JOINT INSTITUTE FOR WOOD PRODUCTS INNOVATION

LITERATURE REVIEW AND EVALUATION OF RESEARCH GAPS TO SUPPORT WOOD PRODUCTS INNOVATION

Photos by Katie Harrell

BOARD OF FORESTRY AND FIRE PROTECTION
STATE OF CALIFORNIA

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A report submitted to the

California Board of Forestry and Fire Protection

Agreement # 9CA04450

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EXECUTIVE SUMMARY

Innovative wood products hold the potential to drive carbon-beneficial, sustainable forest management in California. Their development and deployment can help the State of California increase the pace and scale of forest management and restoration efforts needed to address the problems of overstocked forests and climate change.

Under the umbrella of the California Board of Forestry and Fire Protection, the Joint Institute for Wood Products Innovation (Institute) has produced a review of forest product innovation literature, gaps in forest product innovation research, potential strategic partnerships, and recommendations for near-term priorities to support the expansion of the innovative wood products sector in California.

There are numerous innovative products with sufficient commercial and technical readiness, and potential market size, to justify increased public and private investments in their development. California stands to benefit significantly from support for innovation in the sector through increased local capacity, strengthened regional collaborations, and increased carbon storage in long-lived wood products.

The most promising classes of innovative wood products identified by the Institute at this time include:

- **Mass timber**
- **Liquid and gaseous transportation fuels**
- **Chemically and thermally treated wood**

The Institute also identified a number of less-mature technologies that merit continued monitoring with respect for their potential for commercial deployment. Critical information on the most important innovative wood products considered in the report are displayed in the table at the end of this summary (Table ES-1).

From a policy perspective, the Institute's priority recommendations include:

- **Align State incentives to better account for the climate benefits of forest products.**
  For example, California's Low Carbon Fuels Standard could drive development and deployment of low-carbon and carbon-negative fuels derived from forest biomass. Similarly, Governor Newsom's proposed $1 billion Climate Catalyst Fund, which would focus on transportation emissions reduction, climate smart forestry, and the circular economy, could provide low-interest loans to innovative wood product infrastructure.
- **Promote infrastructure development for innovative wood product processing.**
  For example, the State lacks necessary small diameter sawlog processing infrastructure and dry kiln capacity necessary to manufacture innovative wood products like mass timber and other engineered wood products.
- **Fund research to further innovation in wood products, including:**
  - Development of product layups for mass timber panels from California feedstock
  - Identification of scalable structural wood products from small-diameter and non-merchantable biomass
  - Investigation of subsidy design for mobilization of nonmerchantable biomass to best serve California's climate change goals

More generally, the State can foster a more supportive policy environment for wood products innovation by implementing and supporting programs and policies that:

- Build robust markets for wood products, including small-diameter and non-merchantable wood
- Support science and engineering research capacity, including enhancement of in-state capacity alongside engagement of out-of-state experts
- Leverage State leadership in climate change mitigation, including the promotion and development of low-carbon fuels and products
- Incentivize regional action in forested regions to promote rural economic development
- Account for the benefits of wood product utilization in State funding decisions and regulations
- Provide consistent policy signals for sustainable land management
- Effectively account for forest carbon sequestration in products

The Institute is poised to play a key role in this effort by:

- Funding applied research and analysis to further innovation in wood products
- Identifying opportunities to better align State activities that contribute to long-term sustainability, forest health, carbon storage, bioenergy, and renewable materials
- Informing changes to State and federal policy to promote wood products innovation
- Partnering with existing national and international wood innovation centers and service providers to leverage funding and expertise


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California's 33 million acres of forestland is the largest land-based carbon sink in the State, with trees, shrubs, meadows, and forest soils sequestering carbon from the atmosphere. Decades of fire exclusion/suppression compounded by rising average temperatures and reduced precipitation have dramatically increased the size and intensity of California wildfires and bark beetle infestations, threatening the ability of forests to capture and clean water, serve as long-term carbon sinks, and support native biodiversity. To reverse these trends, system-wide changes in forest management and forest product innovation are imperative. To achieve desired goals, the State must increase the pace and scale of forest management and restoration efforts, build local capacity and strengthen regional collaboration, support forest product innovation, and promote the use of forest products.

Table ES-1. Most important classes of innovative wood products considered by Institute

Product classification	**Mass timber**	**Liquid and gaseous transportation fuels**	**Chemically and thermally treated wood**
Example products	Cross laminated timber Nail bonded CLT Dowel bonded CLT	Renewable natural gas Renewable hydrogen Fischer-tropsch fuels Gas fermentation Fast pyrolysis and hydroprocessing Lignocellulosic ethanol	Acetylated wood Furfurylated wood Thermally modified wood
Purpose	Structural wood product	Transportation fuel	High-durability wood
Carbon storage	Yes (product)	Possible (CCS)	Yes (product)
Range of feedstock required (BDT/year)	900 – 9,000	45,000 - 300,000	420 - 21,000
Technology readiness level (1-9)	9	5 - 8	8
Commercial readiness level (1-9)	6 - 8	5 - 7	5 - 8
Feedstock use	Merchantable logs including small logs	Non-merchantable wood	Merchantable logs & Non-merchantable wood
Potential market size	Medium	Large	Medium
How can Institute influence outcomes?	Market formation activities to promote in-state manufacturing Testing of California tree species, such as true firs, for mass timber products Identify products that could best align with California's forest management goals, including utilization of non-merchantable biomass	Market formation activities to promote in-state manufacturing Develop and assess additional supportive policy Identify products that best align with California's forest management goals, based on feedstock-pyrolysis interactions	Investigate suitability of technology for California tree species Market formation activities to promote in-state manufacturing

REPORT BACKGROUND

The Institute was established pursuant to Executive Order B-52-18 to facilitate innovation and growth to develop and expand a robust and sustainable forest products market sector in California (Table ES-2).

