Integrating North American Working Forests and Wood Products into the Circular Economy

Summary of the CORRIM Circular Economy Workshop
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Center for Urban Horticulture
University of Washington
Seattle Washington

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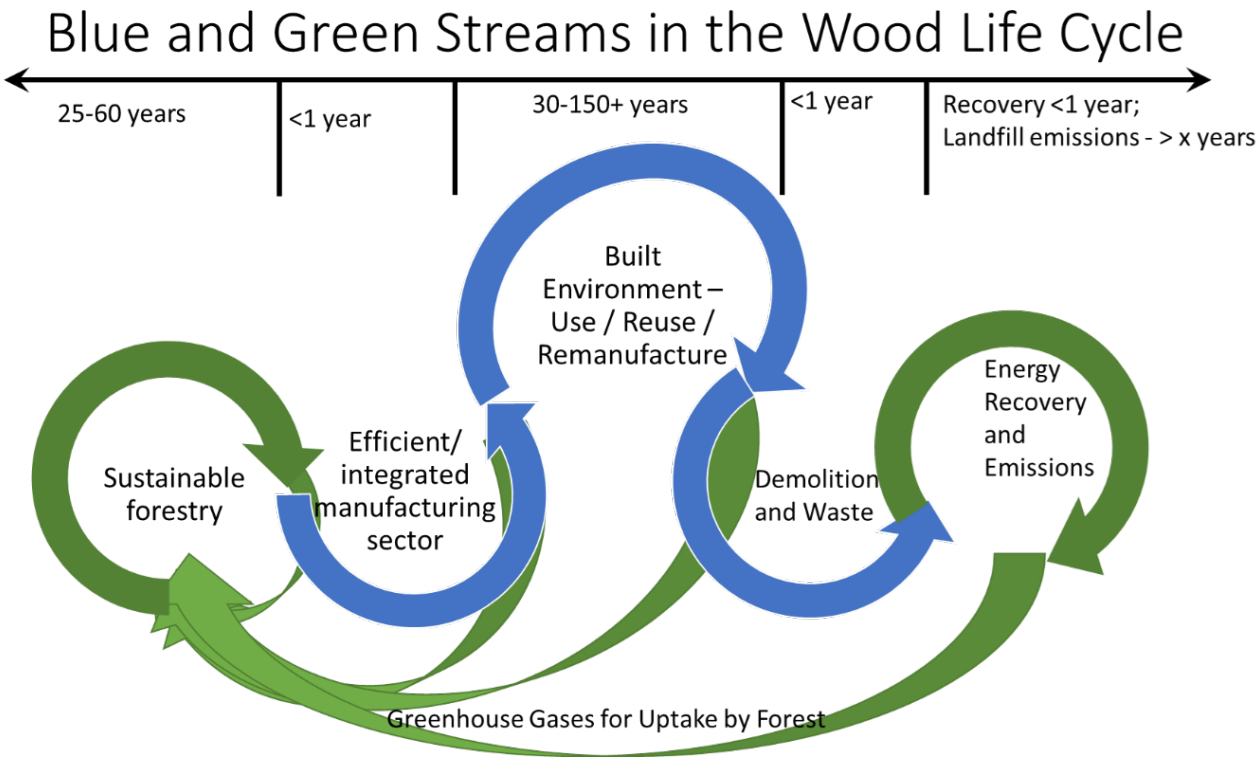

Workshop Summation

This workshop was convened to explore methods for incorporating circularity principles into the North American wood economy. In total we had 41 participants from 3 countries, 13 institutions, 7 trade and research associations, 5 government agencies, 3 consultants, 2 industry representatives, and 1 ENGO. See attendee list for details. This was the first North American conference to explicitly explore research needs for integrating circular economy concepts and approaches across the lifecycle of structural wood products from forest to frame to end-of-use and end-of-life in North America.

We started with an overview of circular economy principles (Figure 1) as well as clarification of the inter-relationships between the circular economy, circular carbon economy, and the bioeconomy, courtesy of Jennifer Russell, Circular Economy Professor at the Virginia Tech's Department of Sustainable Biomaterials.

