages of the chain of custody and often lack the nuance required to account for the individual differences in forests and supply chains. Often, purchasing locally from somewhere you know and can verify easily, surpasses sustainability of these certification systems because you are supporting local efforts, can contribute to equitable wages, and ensure a lower carbon footprint from good forestry practices and reduced transportation distances.

CRTC WOOD SOURCING STANDARDS

The CRTC’s standards for sourcing wood for manufactured wood products are based on Portland Airport’s terminal that utilizes all local wood and creates a framework for sourcing that was more inclusive than the traditional certification schemes. These standards account for the complexities of forest supply chains on the northern Olympic Peninsula. Sustainable wood is defined as wood that is traceable, sourced within 150 miles of Port Angeles, and can fall into at least one of the three following categories:

1. Certified by the rigorous U.S. Forest Stewardship Council (FSC)
2. Traced back to ecological forest management that goes above and beyond local regulations.
3. Wood that was harvested from underrepresented parts of the supply chain (small mills, small family forests, non-profits, and tribal nations)

FSC Certified Wood	Sourced from certified FSC forests
Ecological Wood	- 61% certified as FSC Mix Credit claim - Sourced from a more ecological version of even-aged management (this includes smaller opening sizes, more retention, or longer rotations) -Sourced from uneven aged management (this includes variable retention harvests, single tree and group selection, ecological thinning, and restoration-style treatments) salvage or recycled wood

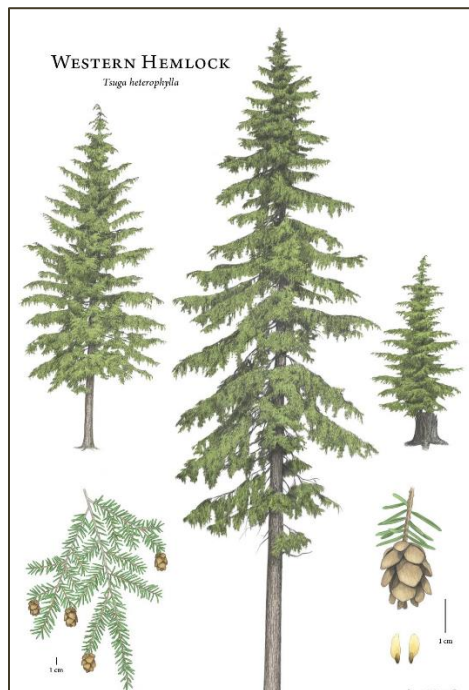
Local Wood	Sourced from underrepresented parts of supply chain including: -Conservation easement -Small mills -Small family forests -Non-profits -Tribal nations
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WHY WESTERN HEMLOCK (TSUGA HETEROPHYLLA)?

Understanding the origins of the ACLT product requires some background on coastal Western Hemlock (CWH) as a timber species. This section will outline the coastal variety of Western Hemlock, its applications to mass timber, and the challenges associated with using this species in engineered wood products.

The Olympic Peninsula is characterized by one of the last remaining temperate rainforests on the planet. Much of the land in the region has been federally protected as Olympic National Park and Olympic National Forest. It also has a significant amount of tribally owned land, one of which is the Makah Tribe.

Trees grow more productively, and older here than in many other places in the planet. Conifers that dominate the region like Douglas-fir, Western hemlock, and Western redcedar can easily live for over 300 years given the opportunity, and up to 800-1,000 years under the right conditions. Sitka spruce, Grand fir, Big-leaf maple, and red alder also make up the forest composition of the region. The area is so biologically rich that it has gained increasing attention with the research surrounding mycorrhizae and how plants communicate, support each other, and create dynamic relationships in this unique ecosystem.



Western hemlock (*Tsuga heterophylla*) is the 2nd most common species in Washington State, behind Douglas-fir. Ecologically, it is an evergreen conifer, shade tolerant, and fast-growing tree that can reach 100-150 feet tall and under the right conditions can live between 800-1,200 years old. On the very western edge of the Olympic Peninsula, including the Makah Tribal Reservation, Western hemlock doesn't need to be replanted when forests are cleared because it reseeds and grows so aggressively naturally.