Table ES-2. Activities as mandated by the Charter for the Institute

Priority Activities as mandated by the Charter			
Review existing analyses of barriers and opportunities to forest product innovation and expansion.	**Identify gaps** in knowledge and **meet with stakeholders** to fill gaps and identify market opportunities of specific interest to those actively pursuing market innovation and expansion.	**Coordinate applied research projects** responsive to the recommendations of the Wood Utilization Working Group and/or Institute Advisory Council.	**Develop a business incubator** for wood products that is coordinated with local chambers of commerce, counties, and community business incubators and leaders.
Additional Activities as mandated by the Charter			
Conduct market research to identify existing and emerging wood products.	**Share market research** findings with "others interested in expanding innovative wood product markets."	**Conduct research and develop strategies** to reduce barriers to innovative wood products.	**Identify new technologies to improve economic viability** of sustainable forest management practices and ecosystem restoration.
Determine potential markets with "sufficient scale and timelines" that "offer substantive assistance to reduce hazardous fuels and improve forest health in California."	**Provide education and outreach** to affected entities, interested parties, the public, media, and policy makers on forest products, innovative wood use, and the work of the Institute.	**Initiate local, State, and federal policy design** for wood innovation and expanded utilization of forest biomass.	**Identify and evaluate relevant standards** –implemented and operational, national, and international – for wood product innovation initiatives "as appropriate."

Under the umbrella of the California Board of Forestry and Fire Protection (Board), the Joint Institute for Wood Products Innovation (Institute) contracted with the University of California, Berkeley and a team of researchers to:

- Review forest product innovation literature, including any associated barriers;
- Identify gaps in forest product innovation research as well as those areas that have yet to be examined in the context of California forests;
- Evaluate potential strategic partnerships with external stakeholders and how best to engage each; and
- Recommend near-term priorities to expand in-state production of mass timber as well as other innovative forest products

This report examines these topics through three separate chapters:

- Chapter 1: **Innovative wood products and key market indicators**
  - Literature review and evaluation of innovative wood products with potential to be manufactured from California feedstocks
- Chapter 2: **Wood supply for value-added wood product innovation in California**
  - Trends and projections of the state of wood feedstock supply in CA that could service new, value-added wood product innovation development
- Chapter 3: **Strategic partnership landscape, gaps, and recommendations**
  - Prioritization of recommended partnerships and actions to be undertaken by the State and the Institute

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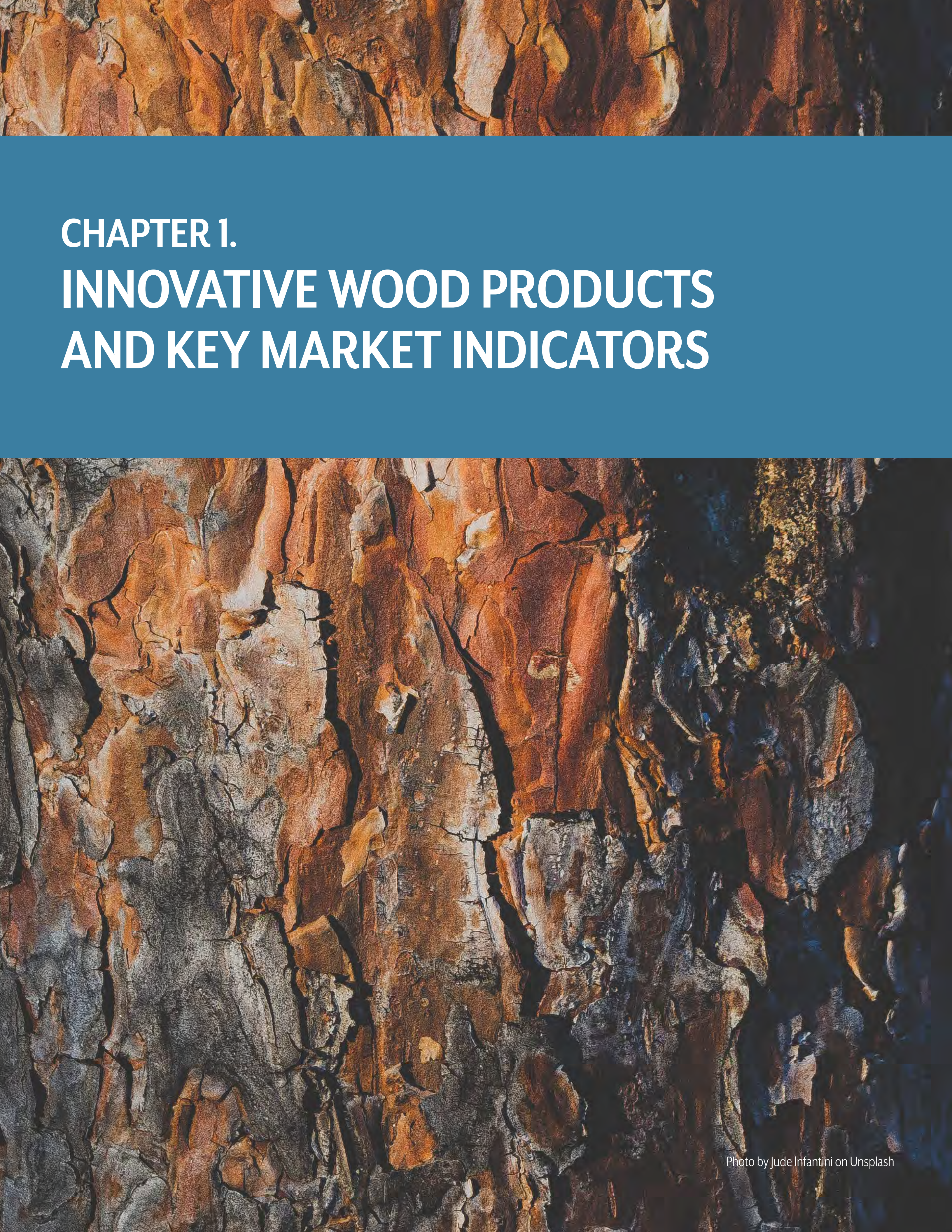
CHAPTER 1.