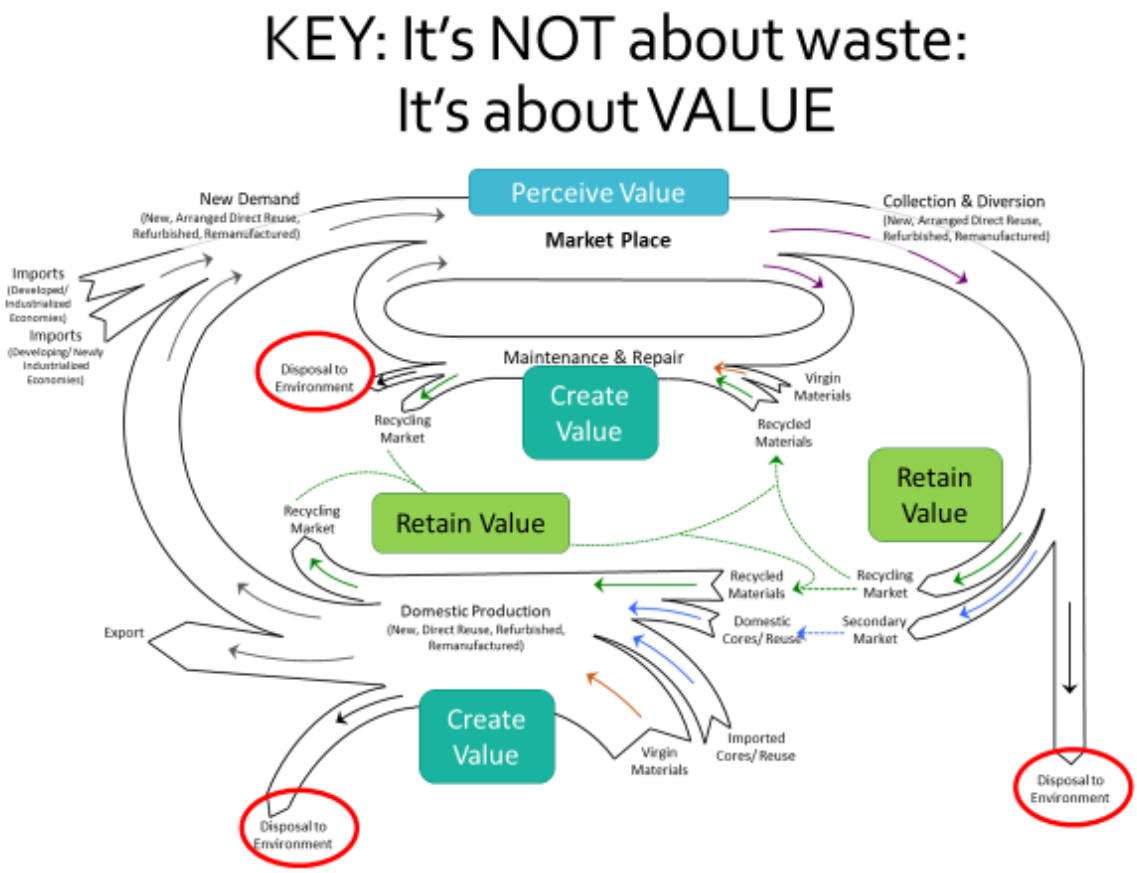

Figure 1: Key Principles of the Circular Economy Model

There ensued a robust discussion on how the current Ellen McArthur Foundation (EMF) model for the circular economy does not explicitly account for materials like wood, which begin their lifecycle in the green stream, and then cross-over to the blue stream for most of their economic lifecycle. This crossover effect is shown below (Figure 2) as a brown overlay on the Ellen McArthur Foundation model for the circular economy. We consider this a first draft of needed model adaptations.

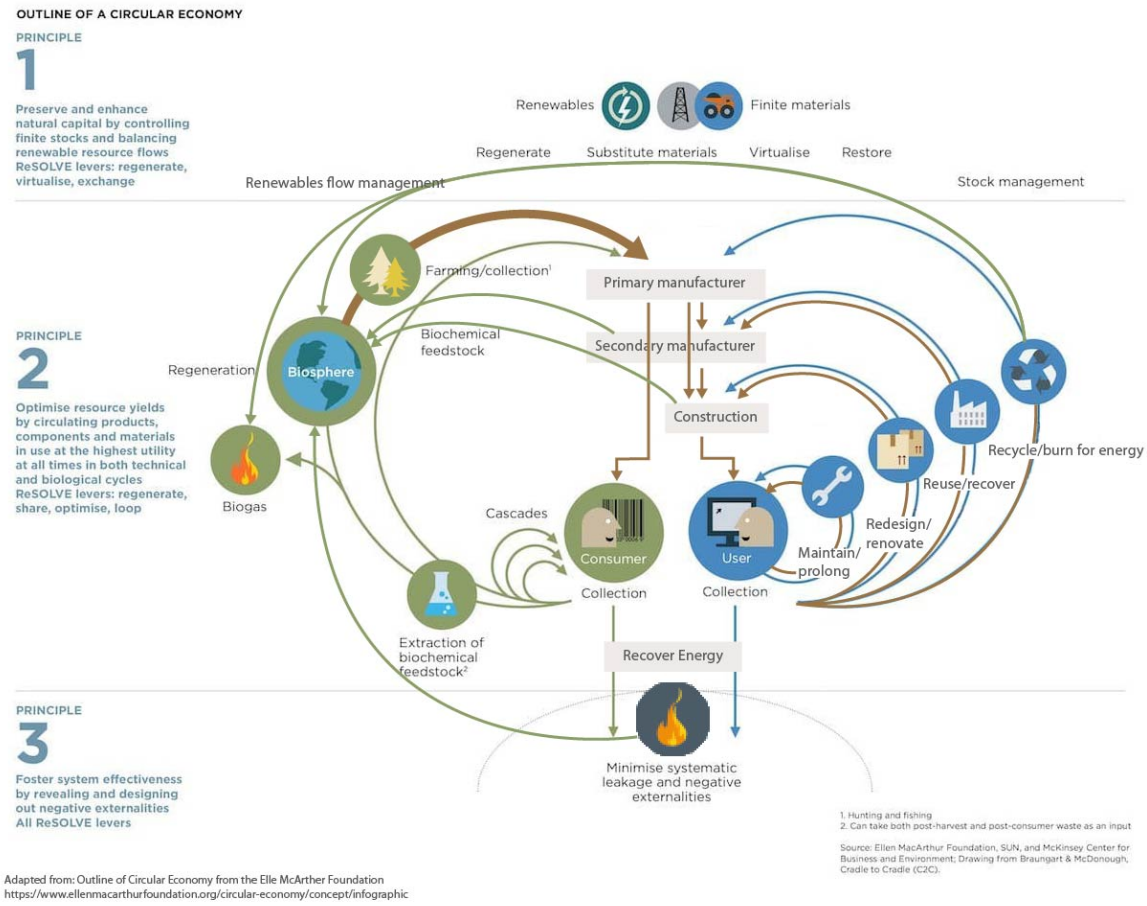

Figure 2: Adaptation of the EMF circular economy model with the addition of solid wood with production steps and cascading uses within both the green and blue streams. Note the separation of the wood material input (thick brown input) into two cascading lines, one following the green stream and the other following the blue stream. In all cases the final collection and disposal can include an energy recovery element that controls GHG emissions.

This crossover effect is not unique to wood. It will present challenges for all biomaterials that are used in the blue stream of the EMF model, including wood and its derivatives such as rayon, as well as bamboo, hemp, cotton, wool, and silk to name the more obvious biomaterials in everyday use. However, wood is unique among biomaterials for its longevity in the blue stream and the number and range of crossover opportunities for wood and wood derivatives, including bio-based chemicals and fibers that are components of hundreds of everyday products. A clear need to explicitly characterize how wood fits into a circular economy was deemed not only a fruitful area of research, but a necessary one. Efforts to refine the model to account for energy, exergy, material, and carbon flows, byproducts, and the multiple crossover opportunities were identified as high priority tasks.