Because it is so abundant and naturally regenerates on the Olympic Peninsula without the need for replanting, it has a high production use, but historically low commercial value compared to its competitor Douglas-fir. Western hemlock is often valued 20-30% less than Douglas-fir on the commercial market making it a less desirable species for growing commercially. In limited markets like the Olympic Peninsula, it also makes it more difficult to make a profit with increased trucking rates, fewer mills, and an overall lower price.

The lower commercial value of Western hemlock has unfortunately given it the common label as a "waste wood" or "low value wood," even though it is produced as part of the Hem-fir mix in commercial lumber and has a wide range of applications for construction. Combined with high logging costs, trucking costs, and low number of mills, Western hemlock has been a difficult species to make commercially viable in the region

unless sold in high volumes. In regard to CLT and mass timber, there are additional technical concerns associated with the species.

Western Hemlock, as part of the Hem-Fir species group traditionally hasn't been used in CLT due to low stiffness and strength, difficult drying characteristics that lead to dimensional instability and bond quality issues, and less robust supply chains compared to more traditional Spruce-Pine-Fir groups. A 2020 report prepared for a Forestry Innovation Investment in BC by Ference & Company summarizes industry feedback on use of Western Hemlock in CLT. Interviews were conducted with industry experts and mass timber manufacturers in BC. Across the board, the primary concern with WH as the lamstock species is drying irregularities reducing dimensional stability and causing poor bond performance. WH is known for containing pockets of especially wet wood. These pockets dry at different rates than the rest of the board which causes warping, twisting, and checking of the boards. This can lead to non-uniform bonding surfaces and dimensional changes to the CLT after bonding which further stresses bond lines. Since bond strength is one of the primary measures of CLT quality, inconsistent drying characteristics would lead to higher rejection rates of finished panels, or even a hindrance to initial qualification of the product. In addition to bond quality the lower stiffness and strength of WH would yield lower structural grade panels than traditional SPF CLT, so there is potentially less economic opportunity with WH CLT. This overall technical and economic uncertainty around Hem-fir as a structural material for engineered wood products hasn't allowed for a robust supply chain to develop. The supply chains associated with Douglas fir are robust and mills commonly produce Douglas fir in usable lamstock dimensions. This is less true for WH.

The challenges and concerns manufacturers have with WH as a lamstock material for CLT can be summarized into three areas:

- The standard WH supply chain isn't ideal for use as CLT lamstock.
- Inconsistent drying properties lead to increased dimensional defects and dimensional instability. These can have an adverse effect on bond quality, structural, and environmental integrity of the CLT.
- WH often has lower stiffness and strength than traditional SPF lamstock materials. This produces a lower structural grade CLT panel.

Despite these concerns, since this report was produced in 2020 at least one BC manufacturer (Kalesnikoff) has adopted the use of WH in CLT. They have achieved PRG 320 certification for CLT using WH lamstock and several large commercial projects have utilized WH CLT. Kalesnikoff is a vertically integrated manufacturer, meaning they log and mill the lumber used in the CLT manufacturing process. This gives them much more control over the supply chain and milled lumber dimensions. So, although the use of WH in CLT is more challenging and may have lower economic value, it is certainly a valid structural material for engineered wood products and its use has been demonstrated in large commercial applications. It is important to note that Kalesnikoff is located in the BC interior and likely isn't sourcing the coastal variety of WH which is plagued to a further degree by the challenges listed above.