INNOVATIVE WOOD PRODUCTS AND KEY MARKET INDICATORS



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1. SUMMARY

Information contained in chapter:

- Matrix summarizing market research across innovative wood products
- Product overview for the following classes of products: mass timber and other structural wood products, pyrolysis (non-energy, solid and gaseous fuels), liquid fuels, nanomaterials, chemically-treated wood, chemicals and extractives
- Detailed market analysis for four classes of products: mass timber, pyrolysis, liquid fuels, chemicals and extractives

Methodologies:

- Literature Review
- Research Gap Analysis

Conclusions:

- There are numerous innovative products with sufficient commercial and technical readiness, potential market size, and investment hypotheses to justify further development. The Institute could have its largest influence on the following classes of products: mass timber, liquid and gaseous transportation fuels, and chemically and thermally treated wood (Figure ES-2).
- Commercial-scale wood product manufacturing will produce multiple products. The most promising combinations of products are not yet known.
- Mass timber products, including panels, beams, and columns, hold substantial promise as new California products made from merchantable, in-state lumber. The Institute can undertake market formation activities to promote development of manufacturing capacity.
- Testing of California tree species, such as true firs, for mass timber products, may help attract new investment and align mass timber with California's forest management goals.
- The largest markets for structural wood products derived from California's non-merchantable biomass (e.g. OSB, mass plywood) are not yet known. More research is needed in this area to identify the products that could best align with California's forest management goals, including utilization of nonmerchantable biomass.
- California's climate policy instruments (especially the low carbon fuels standard) can drive development and deployment of low-carbon and carbon-negative fuels derived from forest biomass. The Institute can undertake market formation activities to promote in-state manufacturing. Scale up of innovative processes to produce low-carbon transportation fuels from forest biomass will require additional supportive policy and additional research on feedstock-pyrolysis interactions.
- There are relatively few well-quantified export opportunities for innovative wood products manufactured in California, with the exception of biocoal/torrefied wood. The export prospects for biochar and other wood products are not well understood.
- Several products lack commercial or technical maturity to currently justify substantial investment of Institute resources. These include some non-energy pyrolysis products and nanomaterials. The Institute should continually monitor potential commercial deployments of these technologies, should conditions change. Smaller grants and other incentives to entrepreneurs and academics could facilitate development of these technologies.

2. MATERIALS AND METHODS

2.1.1 Product narrative

For each product, we attempt to provide the following information in narrative form:

- **Product description**
- **Existing capacity:** Where are commercial facilities located? Which feedstocks do they use? What is their scale?
- **Justification:** Why is this an innovative wood product?
- **Market indicators:** Market size and future potential
- **Barriers to product or process innovation and growth**
- **Research gaps:** Research or analysis that can advance the technical or commercial maturity of this product in California
- **Opportunities for influence**
- **Product substitution:** Products that are being displaced by innovative wood products

2.1.2 Indicators for visual matrix

Representative feedstock required (numerical): How much feedstock we expect a representative commercial-scale facility to process in a year. We report information in either bone dry tons (BDT) biomass or board feet (BF), depending on the product. We use the following conversion factors and assumptions (Shelley, 2007):

- Representative capacity factor: 85%
- 1 BDT = 2 GT (assuming a moisture content on a wet basis of 50%)
- 1 BDT of chips = 200 cubic feet
- 1 ccf (hundred cubic feet) roundwood = 1.0 BDU chips
- 1 ccf roundwood (logs) = 1.2 BDT chips
- 1 GT of logs = 160 BF of lumber
- 1 MBF (thousand board feet) = 6 GT of logs (assumes scribner short log scale)
- 1 BDT ~ 1 MWH
    - » 1 BDT burned in a typical commercial boiler fuel will produce 10,000 lbs. of steam
    - » 10,000 lbs. of steam will produce about 1,000 horsepower or generate 1 megawatt hour (MWH) of electricity

Carbon storage (binary): Carbon emission benefits from wood-based products typically come in two forms, substitution and storage. For instance, biopower displaces other forms of fossil energy (like coal or natural gas), but does not store any carbon, as the majority of the input biomass is burned. In contrast, biochar, long-lived wood products, and geologically sequestered carbon dioxide, also known as carbon capture and sequestration (CCS). If a product is expected to store carbon, we indicate the form of storage as "products," "CCS," or "char." This metric does not encompass substitution benefits, which we expect to result from most, if not all, innovative wood products.