The wood in the circular economy conversation was followed by a summary of CORRIM research on wood which has led to our conclusion that wood as a building material is a carbon negative technology. That presentation by Elaine Oneil, CORRIM's Director of Science and Sustainability, started with a discussion of an alternate circular economy model that we are calling the CORRIM model (Figure 3). The CORRIM model explicitly incorporates carbon flows, that highlight the EMF model blue and green streams with crossover linkages. It is a first pass at framing wood in the circular economy in order to

manage the complexity of the feedbacks and crossover opportunities for wood. It also links back to current measurement methodologies, specifically the definable life stages that correlate to the modules used in the North American Product Category Rule (PCR) for wood system boundary analysis.

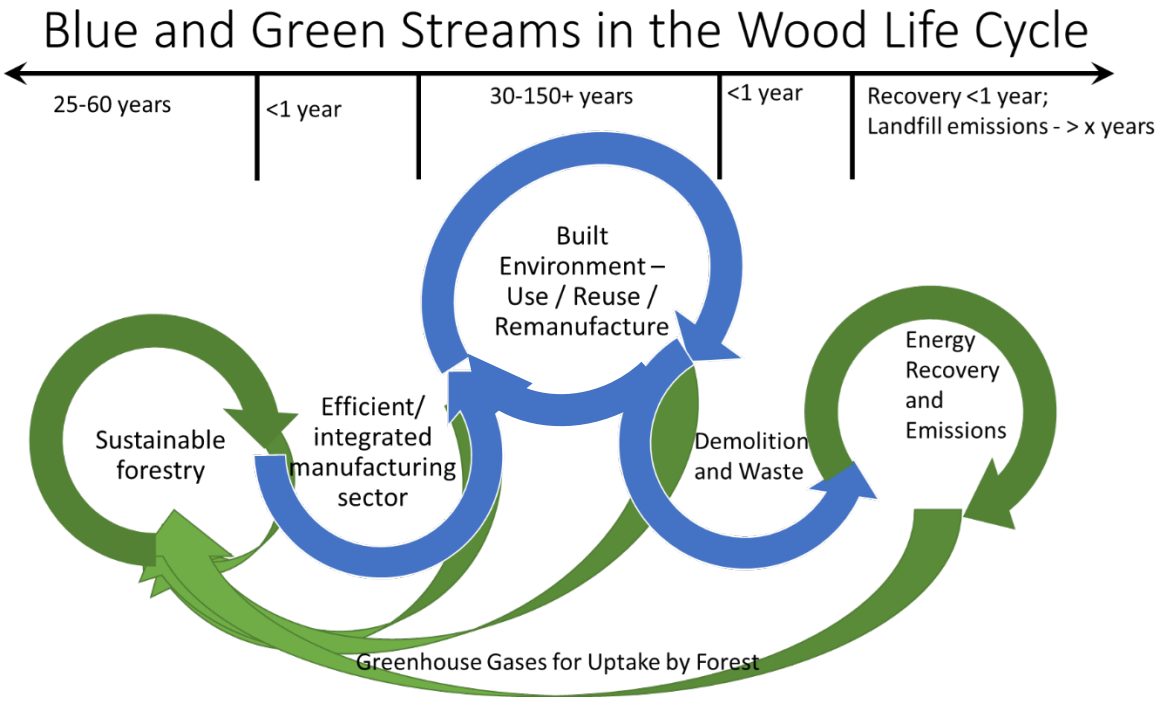

Figure 3 Life cycle of a solid wood product destined for building construction showing the cross-over from green to blue material flows vis a vis EMF circular economy model.

The PCR module for forest growth and harvest, plus manufacturing, is split to reflect the crossover from the green stream in the EMF model, to the blue stream during the manufacturing process stage. The construction module of the PCR is not included in this model but is captured in the crossover flow from the manufacturing processes to the built environment. The junctions in the diagram (Figure 3 – flow direction changes) capture the fact that at each of these flow transitions, there are definable and measurable energy inputs and outputs, and changes in the carbon balance of the system. We also consider the first, and any subsequent uses of wood as a separate category corresponding to the use stage of the PCR. This use stage can further be segregated into definable sub-units corresponding to the circular flows within the use stage that account for re-use, maintenance, repair, refurbishment and remanufacturing until the end of all useful lives for the material consistent with the subcategories of the PCR. The next stage of demolition and waste is separated from energy recovery (the final stage) to permit tracking of landfill stores and emissions separately from energy recovery opportunities, reflecting the distinct differences in energy and carbon balance under these scenarios.

Discussion of the CORRIM circular economy framework included the need for integrating land use into the equation and ended with a proposed framework for integrating the vast silos of work and scales that have been done on wood and wood derivatives using the Pratt Decision Intelligence model for addressing complex systems (silos to solutions chart - Figure 4) as a potential integration method.

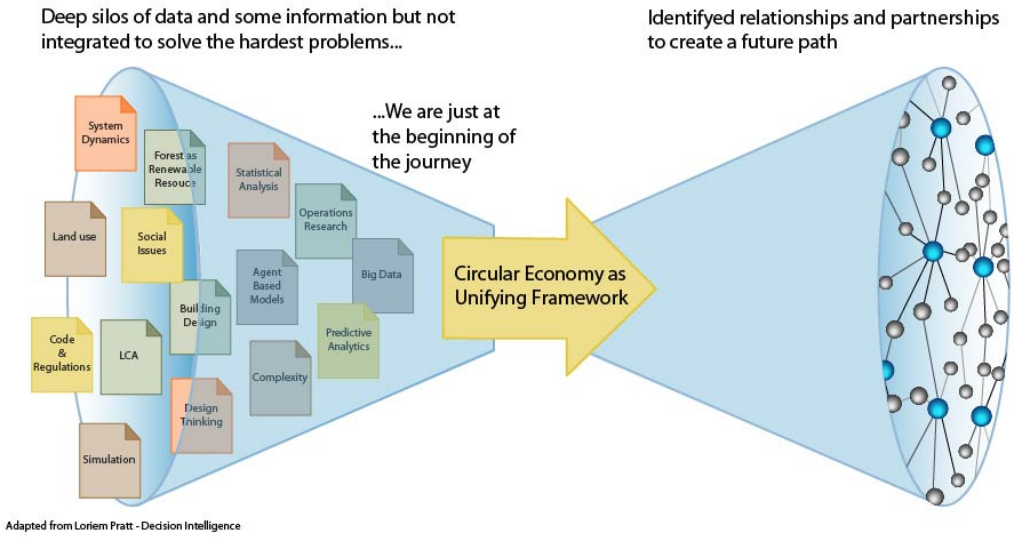

Figure 4 Identifying the linkages that matter at relevant scales to create a unifying model for wood

This Decision Intelligence model accounts for feedback loops, circularity and cross-linkages between disparate process elements, while identifying the key variables (decision levers) driving outcomes (Figure 5). It is particularly relevant when near term decision outcomes generate negative externalities that derail the long term sustainability of a complex system, something which was identified as a key issue throughout the ensuing discussions. Many examples of the long term unintended consequences of failing to value and manage forests were discussed over the two day event, leading to some proposed research and communication ideas summarized under the Forests section of this report.