ACLT AS A SOLUTION FOR RURAL ECONOMIC DEVELOPMENT AND A SUSTAINABLE CHAIN OF CUSTODY

The CRTC has been pioneering a new approach to address the technical concerns of CWH for use in CLT as a viable lamstock material and add value to the species to support the local economy and forestry efforts on the northern Olympic Peninsula. Advanced cross laminated timber (ACLT) and its applications were developed specifically as a solution to the challenges that have plagued WH in the past as an underutilized lamstock material:

THE ACLT SUPPLY CHAIN: The lower volume applications associated with ACLT allow for smaller scale supply chains. We have sourced lumber through small local selective thinning harvests and developed a relationship with the Makah tribe in WA state to source and mill our WH lamstock. The scale of the sawmill fits the scale of the ACLT manufacturing process and allows for a higher degree of control over the drying and dimensional characteristics of the lumber to match the ACLT application.

THE ACLT MANUFACTURING PROCESS: ACLT uses thermally modified western hemlock to address the inconsistent drying properties. This increases the dimensional stability and moisture uniformity throughout the material and gives the ACLT additional benefits in environmental resistance.

THE APPLICATIONS OF ACLT: ACLT panels are much smaller in format than traditional CLTs. ACLT panels are no larger than 4' in width and 16' in length, the majority being less than 12' long. The target application for these panels is fast erect small residential housing, rather than large commercial applications. This application lends itself well to lower structural grade CLT and reduces the need for high strength and stiffness lamstock.

The development of ACLT has taken place over several years, with the help and support of local, state, and federal partnerships. The development process is covered in detail below.

NEW APPROACHES, NEW PARTNERSHIPS, NEW VALUE – THE HISTORY AND DEVELOPMENT OF ACLT

In late 2017 and early 2018, the Port of Port Angeles was looking for additional uptake of the timber produced on the Olympic Peninsula. The Port had a special interest in this arena, as they managed log lay-down yards, the marine terminals responsible for shipping logs in from Oregon, British Columbia, and Alaska, and shipping logs and sawdust/chip products to Asia and other regions. Declining harvests, closure of lumber mills and plywood mills, and downturns in the pulp and paper industry had hit the region very hard, along with added restrictions on federal lands harvests. One promising route was the increased activity in mass timber, most specifically cross-laminated timber or CLT. The Port asked CRTC to provide engineering advice and support to their outreach campaigns due to the knowledge base in construction and materials.

Meetings were held with three major CLT manufacturers in BC, Montana, and Washington State. The outcome did not look positive, as the companies indicated the quantities and quality of the species available in the coastal region was less suited to their processing requirements than interior timber, or in one case, south-east US timber, and these regions would be where they would propose potential expansion, not in Northwest Washington. These reasons were identical to the concerns outlined previously for coastal Western Hemlock.

After this initial review, the question was posed “what could we do with the Olympic Peninsula timber to make it attractive to higher volume producers?” This was against the backdrop of the remaining stud-mill in Port Angeles owned by Interfor processing the majority of the harvested timber, with much of the raw logs being shipped to China for use as 2 x 12 boards for concrete forming. CRTC postulated that if the non-stud mill timber could be processed to make it more dimensionally stable, and then additional materials incorporated to overcome any detrimental impacts of this processing, then there could be some targeted applications that would have higher value and also high-volume demand. A support study sponsored by WA Department of Commerce and carried out by CRTC indicated that this approach, which would use a relatively new-to-North America process called thermal modification or TM, could be combined with composite reinforcements to make a CLT system that would have properties of interest to the Department of Defense (lighter weight, good blast/ballistics performance, excellent sealing against chemical, biological and nuclear threats, and easy to deploy in their critical theatres – arctic, tropics, and desert, with capability to be stored for long periods in containers without excess mold/mildew

degradation). This would also provide excellent benefit to disaster relief housing requirements for (some of) the same reasons.

In May of 2018, the Port, CRTC, and Washington State University personnel met with US Forest Service in DC, Pentagon officials responsible for Army housing, and US Army Corps of Engineers. Critique of the technologies and approach gave positive indications for proceeding, and the Port asked CRTC to continue the development effort. Shortly thereafter, at the Port's Timber Advisory Council meeting, we presented the concepts and had initial interactions with the Makah Tribe's timber manager. We were invited out to meet in Neah Bay early in 2019 and began discussing potential to utilize coastal western hemlock as one of the source materials. At this point in time, the Makah were only selling raw logs, and western hemlock, especially the fast-growing coastal trees, was low in value compared to other desirable species. As a side note, the Forest Service expressed interest in utilization of coastal western hemlock as this was one of the problematic species in the Tongass with little demand, thus a potential major wildfire risk.