Commercial readiness level (numerical ranking, 1-9):

Our assessment is based on guidance from the Advanced Research Projects Agency-Energy (ARPA-E 2014).

Table 1. Description of commercial readiness level (CRL)

CRL	Description
1	Knowledge of applications, use-cases, & market constraints is limited and incidental, or has yet to be obtained at all.
2	A cursory familiarity with potential applications, markets, and existing competitive technologies/products exists. Market research is derived primarily from secondary sources. Product ideas based on the new technology may exist, but are speculative and unproven.
3	A more developed understanding of potential applications, technology use-cases, market requirements/constraints, and a familiarity with competitive technologies and products allows for initial consideration of the technology as product. One or more "strawman" product hypotheses are created, and may be iteratively refined based on data from further technology and market analysis. Commercialization analysis incorporates a stronger dependence on primary research and considers not only current market realities but also expected future requirements.
4	A primary product hypothesis is identified and refined through additional technology-product-market analysis and discussions with potential customers and/or users. Mapping technology/product attributes against market needs highlights a clear value proposition. A basic cost-performance model is created to support the value proposition and provide initial insight into design trade-offs. Basic competitive analysis is carried out to illustrate unique features and advantages of technology. Potential suppliers, partners, and customers are identified and mapped in an initial value-chain analysis. Any certification or regulatory requirements for product or process are identified.
5	A deep understanding of the target application and market is achieved, and the product is defined. A comprehensive cost-performance model is created to further validate the value proposition and provide a detailed understanding of product design trade-offs. Relationships are established with potential suppliers, partners, and customers, all of whom are now engaged in providing input on market requirements and product definition. A comprehensive competitive analysis is carried out. A basic financial model is built with initial projections for near- and long-term sales, costs, revenue, margins, etc.
6	Market/customer needs and how those translate to product needs are defined and documented (e.g. in market and product requirements documents). Product design optimization is carried out considering detailed market and product requirements, cost/performance trade-offs, manufacturing trade-offs, etc. Partnerships are formed with key stakeholders across the value chain (e.g. suppliers, partners, customers). All certification and regulatory requirements for the product are well understood and appropriate steps for compliance are underway. Financial models continue to be refined.
7	Product design is complete. Supply and customer agreements are in place, and all stakeholders are engaged in product/process qualifications. All necessary certifications and/or regulatory compliance for product and production operations are accommodated. Comprehensive financial models and projections have been built and validated for early stage and late stage production.
8	Customer qualifications are complete, and initial products are manufactured and sold. Commercialization readiness continues to mature to support larger scale production and sales. Assumptions are continually and iteratively validated to accommodate market dynamics.
9	Widespread deployment is achieved.

Technological readiness level (numerical ranking, 1-9):

Our assessment is based on guidance from the National Academies of Science Engineering and Medicine for emerging bioenergy technologies (National Academies 2018).

Table 2. Description of technology readiness level (TRL)

	TRL	DOE Definition	Description, with application to biopower
Applied Research	1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples include paper studies of a technology's basic properties.
	2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
	3	Analytical and experimental critical function and/or characteristic proof of concept	Active R&D is initiated. This includes analytical and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology (e.g., individual technology components have undergone laboratory-scale testing).
Development	4	Component and/or system validation in a laboratory environment	A bench-scale components and/or system has been developed and validated in the laboratory environment. Bench-scale prototype is defined as less than 1% of final scale (e.g.; technology has undergone bench-scale testing with biomass feed stock/ simulated feedstock of 0.1-1 t/d)
	5	Laboratory-scale similar- system validation in a relevant environment	The basic technological components are integrated so that the bench-scale system configuration is similar to the final application in almost all respects. Bench-scale prototype is defined as less than 1% of final scale (e.g.; complete technology has undergone bench-scale testing using actual dry biomass feed stock of 0.01-1 t/d).
	6	Engineering/pilot-scale prototypical system demonstrated in a relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. Pilot-scale prototype is defined as being 1-5% percent final scale (e.g., complete technology has undergone small pilot-scale testing using actual dry biomass at a scale of approximately 10-50 t/d).

	TRL	DOE Definition	Description, with application to biopower
Demonstration	7	System prototype demonstrated in a plant environment	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Final design is virtually complete. Demonstration-scale prototype is defined as 5–25% of final scale or design and development of a 50-250 t/d dry biomass plant (e.g., complete technology has undergone large pilot-scale testing using dry biomass feedstock at a scale equivalent to approximately 50-250 t/d).
	8	Actual system completed and qualified through test and demonstration in a plant environment	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include startup, testing, and evaluation of the system within a 50-250 t/d dry biomass capacity plant (e.g., complete and fully integrated technology has been initiated at full-scale demonstration including startup, testing, and evaluation of using dry biomass
	9	Actual system operated over the full range of expected conditions	The technology is in its final form and operated under the full range of operating conditions. The scale of this technology is expected to be 50-250 t/d dry biomass capacity plant (e.g., complete and fully integrated technology has undergone full-scale demonstration testing using dry biomass feedstock at a scale equivalent to approximately 50 t/d dry or greater)

Feedstock use (binary): Innovative wood products can be made from traditional "merchantable" wood, or "nonmerchantable" biomass. While the definition of "nonmerchantable" varies, it typically includes harvest / logging residues (tops, branches, and small-diameter wood) and wood that is of poor-form and inferior quality. We classify mill residues as "nonmerchantable," even though most mill residues are used for power generation, heat, mulch, or other conventional wood products at present.