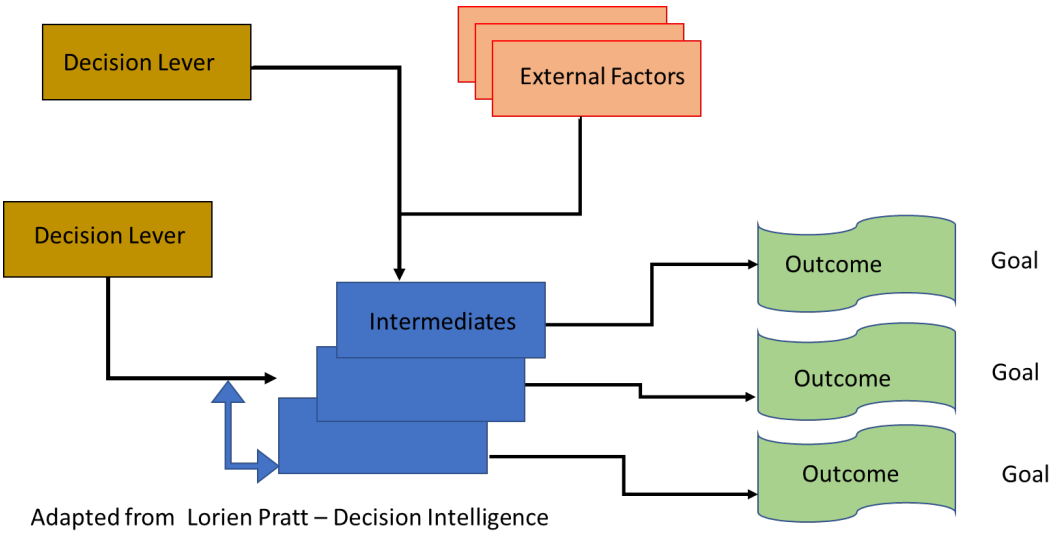

Figure 5: Decision Intelligence Model for Identifies the key drivers of system change.

Next, we heard from Alan Organschi, Yale Faculty member and principal of Gray Organschi Architecture about Designing a global carbon sink in the built environment. The urgency of the challenge of addressing the enormous carbon footprint of the built environment coupled with the double specter of climate change impacts and population growth, makes the talk a poster child of a perfect description of a “wicked problem”. We learned that it is a wicked problem with a feasible technical solution if we can

imagine a new way of building that results in cities becoming carbon sinks instead of carbon sources. The change would incorporate mass timber wood products, some of which have proven themselves over nearly 100 years. The proposed approach would alter our building morphologies and city density (Figure 6).

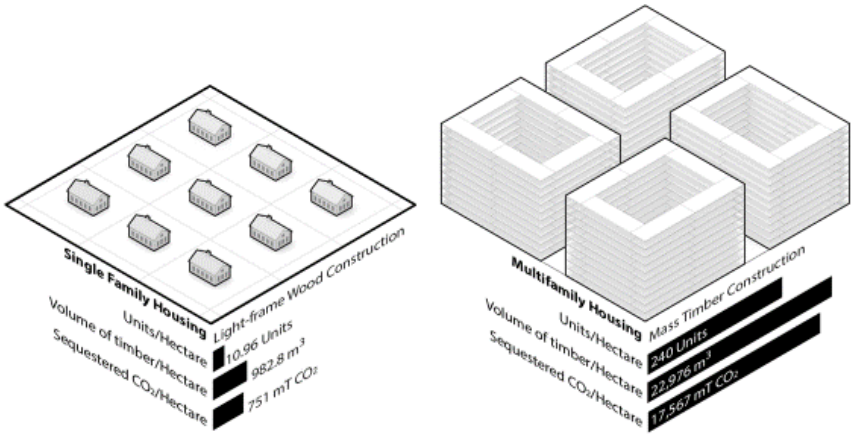

Figure 6: A 23 fold increase in the carbon stored in the build environment by modifying building morphology and density.

Even with a marginal price on carbon, the changes to the built environment could provide significant economic return to the cities that engage in these practices. These changes would require much better integration and cross linkages throughout the supply chain. One key takeaway is that the change from a linear economy to a circular economy starts with the creation of a circular knowledge economy that links downstream users to upstream processes in a streamlined and coherent manner. This can be best illustrated by an interconnecting "buckyball" as shown in Figure 7.

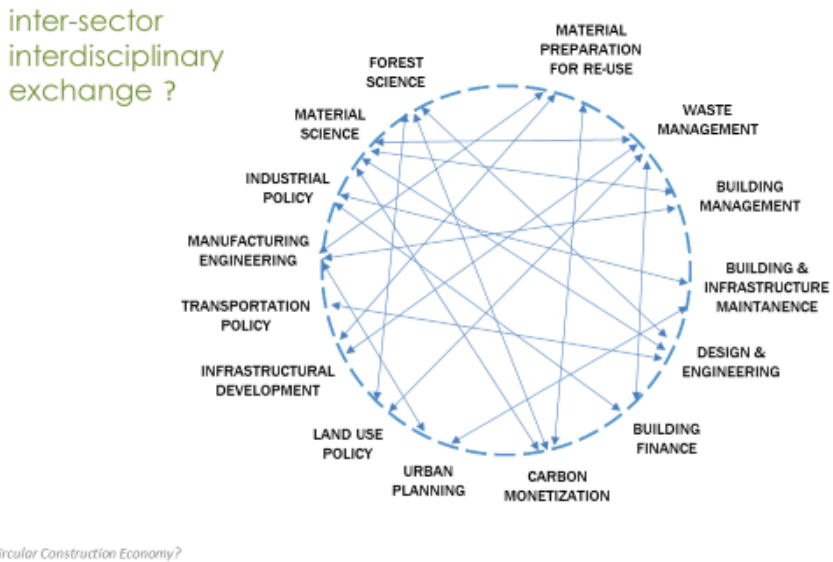

Figure 7: Develop a circular knowledge economy that builds relationships up and down the value chain for improved outcomes.