The CRTC later traveled to Champaign, Illinois to meet with USACE engineering staff and discuss the outlines and goals of a plan to evaluate this approach, and a small contract was initiated from their Broad Agency Announcement to do a trial around our ideas and approach. CRTC fabricated test panels, contracted WSU and University of Washington to do preliminary testing and analytical work and worked collaboratively with USACE at the Construction Engineering Research Laboratory to evaluate properties of the thermally modified western hemlock with added composite reinforcement. Early samples were provided from harvests by Chickadee Forestry, milled by a local portable miller, and pressed into panels on the equipment at WSU. In eight months, the team was able to fabricate and erect a demonstration structure, provide evaluation screening of the panels, and show potential to utilize UW modeling capability to predict performance.

With this successful initial effort, the CRTC began in earnest to evaluate the complete structure of a supply chain that could make a business case for long-term price stability, dedicated supply of non-traditional dimensional boards, and a partnership that would retain the primary value of these materials on the Olympic Peninsula. This was during the massive supply disruption of lumber due to COVID and with typical lumber prices seeing nearly 3-times the price at retailers. CRTC was successful in grant applications that allowed the purchase and provision of a small lumber mill for the Makah Tribe and installed this and the associated building and drying kilns out in Neah Bay. CRTC also was able to procure its own thermal modification kiln so that shipments to Montana for processing would be avoided and also enable the process to be more amenable to Makah-supplied timber.

The Makah sawmill opened in early 2024 (CRTC purchased logs from the Makah prior to this and had them contract milled on-site) and immediately began supplying the specific dimension lumber needed for the USACE project, a huge win for all parties. As word spread of the relationship, other companies that used thermally modified lumber for siding and trim began to request CRTC's TM kiln services, which then began to expand into also supplying western hemlock which we could now source locally from the Makah Sawmill. The next stage to this effort will be expansion of the kiln-drying capacity and milling capacity in Neah Bay, in conjunction with tripling of the capacity of CRTC's thermal modification with a second, larger TM kiln.

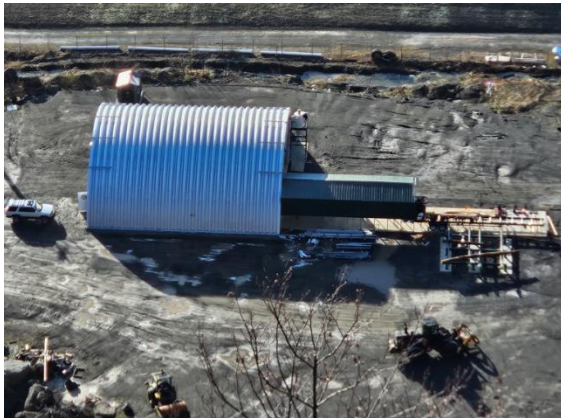
Key to the development have been several entities that deserve recognition beyond the ones noted above: a) input from UW, first exposing the Port and CRTC to the benefits of thermal modification; b) working with Thermawood Technologies in Polson, Montana for initial contract TM services and understanding the limitations of different types of TM processes; c) openness of the CLT manufacturers to visit their facilities and see high-volume processing taking place and understanding where in the value-chain the Olympic Peninsula's opportunity could fit; d) feedback from multiple architects on the positive and potential negative aspects of thermally modified CLT panels; e) discussions with many through the International Mass Timber Conference in Portland, OR on how a small-volume market entrant could navigate the intricacies of a new lumber requirement; f) dedicated efforts by multiple researchers, especially UW, WSU, and CERL to move the technologies forward rapidly, yet carefully; and g) teaming

with Makah and others to not only be a part of the supply chain, but also to be a part of the design and adoption teams that provide dual-use opportunities in military and civilian applications.