International markets (binary): Are there existing international markets for these products?

Elsewhere in this report, we attempt to evaluate if California is in a unique position to meet this need based on technological leadership, forest management practices, location, proximity to shipping, or other reasons.

Potential market size (categorical: S, M, L): This is an estimate of how much wood Californians might consume in-state should the product be adopted at scale. This is an inherently subjective metric, but is typically derived from estimates of existing demand. California's timber harvest was 1,572 million board feet (MMBF) in 2016.

Table 3. Categories for market size determination

Category	Market size (BDT/yr)	Market size (MMBF/yr logs)
Small	<100,000	<33
Medium	100,000 – 1,000,000	33 – 333
Large	>1,000,000	>333

Research or analysis need (Low/Medium/High): Is there research or analysis that can advance the technical or commercial maturity of this product in California?

Can Institute influence outcomes (Low/Medium/High): The Joint Institute is searching for products that have a large potential market size, have an actionable research or analysis need, produce large carbon benefits, have a viable source of policy support, and use nonmerchantable wood. The authors consider all of these metrics in assessing the ability of the Institute to influence innovative wood products development in California.

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3.VISUAL MATRIX

Mass timber panels			
Product Classification: Mass Timber panels	**Cross Laminated Timber (CLT)**	**Nail bonded CLT**	**Dowel bonded CLT**
Representative feedstock required MMBF/year (BDT/year)	Small: 2.1 (6300) Medium: 6.4 (1900) Large : 12.7 (3800)	Min: 0.3 (900) Typical: 1.0 (9000)	Typical : 0.85 (2550)
Carbon storage	Yes (product)	Yes (product)	Yes (product)
Technology readiness (1-9)	9	9	9
Commercial readiness (1-9)	8	7	6
Feedstock use	Merchantable logs >8" DBH Minimum grading: #2 on faces, #3 in cores	Merchantable logs including small logs	Merchantable logs including small logs
International markets	Yes	No	Maybe
Potential market size	Medium	Small	Small
Research or analysis need	Low	Medium	Medium
Can JIWPI influence outcomes?	High	High	High
Purpose	Structural wood product	Structural wood product	Structural wood product

Pyrolysis: non-energy products				
Product Classification: Pyrolysis-non-energy products	**Wood Vinegar (Pyro-ligneous Acid)**	**Carbon Black**	**Biochar**	**Activated Carbon**
Representative feedstock required (BDT/year)	35,000 (Corigin LLC)	Unknown	150,000 (National Carbon Technologies)	150,000 (National Carbon Technologies)
Carbon storage	No	Yes (product)	Yes (char)	Yes (char)
Technology readiness	5	4-5	9	9
Commercial readiness	2-3	3	5	9
Feedstock use	Non- merchantable	Non- merchantable	Non- merchantable	Non- merchantable
International markets	Yes	Yes	Yes	Yes
Potential market size	Uncertain	Large	Uncertain	Large
Research or analysis need	High	High	High	Medium
Can JIWPI influence outcomes?	Low	Medium	Medium	Low
Purpose	High-value agricultural product	Bulk material for transportation	Multiple uses	Filtration

Pyrolysis: solid and gaseous fuels			
Product Classification: Pyrolysis – Solid and gaseous fuels	**Torrefied Wood / Biocoal**	**Renewable Natural Gas**	**Renewable Hydrogen**
Representative feedstock required (BDT/year)	149,000 (Restoration Fuels)	250,000 (GTI Stockton)	45,000 (Clean Energy Systems)
Carbon storage	No	Possible (CCS)	Possible (CCS)
Technology readiness level	8	6	5
Commercial readiness level	6	5	5
Feedstock use	Non-merchantable	Non-merchantable	Non-merchantable
International markets	Yes	Yes	Yes
Potential market size	Medium	Large	Uncertain
Research or analysis need	Low	High	High
Can JIWPI influence outcomes?	Medium	High	High
Purpose	Thermal energy production	Transportation fuel	Transportation fuel

Liquid fuels				
Product Classification: Liquid Fuels	**Fischer - Tropsch Fuels**	**Gas Fermentation**	**Fast Pyrolysis and Hydroprocessing**	**Lignocellulosic Ethanol**
Representative feedstock required (BDT/year)	68,000 (Red Rock Biofuels)	133,000 (Aemetis, Inc.)	300,000 (SPI Camino site)	100,000 (Axens/ Anderson Biomass)
Carbon storage	Possible (CCS)	No	Yes (char)	Possible (CCS)
Technology readiness level	7	8	6	8
Commercial readiness level	6-7	6	5	6
Feedstock use	Non-merchantable	Non-merchantable	Non-merchantable	Non-merchantable
International markets	Yes	Yes	Yes	Yes
Potential market size	Large	Large	Large	Large
Research or analysis need	Medium	Medium	Medium	High
Can JIWPI influence outcomes?	High	High	Medium	Low
Purpose	Transportation fuel	Transportation fuel	Transportation fuel	Transportation fuel