With these interconnections, not only can the innovations needed in design be integrated into product development, but the innovations needed for designing for dis-assembly can be incorporated into the

information package associated with each building component, much like a social security number is connected to a person for life.

More details and links to all three of these presentations can be found at https://corrim.org/circular-economy-workshop/.

After setting the stage for our discussions, participants formed break-out groups to tackle questions that were aggregated into eight categories based on their input. These categories were:

1) Characterize how circular economy, bioeconomy, and circular carbon economy frameworks can be integrated and used to frame the research need for integrated problem solving in the wood economy in North America. (a kind of CE 101 for wood within these systems)
2) Develop questions that can direct integrated operational research, with an awareness of systems-level opportunities and implications.
3) Identify data sources and tools, both extant and required.
4) Identify research, development and deployment needs for solid wood (within the blue/technical stream)
5) Identify research, development and deployment needs for wood residues (bioenergy and biochemical uses within the green/bio-stream).
6) Explore linkages to land use and land use change that are integral to circular economy, bioeconomy, and circular carbon economy outcomes.
7) Identify policy, education, outreach, and communication needs that can aggregate and deliver current knowledge to the forest and wood products sector, the design community, land use and city planners and code officials, elected representatives and the public
8) Characterize how non-market concerns influence the adoption and diffusion of these framework principles in the wood economy.

Outcomes and Discussion

The discussions, lightening sessions (3 minute talks designed to illuminate specific areas of concern) and synthesis topics identified several areas of contention, and many, many research opportunities. These discussions can be (loosely) categorized into five topics: 1) developing a circular economy model that works for biomaterials 2) data needs, data synthesis, and data transparency; 3) past end-of-life – what do we need to know 4) sustainability of forests and businesses, and 5) systems analysis. There is a tremendous amount of cross over between these topics as they feed forward and back within the system. Themes are synthesized below, with a more complete record available from the meeting audio files. Please contact us if you would like more information. Contact details are at https://corrim.org/circular-economy-workshop/.

Research Themes

1) Developing a Circular Economy Model that Works for Biomaterials

As noted in the overview, there was a robust discussion on the flaws and opportunities inherent in the EMF model as it pertains to cross-over materials like wood. Here cross-over means materials that flow from the green stream to the blue stream and back again. Key concepts that do work in the EMF model include the idea of looping (re-use, re-manufacture, re-purpose, recycle), cascading uses, a hierarchy of uses based on value, and its acceptance and momentum in other parts of the economy. However, there are significant concerns about how the EMF model handles biomaterials that are used rather than

consumed, like wood. These include terminology, missing flows, lack of multiple pathways for cross-over flows, and concepts like extraction and virgin materials. There is no reflection of the inherent circularity of the carbon cycle. The EMF model is too specific on the bioeconomy side with an oversimplified energy recovery depiction, but not specific enough on the blue side. There is no decision structure or information on allocating value in making informed decisions on flow. The model does not reflect sustainable and non-sustainable sources of wood materials and their inherent differences from a carbon perspective. It does not reflect energy and exergy flows, or carbon flows. It does not distinguish between pathways that may generate more waste and emissions when adding value than alternative lower value pathways that start with sustainably sources materials. It does not have the opportunity to add by-products, including environmental benefits and tradeoffs into the decision matrix. It doesn't have a clear accounting framework (i.e. is value measured in financial terms, economic activity, carbon sequestered, emissions avoided, jobs created, or some other metric?). And finally, there is no real way to incorporate material longevity as a critical part of the model.

This list clearly identifies the major shortcomings of the EMF model as it pertains to biomaterials. However, the broader concept of circularity, creating value through cascading uses, and finding efficiencies within this complex system were embraced as a pathway forward. It was felt that working within the context of circularity is important, but we can reinvent the form to match the needs of crossover materials like wood. This list also began the process of identifying which elements we believe are important for moving forward and we spent a significant amount of time daylighting those challenges.

Given the many identified challenges, a competing biomaterial circular economy model for wood was proposed. It included 3 parameters – economic, social, and ecological - with metrics associated with each parameter. One of the key metrics concerned the longevity of C storage in wood products, including all the cascading uses. A sustainably sourced wood product metric was included which was analogous to ISO 21930 requirements or ASTM 7614 sourcing requirements included in the PCR for North American wood products. Social benefit was measured using jobs, revenue, and local economic activity metrics. Ledger approaches were discussed for tracking the carbon (sequestered, emitted, and stored) as an accounting method to arrive at net carbon benefit. It was noted that the biomaterials circular economy framework may already exist as a component of sustainable development goals. It makes sense to link the eventual CE model for biomaterials back to sustainable development goals, and also back to existing sustainability metrics such as those currently in use for North American wood product Environmental Product Declarations (EPD). There were additional frameworks to consider in developing a model. These include the GHG Protocol Corporate Standard that corporations are using to meet global warming goals using reductions in direct emissions (scope 1), indirect emissions (scope 2), and scope 3 emissions (entire supply chain). Since wood, in its many forms, is an input material for many, if not most organizations, structuring models to capture data and information that would be useful for this effort would be desirable.