Critically, the State of Washington has been an amazing partner in assisting through grants, connections, encouragement, and support to enable the effort to have proceeded from concept to reality in an incredibly short time, considering that this is the first time (world-wide to our knowledge) that anyone has been able to develop and use thermally modified wood in structural applications, with significant opportunity and demand for affordable, highly durable, and beautiful homes. Working with the USACE and specifically the Engineering Research and Development Center – Construction Engineering Research Laboratory and their other sister labs has enabled development of potential game-changing semi-permanent structures for rapid deployment, soldier protective housing as well as future disaster relief housing. All this speaks to future strong demand for the Makah Sawmill lumber and will benefit the region, Tribe, and local economy greatly.

THE ACLT SUPPLY CHAIN

The Makah tribe is the primary supplier for Western Hemlock for ACLT, but the CRTC has also been able to source WH from SFLOs, showing equitable supply chains from both tribal and private landowners. As mentioned previously, WH has traditionally been a less profitable species to manage for small private landowners and tribal forests, especially in more isolated rural economies like the northern Olympic Peninsula. ACLT offers a higher value opportunity for these logs and supports local supply chains that drive down transportation costs. Higher value applications for these underutilized species could lead to more profitable landownership and promote the use of more sustainable forestry practices. Partnering with the Makah tribe provides a steady volume of sustainably sourced lumber for ACLT which allows for supplemental sourcing from other small landowner harvests. The Makah forestry enterprise employs a number of sustainable forestry practices including 60-year harvest rotations, replanting a mix of native timber species, no herbicides, leaving slash onsite, and leaves large buffers between habitat and riparian zones.



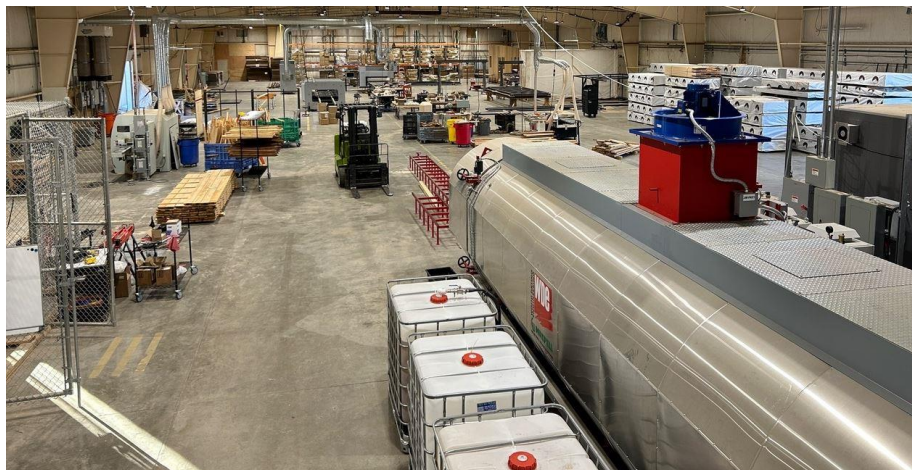
In the scale of the lumber industry in WA state, both the CRTC and Makah Sawmill are very low volume operations. CRTC would have trouble purchasing lumber directly from large mills and would have very little control over the lamstock dimensions. Similarly, a small remote Sawmill could have trouble scaling to the higher volume demands of large customers or have trouble managing numerous small customers with a wide variety of dimensional needs. This matching of scale allows for economical use of WH for ACLT. Since the completion of the Makah sawmill in the spring of 2024, the tribe has been supplying the CRTC with a steady supply of coastal western hemlock in ideal lamstock dimensions for the ACLT product. The two

drying kilns operate continuously and there is additional funding in place to increase the kiln drying capacity with several additional units. The CRTC purchases kiln dried (12% moisture content) 5/4 x 6 rough lumber for ACLT lamstock. The forest, sawmill and CLT manufacturing facility are located within a 70-mile radius which cuts down significantly on transportation costs and emissions. The ACLT product has provided a means for collaboration and profitable operation between the CRTC and Makah sawmill and allows for supplemental use of SFLO lumber. Together both operations can continue to scale and grow this mutually beneficial chain of custody.