Nanomaterials			
Product Classification: Nanomaterials	**Ultra-strong Wood**	**Transparent Wood**	**Wood Fiber Insulation Board**
Representative feedstock required (BDT/year)	Unknown	Unknown	90000 (GO Labs)
Carbon storage	Yes (product)	Yes (product)	Yes (product)
Technology readiness level	3	3	8
Commercial readiness level	2	2	5
Feedstock use	Merchantable	Non-merchantable	Non-merchantable
International markets	Unknown	Unknown	Yes
Potential market size	Unknown	Unknown	Unknown
Research or analysis need	High	High	High
Can JIWPI influence outcomes?	Low	Low	Medium
Purpose	Structural wood product	Structural wood product	Insulation

Chemically and thermally treated wood			
Product Classification: Chemically treated wood	**Acetylated Wood**	**Furfurylated Wood**	**Thermally modified wood**
Representative feedstock required (BDT per year)	7000 (Accsys Technologies PLC)	1750 (Kebony AS)	420-21,000
Carbon storage	Yes (product)	Yes (product)	Yes (product)
Technology readiness level	8	8	8
Commercial readiness level	5	5	8
Feedstock use	Merchantable (Accoya) & Non-merchantable (Tricoya)	Merchantable	Merchantable
International markets	Yes	Yes	Yes
Potential market size	Medium	Medium	Medium
Research or analysis need	High	High	High
Can JIWPI influence outcomes?	High	High	High
Purpose	High-durability wood	High-durability wood	High-durability wood

Chemicals and extractives					
Product Classification: Chemicals and extractives	**All Chemicals and extractives**	**Chemicals from Sugar**	**Chemicals from Lignin**	**Chemicals from Pyrolysis oils**	**Wood Extractives**
Representative feedstock required (BDT per year)	Varied	690,000-940,000	625,000	175,000	70,000
Carbon storage	No	No	No	No	No
Technology readiness level	8-9	8-9	7-8	7-8	8-9
Commercial readiness level	7-8	8-9	7-8	6-7	7-8
Feedstock use	Non-merchantable, may be hardwood or softwood	hardwoods, requires careful pretreatment	Pulp chips, may be hardwood or softwood,	Non-merchantable wood	Pine
International markets	Yes	Yes	Yes	Yes	Yes
Potential market size	Large	Large	Medium	Large	Large
Research or analysis need	High	Medium	High	High	Low
Can JIWPI influence outcomes?	Low	Low	Low	Low	Low
Purpose	Multiple	Commodity chemicals	Value-added chemicals	Chemicals and food additives	Pine chemicals

4.0 DETAILED EXAMINATION OF PRODUCTS

4.1. Mass timber panels

Introduction

The report is concerned with commercially fabricated massive composite panel product comprised of cross-layered pieces of dimension lumber or wood veneer bound together by structural adhesives, and to some degree with panels similarly made of dimensioned lumber but bonded with nails or hardwood dowels, so that the whole panel is acting as a single load bearing or floor element. These are all relatively new to US but well developed in Europe engineered composite products. These products enable use of wood for buildings taller than current limit of 65 feet and revolutionizing the use of timber in construction. They allow weight reduction in buildings, thus reducing seismic demand on the building lateral system and reduce gravity system foundation loading. While the most apparent distinction between these three is the way the layers are bonded together, they also differ substantially in the raw material sourcing, manufacturing technologies, load bearing capacities, and, consequently in the scope of potential uses. These three are briefly defined and described below.

Products overview:

Cross-laminated timber (CLT), the best known, and the most common of these three, is defined as "a prefabricated engineered wood product made of at least three orthogonal layers of graded sawn lumber or structural composite lumber (SCL) that are laminated by gluing with structural adhesive." [1]. The panels can be used as prefabricated load bearing wall, floor and roof elements. The product and the new building technology it enabled have been originally developed in the Alpine region of Europe in 1990s, and then gradually evolved into a viable industry, consequently gaining hold in other regions of the world. Currently, there are about 60 CLT manufacturing lines operating all over the world. The global production of structural CLT in 2020 is about 2 million cubic meters (or nearly 850 MMBF), of which about 70% is still coming from the Alpine region and about 43% from Austria alone [2]. Most of the CLT is certified for structural use in many countries and is being used in construction of tall mass-timber structures (tallest to-date is 18-story Brock Commons on the campus of University of British Colombia in Vancouver Canada, though taller buildings are already in various stages of development). However, the adhesive bonded CLT is also manufactured for access mats or "temporary timber pavements," which are considered a non-structural commodity.

Nail-bonded CLT: is a massive prefabricated cross-laminated panel whose layers, rough sawn boards, are bonded with nails. This product should not be confused with one described as nail-laminated timber or NLT, commonly used as beams and floor panels in timber structures in North America, where all layers are oriented parallel to each other. The nail-bonded CLT technology might had predated the development of the adhesive-bonded CLT, but the real breakthrough came with a Solid Timber Wall system patented in Germany in 2005 as Massiv-Holz-Mauer, or MHM [3, 4]. MHM is fabricated on small scale turn-key three-step Hundegger production lines. The lines consist of specialized molders, automated layup and nailing station and a CNC finishing center. Relatively short fluted aluminum nails do not interfere with cutting tools. The intended use of this product is as load bearing and division walls for low raise buildings in moderate exposure to moisture (below 20%) and at low to moderate exposure to corrosion [4].

There are more than 30 licensed MHM plants across Europe, and the latest assessment of their total output in 2018 was about 73 thousand cubic meters (or over 30 MMBF).