The alternate method would need significant analytical work and modelling development as it would need to specifically account for 'avoided' emissions (akin to a consequential life cycle analysis, or some kind of trade-off assessment model). The 'avoided' category would measure the outcomes from using wood instead of alternative choices. Some examples included recovery of residues for energy instead of slash burning, conducting fire risk reduction thinnings to manage wildfire, substituting wood for other energy intensive materials, and keeping forest land forested by providing stable economic returns to landowners. Prior biofuels (forest residues to fuels) analysis examples were used to characterize the need to include ecosystem benefits such as cleaner air and reduced fire risk into the equation of

financial decision making associated with the adoption of biobased technologies. Connecting these multiple research streams is needed to move biofuels, re-manufacturing, re-use, and re-deployment into the mainstream of our economy. This effort to incorporate very specific measures that internalize these externalities (the "avoided" outcome) could be developed, potentially using a techno-economic modeling platform. It was noted that throughout the discussion our group (of wood experts) moved seamlessly between discussing wood as a material, and wood as a carbon flow measured in units of carbon or CO_2e. Most materials, (except maybe water), do not have this kind of distribution within an economic model which may pose significant accounting challenges within any generic circular economy model.

Many questions around specific issues related to measuring circularity were identified over the two day workshop. Each will play a role in an eventual CE model that works for biomaterials like wood. These include elements specific to processes, allocations, economics, trade-offs, integrating across multiple temporal and spatial scales, and integrating across disciplines to name a few. The largest discussion themes were grouped into the other topics.

No discussion of circularity would be complete without a mention of design. All steps in developing a circular economy need a design requirement to improve durability, minimize eventual waste, and reduce the amount of toxics, or potential toxics in future products. Design can inform the source of material, its first use, reuse, repair, and refurbishment. It may even determine if the material can be recovered or even burned for energy at the end of its final life.

A Path Forward

Opportunities to use extant examples of simple circular value chains were identified as 'low hanging fruit' that could be used to characterize and daylight where the EMF model works, and doesn't work, in a simple wood product stream. Some specific examples where re-use is already common were discussed, including pallets, wine barrels, road mats, and some kinds of furniture. The supply chains for some of these products may be complex and may include both sustainable and unsustainable sources of wood. As part of this analysis, it would be necessary to characterize/ differentiate the origin/source of wood as sustainable versus unsustainable as the carbon consequences are likely to be different. This work could then inform a more robust CE model for wood which would then be applied to several products as a test validation. In more complex cases involving wood used in buildings, with multiple co-products and pathways for re-use, refurbishment and recycling, we can anticipate a need to adjust the model, with a goal towards making it simple, transparent, and user friendly.

The goal of developing the wood CE model would be as a framework for eventual decision making tools, such as a software tool to make the flows visible. There are both near term and long term research projects that were apparent in this discussion.

Data Needs, Data Use, and Data Transparency

There were many data needs identified throughout the supply chain. Specific requirements for updated data on housing stocks and stock changes, demolition rates, land-filling rates, energy recovery rates, and construction waste (by building type) were considered critical for understanding wood flows in the blue stream. There is also a great need for a wood inventory, including inflows/outflows, that expands the blue stream to include some combination of forest stock and flow data, construction and demolition waste flows, imports/exports, and non-structural uses (including fiber for paper, textiles, chemicals, non-traditional uses (cement binder), and energy). These coarse filter data would then need to be refined to identify how much of the material in building re-use stock is usable, its quality, the cost to

recover it, where is it best used in the blue or green streams, and how to we measure the benefits of its recovery. This daylighted the need for a trade-off analysis.

The idea that rare old wood in 100+ year old buildings is immeasurably valuable and shouldn't be subject to economic considerations was brought forth as a consideration for scientific evaluation. Like the conversation of 'avoided' issues, where we grappled with finding ways to internalize the externalities presented in ecosystem service benefits, there is a need to explicitly quantify the value inherent in old wood. This need resides in the social science and marketing realms, not in the technical and operational scientific realm. LEED as a building certification system has five data components - carbon, health, social, ecosystems, and circular economy and a philosophy of transparency first. Understanding what EPD can provide for these transparency requirements, and what they don't do well, requires better communication between data users (architects/engineers) and data producers (scientists/analysts).

There are data in many different places, and it is under the management and control of a plethora of scientific, government, and corporate entities. This disaggregated system of data ownership and generation is inefficient, as scientists at all institutions are wasting time chasing data instead of analyzing it in order to find new and innovative ways to advance the system. This became fully apparent when the team mapped where the primary information comes from for generating a single EPD.

Discussions ensued regarding what was sufficient to capture the uncertainties inherent in the supply chain at the sector, product and regional levels. For comparison purposes, there are 6 cement and 14 steel manufacturers in the US and easily thousands of wood producers in the US alone (not counting Canada which is part of the North American wood EPD production process). The large number of producers could result in large variabilities for a North American wide EPD. There is a need for more data, better data, and a clearer path for accessing it.

The idea of generating data that can be attached to the wood product (like a barcode or QR code) and incorporated into a database so that in the far future (50 years?), when the building is disassembled, the origin and structural properties of the wood could be included in the decision for re-use, was discussed. The technology for this database development is in a nascent stage but could build logically from the grade stamp technologies currently deployed. This was viewed as a fabulous idea, but our first priority should be to organize our current data to supply current needs, with an eye to creating a database that seamlessly incorporates future technological advances.

A Path Forward

A LEAN process was recommended to ensure that these disparate data sources can be used effectively to answer the key questions, identify weaknesses, gaps, missing data, and representativeness. As part of the LEAN process, it was suggested that a digital platform be developed that would make it easier for data suppliers to complete surveys and easier for analysts to access data. The first step includes a meeting with relevant data analysts and scientists to start a LEAN process and gap analysis. It is also necessary to make a better case to manufacturers about the need to include their data in the pool of information, how it is used, and what outcomes are possible from participation. This internal sector wide work will help with internal cohesion and funding and external information demands – including to data users and data aggregators like EC3.

There was a clear recognition that we have a significant amount of data and need to winnow the questions we are interested in to see what data we can use and what we need to develop.

Past End of Life – What do we Need to Know?

De-construction and Re-use of the Current Building Stock
Estimates are that 30% of the current housing stock will be demolished by 2050. It will be critical to identify how much of the material in the building stock "forest" is usable, at what cost, and at what benefit. The point was made that at least some of this material has significant cultural, historical, and emotional value which can serve as an inspiration to retain and recover the wood. The challenge will be in measuring it in a way that incorporates that value. This is not likely something the assembled scientists would do, but it is a fruitful area for social science inquiry.