THE ACLT MANUFACTURING PROCESS

The technical cornerstone of the ACLT product is thermal modification (TM). TM is a thermal process that takes wood to high temperatures in the absence of oxygen. The high temperature exposure produces chemical changes to the wood and its ability to absorb moisture. The chemical changes are mostly associated with the removal of hemicellulose, which is the main component of wood's microstructure responsible for the absorption and desorption of water. It also removes most of the extractives (fats, terpenes, resins, etc.) and increases the crystallinity of cellulose which is one of the primary structural components. The resulting material has a much lower equilibrium moisture content (5-8%) and significantly higher dimensional stability. The reduction in water absorption and carbohydrates increase the materials resistance to fungal decay. The changes do increase the brittleness of the material which reduces the overall strength of the wood. This has been the primary hinderance of the use of TM wood in structural applications. The thermal process completely dries the wood, to nearly 0% moisture content followed by a re-conditioning period back to equilibrium. This kind of thermal treatment has been recommended by industry professionals to address the inconsistent drying characteristics of WH (1). The TM process completes the drying process and ensures a uniform moisture content throughout the wood. The CRTC has produced production scale ACLT panels using TM lamstock. Third party testing has verified equivalent performance to PRG 320 bond line quality standards (published results are to be released in the summer of 2025).

The other unique aspect of ACLT is the scale and replicability of the manufacturing process. ACLT panels are typically produced in 4' x 8' or 4' x 12' varieties which is very small compared to the industry standard (12-20' x 60'). This reduces the size and equipment requirements significantly. Material handling is simplified by only having to move 13' boards and panels that weigh less than 300 lbs. The size requirements of the press and layup station, CNC, and planer lines are reduced which simplifies layout and material handling options. Although finger jointing is still a possibility for utilizing off-cut waste, it isn't needed to produce 20' or greater longitudinal boards. The CRTC designed and fabricated a custom pneumatic press fit to the application which produces panels up to 4' x 12'.



To quantify this difference in scale, take a traditional mass timber manufacturer like Mercer Mass timber and CRTC as a comparison. Mercer's facility in Spokane can process 140 boards/minute and produces 1400 panels per month. CRTC's final production capacity is not yet fully determined but is estimated at about 6000 boards per week. It only

takes Mercer 1 hour to process the number of boards CRTC would process in a week. The logistics of a supply chain that can support CRTC is several orders of magnitude simpler than one that supports a traditional CLT plant. Manufacturing at this scale is much simpler and has the flexibility to allow for the use of "more difficult" species such as WH, and smaller scale supply chains.

Simplifying the scale of the manufacturing process reduces the cost and makes it easier to replicate the ACLT model in other locations and with other wood species. Manufacturing at a smaller scale with lower

throughput simplifies the substitution of traditional SPF lamstock with under-utilized species. For a traditional CLT manufacturer, replacing even part of their feedstock volume with WH would still require massive quantities of lumber. This is a major barrier to entry for under-utilized species and small rural chains of custody, but one that can be alleviated by purpose-built products like ACLT.

THE APPLICATIONS OF ACLT

Due to the low production volume and smaller panel size of ACLT, the end use of the product differs from traditional CLT. Where traditional CLT is tailored to multi-story, multi-family commercial applications, ACLT is tailored to small residential or quick erect housing. The structural requirements of these applications are much less demanding and benefit from the unique features of ACLT. Since the spans and loading requirements of these applications are much lower than large commercial structures, the need for high structural grade panels and lamstock are lessened. This increases the economic viability of lower strength species such as WH. The less demanding applications also foster the use of TM materials which have slightly lower strength than un-modified materials. The ACLT product has gone through rigorous structural testing at Washington State University and has demonstrated structural performance equivalent to V1 grade panels from the PRG 320 standard.