Dowel bonded CLT: is a massive prefabricated cross-laminated panel whose layers, rough sawn boards, are bonded with hardwood dowels. This is the latest of the cross-laminated timber products and should not be confused with one marketed in North America as dowel-laminated timber or DLT, for use as beams and floor panels in timber structures, where all layers are oriented parallel to each other. The low moisture content and tight fitting of the dowels at the time of assembly assures durable tight connection once the dowels swell as they gain moisture in the ambient conditions. The panels are assembled in highly automated lines. Only two commercially successful systems are known to-date: 1) developed by Thoma Holz 100 company in Austria [5] and 2) developed by Swiss industrial hardware manufacturer TechnoWood [6]. By mid-2019 the company installed 8 highly automated lines in Europe. Unlike other CLT products, some layers of the dowel bonded CLT are arranged at 45 or 60 degrees to the surface layer direction. The dowel-laminated CLT panels are intended for use as load bearing wall, floor and roof panels in low raise (up to 4 story) timber structures [7].

Carbon storage: All three types of panels store carbon embedded in the lumber making up the layers of these panels. However, the life cycle for the non-structural access mats (CLT and nail-bonded CLT) is relatively short compared to the structural elements, designed for at least 50 years of service. It should be also noted that the carbon balance is less favorable for the nail-bonded CLT due to presence of a substantial number of aluminum nails, and in the CLT bonded with petroleum-based adhesives. Trials with bio-based adhesives are currently being conducted. Dowel-bonded CLT is marketed as 100% wood product. The utilization of the waste stream generated in production is discussed separately, below. Eventually, the carbon balance of entire buildings will depend on the contributions from other building and finishing materials being used along with the cross-laminated panels.

Nail- and dowel-bonded CLT utilize raw sawn lumber and can tolerate substantial presence of wane and surface issues. Elimination of aggressive planning step, necessary in adhesive-bonded CLT may weigh favorably on their carbon balance.

Technology readiness level: All three types of mass-timber panels are currently manufactured by commercial entities. CLT is manufactured in Europe, North America, Asia, Australia and in Africa. Therefore, all three qualify as "systems operated over the full range of expected conditions commercially" (technology readiness level 9).

Commercial readiness level of the presented massive cross-laminated timber panels varies by product and by region.

CLT has the best market awareness of these three, particularly in the Alpine region of Europe, where the technology has been present for decades. Companies in other regions still spend substantial amounts of resources on education and developing the local markets. That applies both, to Europe outside the Alpine region and to other CLT producing regions. At this stage, large Austrian companies operating in foreign markets are perceived by the local manufacturers as allies in developing the market even as they are competitors in the same local project pool. Market readiness in North America is still a work in progress.

Nail-bonded CLT is much less known in Europe, and virtually unknown in other regions. The operation tends to be very local. Our assumption is that the recognition of the umbrella Hundegger license and marketing skills of local manufacturers decide the success of individual operators. Local investors in California would have to be educated on the potential of the MHM technology and alerted to substantial differences in its capacity compared to adhesive-bonded CLT (cannot be used as floors or in high-rise structures; probably not good for seismic or high wind load applications either).

Dowel-bonded CLT is the newest of these products. Although it is not widely known outside the Alpine region of Europe, its use is not much different from that of adhesive-bonded CLT, except that it is not suitable for tall timber structures (seismic and high wind load performance unknown). Dowel-bonded CLT is marketed to high-end investors, to whom the "100% wood" appeal justifies higher cost of the material. However, the manufacturers claim that on the long term the technology may compete with adhesive-bonded CLT on cost as well. This is because the production may use rough sawn lumber and does not require adhesives. Considering California seismic requirements, the market will probably benefit from the promotion and market development of the adhesive-bonded CLT.

International markets potential of the massive cross-laminated timber panels must be considered in the context of these technologies not being involved in commodity markets.

CLT and dowel-bonded CLT: The end products are buildings/structures or "projects." In absence of specific data at hand, anecdotal evidence should be sufficient to prove that projects are relatively easy export items: Binderholz and KLH, two Austrian leaders of the CLT industry are shipping projects from a land-locked Alpine country to Australia, Asia, Oceania and North America. For California, exporting projects should be much easier due to the access to the Pacific Coast and large ports. It should be said, however, that the export potential for dowel-bonded CLT is purely hypothetical. As of today, we are not aware of any dowel-bonded CLT projects executed outside Europe.

Nail-bonded CLT: Since this product cannot be used as floors, it is much harder for the manufacturers to sell complete projects based on this technology alone. To our knowledge, the focus of this industry is local. We are not aware of MHM-based projects crossing borders.

Feedstock use has to be considered separately for each of these products, although all three utilize lumber from merchantable logs.

CLT production in North America is regulated by prescriptive ANSI/APA PRG320 standard that regulates the grades and dimensions of lumber used as lamstock. The minimum requirement for the layers aligned with the principle loading direction is visual grade #2 or better, and for the transverse pieces #3 and better. While both grades allow certain amount of wane, manufacturers tend to use perfectly square pieces because wane pockets in the panels form water catchment wells at the construction sites. It follows that logs with diameter too small to produce substantial volume of lumber free of wane may not be favored.

Nail- and dowel-bonded CLT, on the other hand, are not regulated by any product standard. Their use in some European countries is allowed in low-rise structures based on European Technical Approval certificates issued to individual manufacturers (see for instance [4]). The panels are not nearly as air tight as adhesive-bonded CLT, and so wane is not perceived as a substantial problem.

Nail-bonded CLT uses rough sawn boards rather than nominal 2x stock. The surface is not considered for visual quality. That means, that there should be greater potential for utilization of lumber of lower quality than required for the adhesive-bonded CLT. It also makes it more likely for this technology to be able to utilize lumber sawn from small diameter logs.