Overall, this component of the value chain has a critical need for a framework/decision matrix that can help identify which use/re-use is the most "appropriate" and how to measure "appropriateness". One suggestion to help develop the matrix was to develop a PCR (product category rule) for re-use/re-design for deconstruction. In order to develop this matrix several key data needs were identified including:

1. a detailed understanding of the building inventory,
2. the recoverable amount of the building inventory,
3. its shape, quality, and end use (green side or blue side of the circular economy)
4. its value (financial, commercial, and/or carbon benefits),
5. the dominant factors that are barriers to de-construction (e.g. financial, technical, standards for re-use, skilled labor force, demand/supply locations, need for re-processing, remanufacturing and recertification of materials, lack of standardization of materials)
6. the trade-offs associated with using the reclaimed wood in terms of energy and material and carbon efficiency.

Each of these areas will provide fruitful areas for research well into the future.

De-construction and Re-use of Future Building Stock
There is a need to document the design, how it was engineered, and why, to ensure that the materials can be re-usable consistent with the safety, structural, and technology needs of the future when the building may be de-constructed for reuse. Buildings as Material Banks (BAMB) models do this, but there was no clear consensus regarding their sufficiency or scope. The timing and kind of re-use decisions should also be part of the decision matrix with value driving re-use decisions. Again, the question of how to measure value arose with an additional metric concerning durability. It was posited that the most durable products should be the hardest to reach (for eg: in the middle of the wall, not the covering, or furniture). This approach would allow lower quality or value materials to be upgraded as necessary, while the structure itself is retained as a durable legacy element.

There was a robust discussion regarding the use of something like a QR code for each piece of wood in order to provide a clear picture for the architects and engineers of the future. That included the kinds of information that could be put into the QR code such as engineering properties, origin, location, provenance, forestry management, etc. The challenge to that idea is that we may not have all the data needed to ensure this system would have a high degree of confidence which may result in a loss of credibility and confidence in the outcome.

It was suggested that to start the QR code could include one or two pieces of information. That would allow the market to inform the structure of the information and provide valuable insights on how it is used. The team thought starting with origin information might be the most fruitful path. This is

different than current certification systems which bundle a lot of information. This approach would unbundle the information which would allow the consumer to identify the attributes that matter most to them. Tracking systems could be linked to current grade stamp technologies that are mill specific, however it is unlikely that upstream data is currently available with a high degree of granularity and may be difficult to develop without significant technological investments.

While there is a need to increase transparency for the first use, it is also critical to understand what the second user might need 30, 50 or 100 years into the future. It will be necessary to understand, model, or predict what a future designer would want to know at the wood piece level, wrap level, or bill of materials level. Some key attributes we anticipate will matter are presence of glues and their composition, nails, connectors, CCR treatments, and quality characteristics.

It was recognized that there are an infinite number of solutions in the product development and design space for engineered wood, so it is important to prevent coalescing around limited options too soon. This includes opportunities for future products that are currently not commercial (e.g. nanotechnology that could make wood fiber a much larger part of the engineered built environment with near term advances in carbon fiber cement and 3-D printing, to name just a few). Lots of work still needs to be done with parametric modeling and big data analysis to meet the goals of current and future design teams.

For both current and future buildings, the building codes dictate construction and demolition. Currently there is no code for 'Designing for Demolition' (DfD). There is also no building code that includes an embodied carbon target. These codes will not develop until a clear path is charted. To do so, a focus on national level scenario data is a good first step.

The Path Forward

There are three components to the path forward:

1. the development of a framework matrix populated with local, regional, and national data on current building stock, expected demolition rates, potentially recoverable material, its value, and future markets.
2. The development of data to be incorporated into new construction that documents design parameters so that future design teams can make better re-use decisions as they will have better information on the provenance, strength, and safety considerations of using the reclaimed wood. Part of this development includes increased granularity and data transparency.
3. With these kinds of information, work on building codes to incorporate reclaimed wood could proceed.

Sustainability of Forests and Businesses

Significant work is needed to simplify information on forestry, the forest sector, and the relationship between forest use and forest sustainability for design teams, policy makers, and the public. There is a perceived lack of transparency in the current EPD structure because elements like biodiversity are not discussed. It was noted that the underpinnings of EPD are LCA, and while they are a fabulous tool for tracking inputs and outputs from the technosphere, doing the same with inputs and outputs from the natural environment is more problematic. That said, even if LCA were equaling good at tracking inputs and outputs from the natural environment, the functional unit scale relevant for an EPD (per m3 or per lineal foot for e.g.) is not translatable to a scale that matters for elements like biodiversity because they

can only be assessed at a landscape scale or larger. Even accounting for stable carbon stocks is problematic in an EPD as it is not measurable at the scale of a cubic meter. This has led towards incorporating additional elements into the PCR and EPD, including elements of ISO 21930 that require explicit information on forest sustainability, either from certification sources or country wide data. It is unclear if this will be sufficient to address transparency concerns.

There is a need to characterize what LCA and forest certification measure with respect to forest sustainability given that the measurement systems are complementary and not overlapping. As manufacturers are the ultimate data providers, efficiency in data collection would help ease their burden, while increasing transparency. Developing models to link across scales from product LCA models to land use and global trade models may help to increase this transparency.

A core element of forest sustainability, as it pertains to providing wood to the economy, requires keeping forest land as active working forests. Maintaining forest land matters globally and nationally, but is most critical at the regional scale because that scale matters given the relationship between maintain working forest and a sustainable, profitable milling infrastructure. This led to discussion on clustered development, including current models and future opportunities given local and regional growth management laws, goals, and priorities. The presentation on 'Timber Town 2.0' is one way to think about clustered development, but there are other ways to approach maintaining forest land even without mid-rise CLT buildings. It will work differently in different counties, so after developing a proof of concept it would be necessary to take it to scale in the country, and then across the globe. That will require market analysis, population growth analysis, and an understanding of ownership patterns in order to model various scenarios of development (e.g. clustered, dispersed, infill). The basis of the evaluation could be measured in a number of ways including a carbon benefit comparison, cost/profit and/or social acceptability given the role of private property rights in different regional cases. Interactions between development and land use change (forest conversion), including developing agent-based models to explain the drivers of conversion were listed as potentially fruitful areas of research.