In addition to the structural considerations, the combination of small format panels and thermal modification make the ACLT product particularly well suited to quick-erect and small residential applications. The benefits of thermal modification are mostly associated with an increase in dimensional stability and environmental resistance. The small panel format can eliminate the need for cranes and large material handling equipment which reduces assembly costs and logistics. The benefits to quick erect housing applications are summarized below:

- Increased dimensional stability of panels allows for multiple installations and assemblies. Panelized components can be fit together multiple times with precise accuracy even after exposure to changing temperature and humidity.
- Increased environmental resistance improves panel performance and durability in adverse conditions. This includes resistance to mold, mildew and moisture.
- Reduction in density from TM yields a lighter weight panel than an equivalent sized traditional panel. Small panels can be handled with relative ease by 2-3 people without the use of a crane. This can simplify construction on sites with difficult access, such as remote locations or small inner-city lots.



In collaboration with the Army Corp of Engineers, the CRTC has developed a military and disaster relief housing solution that uses a hybrid ACLT/steel container system that can be assembled and disassembled by a small crew in less than 2 days. This project has provided structural and assembly data to validate the performance of ACLT and pave the way for other housing applications. Most notable developments include structural tests to validate compliance with the PRG320 standard and seismic testing of prototype structures to demonstrate performance. Fire testing of the ACLT is currently in progress, as are published

results of testing. The small, thermally modified panels can meet the requirements of rapidly deployed housing for military and disaster relief applications.

ACLT has also made strides in residential applications. Most notable and relevant to this case study is a housing partnership with the Makah tribe to build tribal housing out of ACLT using lumber logged and milled on the reservation. In late 2024, a team was assembled from the Makah and CRTC to co-design a small 2-bedroom, 1-bath home that would use the Advanced Cross-Laminated Timber product from CRTC, making for a complete circular chain, Makah logs to their mill to CRTC's processing, back to Makah Tribal homes.



The effort was extremely positive, looking back at the Makah's long history of how they built homes centuries ago, how use and living in such a home would meet cultural and historical feelings, how to adopt modern ACLT technology to mitigate environmental effects and provide truly durable homes, and importantly – how to minimize up-front and operational costs with a mix of modern technologies and traditional designs. This 965 s.f. home with a covered 465 s.f. large concrete lanai/deck provides a wonderful case study of cost-effectively addressing the demands of living in an area with over 100-inches of rainfall per year, Pacific windstorms, yet with a dry summer that leads to water restrictions for a few months each year. As the project progresses, we all hope and anticipate these benefits can be realized by a large cross-section of Tribal and other communities in the State. We honor the elders, past, current, and future who have led us to this point, and the keiki who will carry forward these efforts for the foreseeable future. It is wonderful to see how well managed forests create opportunities when married to well developed and well managed technologies and the outcome of these heartfelt partnerships and new community. This is significant not only in the use of ACLT for high quality tribal housing, but also in completing the chain of custody on the Olympic peninsula.

UTILIZATION OF ACLT WASTE

There are three stages of wood waste identified as part of the total wood supply chain for ACLT panels. Due to the stage of development the project is in, some of these waste streams are still being determined and developed. For example, grant funding is in place for purchasing a briquette maker and boiler for heating the manufacturing facility. There is an ongoing development project funded by the Department of Commerce for repurposing chips, saw dust, offcuts, and other composite waste for making various building materials such as building blocks, cladding materials, and insulation materials that could be used in ACLT



housing applications. These solutions will continue to be developed and researched as the manufacturing process continues to scale. Heartwood Biomass, located in Oregon, has been a resource and inspiration for adapting to market needs and providing a range of options in repurposing low-value wood, chips, and sawdust in the community.

Currently, all the clean planer shavings are donated and picked up regularly by a local organic farm. Through this partnership we have been improving logistics with other local farms and developing options for producing compost and fertilizer from wood products. We have anecdotal evidence from farms on the Olympic Peninsula that there is a desire for more wood chips in the community that local arborists and mills have not been able to meet yet. There is strong potential for being able to provide more wood to the community through our processes.

In the forest there is an increasing capacity in the region with two new operators that are able to use forestry mulchers in the field to break down slash on site, expediting the speed of decomposition on site and reducing the leftover fuel load in forestry operations. Grinders located onsite at the Makah sawmill could process bark-caps and out of spec boards into large volumes of wood chips. This is a possible additional revenue stream or asset to the community. Due to the rural and isolated nature of the Makah reservation, shipping costs associated with high volumes of wood waste further justify local solutions that benefit the community and keep costs down. At sufficient production volume, for example 8 tons/hour, a wood incineration energy system could produce up to 100kW of low emission (very clean burning) energy and feedback directly into Neah Bay's grid. This improves energy independence for rural locations that suffer from interruptions in electricity.

While there is still more development in progress, we look forward to sharing resources as we continue to expand our opportunities for repurposing waste products into community resources. For now, here is a short list of examples of what the waste products are at each stage of production and where that waste is being utilized.

Stage	Products	Notes/Uses
Forestry/Logging	Slash, log end cuts	Forestry mulcher on site, biochar, reasonable amount left for decomposition/soil health. Dependent on forestry operations.
Sawmill	Bark caps, sawdust, off-cuts, reject boards	Chips for local pulp mill, firewood, and off-cuts donations to local lumber stores.
ACLT Manufacturing	Clean planar shavings and sawdust, sawdust with polyurethane glue, reject boards, cutouts, and offcuts	Depending on product chipping, selling in outlet store, pelletizing or briquette production, re-format/reuse for other products in house. Development project to extrude and compression mold building materials from ground up wood and composite waste and use those materials in ACLT housing applications.

CONCLUSIONS/CONSIDERATIONS ON REPLICABILITY:

Forests across the Pacific Northwest are facing increasing pressures from climate change and overstocking, leading to forest health issues and increased fire risk. Additionally, the decrease in small mills and forestry operations have left many rural communities struggling to keep up with forest management. Jobs have been lost in this sector over time and forestry has been focused into bigger operations, bigger mills, and along major truck routes. Timber species like Western Hemlock see disproportionate use and value, in comparison to the volumes present in Washington state forests.

Addressing these problems in a way that is beneficial to the land, community, and economy takes a specialized approach with attention to each stage of the chain of custody. While it can seem overwhelming to address all these issues at once, we believe that many communities already have these solutions in place and just require some innovation to connect the dots. The ACLT product and supply chain was developed over time as a solution to address local economic and forestry needs, identifying Western hemlock as an under-utilized timber species that is readily available in the region. What are the ways we could leverage that? What other resources might be available? What advantages do we have as a community, and how can we connect the dots?

A key component of this project is to demonstrate how other communities can address their own set of forestry and economic challenges and turn a very common problem into not only a solution, but something

that can provide jobs and resources to a community. This approach supports sustainable forest management, reduced carbon footprint in logging transport, new industries that support affordable housing, and more possibilities for repurposing waste into new products.

Our hope is that by demonstrating the success of this model in our community, it empowers other communities to envision a new path forward for resolving similar issues. Here are some of the questions to consider for developing a similar model in your own community:

- What locations have under-utilized wood species that are creating problems in forestry?
- What are the forestry operations and small milling operations in the area? Are there opportunities for growth?
- What are the technical barriers to utilizing that species in an engineered wood product?
- What are the housing needs of the area?

The CRTC team has had the benefit of an extensive research team and collaborators to help make this process a reality, and part of our work is dedicated to helping share this knowledge with other communities. This project was always intended to be replicable and adaptable based on the needs of the community. If you have interest in learning more or partnering with us to see how your community can build something similar, please reach out to the team.