The Path Forward

In order to complete a large scale synthesis of topics related to forest sustainability, aggregation and organization of existing information on each question is needed. The three priority topics for a large scale synthesis are forest conversion, biomass use to obtain 'avoided' benefits, and sustainability of forest resources under different demand scenarios. Key questions are elucidated below. Each synthesis is likely to generate a significant number of researchable topics across multiple scales.

1. Characterizing the relationship between development pressure and forest conversion. What is the true cost of sprawl in terms of forests converted, linear feet of roads, electrical, fiber optics, water, sewer etc? Is there a sweet spot that optimizes land use intensity/density with different built environment modalities (e.g. single family, multifamily, tall wood, aggregated etc). An optimization exercise that builds on emerging data on whole buildings that factored in land use, carbon, cost, infrastructure, and population growth may yield interesting and informative results. One particular challenge at the larger scale is that population growth and needs for new building construction is on the global south, whereas sustainable forestry is practiced largely in the global north.
2. Characterizing the differences in material flows from farmed forests (e.g. managed plantation forests), mined forests (e.g. wood from forest land conversion), virgin forests, opportunistic wood sources (e.g. urban tree recovery, grassland rehabilitation, fire risk reduction activities,

orchard renewal), and co-product streams that arise from primary and/or secondary wood manufacturing processes. This would help illuminates questions such as: How much of current global forest product production is "sustainable" whether certified or not? How much could "intensification" (I.e., greater volume production) of sustainable forest increase production to meet greater demand from increased use of wood in construction? And what would the price of carbon need to be to result in enough sustainably produced wood to avoid deforestation?

3. Characterizing how, and under what conditions, low value material is used (or not used). Of necessity this section will need to link back to the 'avoided' elements identified in the circular economy discussion in order to integrate the co-benefits of utilizing low value forest materials (forest residues, thinnings from fire risk reduction, low value species, low quality wood) into the value proposition for managing forests for economic value. It would be designed to answer questions like: is biomass energy part of the circular economy? What metrics can be used to make the connections between forest management and forest health? How do we identify barriers to utilization that are driven by lack of markets and local conditions that limit market development? What kinds of communications strategies are needed to daylight the different values associated with different kinds of energy generation from biomass?

Systems Analysis

There was candid acceptance that the EMF model, or indeed any model of circularity is a dream, and the reality in terms of wood circularity, is far from that dream particularly in conventional stick-frame housing stocks. One clear goal would be to conduct a material flow analysis that maps out the eventual fate of all materials at the present time. This would serve as a baseline for improvement. There are many existing data sources that could be used to track flows, though some additional data gathering would be needed. Once that work was accomplished it could lead to further analysis regarding the barriers that inhibit more (or further) circularity within the wood economy. Some key questions that were deemed critical to drive this process are:

1. What are the barriers to completing the circles within each subsector of the economy?
2. How does source (non-sustainable vs sustainable) affect this?
3. What is the allocation of wood fiber between uses?
4. How much is being recovered for reuse or to capture energy value?
5. What is the difference between today (current conditions) and the future?
6. What are the near term versus long term data needs?
7. Are their data, or can it be produced within a reasonable amount of effort in the near term to answer key questions?

Using this baseline data, scenario analysis could be completed on a local, regional or national level for a few products to identify improvement opportunities. These scenario analyses could evaluate potential pathways for improvement using a range of different frameworks.

Defining Value Frameworks

It was mentioned that our current system measures value in financial terms but in the future we could be measuring value in terms of carbon. As the circular economy is ideally driven by value allocations, rather than waste reduction, a larger systems analysis study to dissect outcomes using different value metrics would be one method to explore barriers to improved circularity. Some examples that would benefit from comparative analysis are the differences in value if wood use choices are allocated or re-allocated based on financial return; carbon benefits or carbon efficiency metrics, including displacement and substitution benefits; life cycle assessment (LCA) metrics; techno-economic (TEA) metrics; waste

reduction; or longevity in use. These different value assessments could be used to confer a hierarchy of values for re-using, repairing, re-furbishing, or remanufacturing wood under given use conditions.

There is also a need to advance the current comparative analysis of wood relative to other structural products. This advancement could take the products through end of life to the next life, including assessing re-usability, renewability, and the need for re-manufacturing. There are also opportunities to place this comparison in a framework of environmental, social, and economic outcomes that quantifies avoided externalities. These comparisons should be advanced to the whole building level (in progress now), and then to the community, region, and national level. These data are needed to underpin any proposals to modify building codes on the basis of environmental performance.

Buildings as material banks (BAMB) is a European construct that should be introduced to North America. It would be a component of a full inventory of wood, including forests (managed, unmanaged, and reserved), buildings, construction and demolition waste, landfills, and urban trees. For full utility it would need to capture the flows through the wood inventory components, including imports and exports across definable boundaries (regional, national, North American wide etc). This kind of information could help inform scenario planning, policy, and process improvements. In the long term it may lead to optimization in terms of building size and development density. While there are key elements of this work that are found under data and re-use, the integrative nature of the concept dictates that it be treated as a synthesis topic.

Businesses and Circularity

The GHG Protocol Corporate Standard provides the impetus to develop business models that quantify the value of the carbon benefits in the business supply chain as part of a corporation's economic value assessment. When these drivers are understood, it will inform upstream data collection, tool development, and circularity choices. It will also inform the institutional, policy, and legal constructs that are most likely to support circularity in wood products. There were several questions to explore regarding how such changes will affect the way business is conducted today, both in the forest sector and in the building and re-use sectors.

The Path Forward

Identify barriers for creating a circular wood economy.

1. Economic / markets
2. Institutional / legal
3. Technical / LCA

At the product scale start with cascading LCA that take the material through a series of hypothetical lives to the eventual fate of landfilling or energy recovery. At the regional economy scale an analysis similar to the UW analysis that incorporates the full suite of primary materials through estimated end of life with scenarios for extending the life of these materials could be used to identify the most efficient pathways for addressing circularity in the wood economy. Characterizing a method for equitably recognizing and valuing BAMB as a core part of the circular economy in institutional and policy constructs would inform and perhaps drive the current corporate focus on sustainability as a core component of their business models.