Dowel-bonded CLT uses rough sawn lumber in core layers, but dressed lumber is needed for face layers, which often are meant to be visible in structures. Also, bonding with dowels requires wide-face lumber (likely more than 8 in) to form two rows of successful dowel bonds in each surface layer. This likely limits the prospect of utilization of small logs.

Potential market size for massive structural cross-laminated timber panels is difficult to assess, because the industry is still very young. Even as the annual production volumes of CLT increase at an almost exponential pace, the 2 million cubic meters (or 848 MMBF) global output projected for 2020, still represents a boutique-scale compared to any of the known commodity-oriented forest products industries. Market sizes for *nail- and dowel-bonded CLT* are proportionally even smaller. Consequently, the mass cross-laminated timber panels should not be considered THE solution on their own, but as an element of a broader solution strategy.

That said, one should consider the following comparison based on current CLT production data.

CLT: Currently about 70% of global CLT production is manufactured in the Alpine region of Europe, which, by ***Holzkurier*** standards includes not only Germany, Austria and Switzerland (often referred to as DACH region) but also Northern Italy and Czechia (Czech Republic). This region is about twice as large as California in terms of land area, population and GDP. Still, it is not in a different league, and even if taken by proportion, California may be in position to support a substantial fraction of the global CLT production. The perspective is even more interesting if one focuses on Austria alone, a country about 5 times smaller than California in terms of the metrics mentioned above, which is believed to have produced nearly 400 thousand cubic meters (169 MMBF) or over 43% of global production of CLT in 2019.

Table 4. Comparison of California and European markets for CLT

	Area		Population (million)	GDP	CLT output (2019)[2]
	(1000 sq mi)	(1000 km^{2})		(Trillion $)	(1000 m^{3})
DACH+I+CZ	333	863	171	7.815	683
Austria	32.4	83.9	8.8	0.461	393
CA	164	424	40	3.000	0

Potential for JIWPI influence outcomes:
Given current pace of the adoption of the building technologies based on mass cross-laminated panels in North America, recent development of CLT and allied products manufacturing lines along the West Coast of the US, and the relative potential of the state, launching of the related industry in California is not a matter of if, but when. It is within JIWPI powers to accelerate this process and make the industry a partner in meeting California's forest management goals. Suggestions of specific opportunities for JIWPI actions are listed below:

- Education and product awareness (a collaboration with partner universities and the Tallwood Design Institute in Oregon):
    a. Targeted workshops and seminars for architects, engineers, contractors, potential manufacturers, potential investors, communities, building administrators, local and state authorities such as fire marshals.
    b. Site tours for potential manufacturers, investors and community leaders. The tours should target manufacturing lines and communities where the new building technologies based on mass-timber panels are already well established (like Alpine Europe) but also regions where the technology has been adopted later, such as the Pacific Northwest. The prior will provide examples of diversity of possible approaches in nearly mature environment, while the later, facing similar opportunities and challenges, are good models and case studies California.

- Work with policymakers and regulators to identify and remove barriers specific to California.
- Study the potential impact of mass-timber panel industries on the issues specific to California, including housing affordability, fire, seismic risk, rural economic development, and emergency response. A holistic approach to mass-timber market development can ensure that mass timber meets the scale of California's housing, economic development, and forest management goals.
- Consider state incentives for new mass-timber panel companies, with incentives tailored to the level of alignment with state-specific issues (e.g. feedstock sourcing, engagement in development of affordable housing).

For instance, it seems that California may be in a position to promote smart low-cost/large-volume projects (related to affordable housing) rather than one-of-a-kind, high-profile/high-risk "unicorn projects." Promoting smart, modular, low-cost/high-volume projects could incentivize local companies to quickly build the production volumes. Creative solutions for such smart and efficient designs appropriate for affordable housing units could be incentivized by state competitions.

Market structure

General comments: All structural cross-laminated timber panels discussed here are specialty products, by which we understand that all panels are custom produced and fabricated for specific projects. Prefabricated mass-timber structural panels have no precedent in timber construction, offering new opportunities in design and construction to professionals intimately familiar with the product. It is however very similar to precast concrete industry that produces premanufactured components and deliver them to address specific project requirements. And just like in precast industry, as market matures, some standard products opportunities will likely emerge. Historically, however, there have been strong incentives for companies to control the project acquisition process by integrating certain level of architectural and engineering design services, project management, and quite often construction services or construction supervision. In this regard, buildings are the actual product of the industry, and the panel production becomes a stage in a process that begins with project commission and ends with closing the shell of a building. In reality, the level of vertical integration varies substantially both between and within the three products discussed.

Another common theme is the existence of intrinsic barriers preventing commoditization of massive cross-laminated panels even in most developed markets. The principal issues are the large dimensions and mass as well as the embedded value of individual panels. It simply does not make much sense for anyone in the industry to carry the cost of intermittent storage and waste generated if standard-sized panels would have to be substantially trimmed for specific projects. Producing prefabricated panels finished for specific design and on-time delivery to the construction site is for the time being the most efficient solution.

CLT: The organic development of the global CLT industry over the last 25 years resulted in a substantial diversity in the manufacturing processes, levels of automation, scales of operation, products and services options as well as in market strategies.

Ownership of the CLT plants varies from family enterprises to international holdings. Most CLT companies show some level of vertical integration within their complex value chains. The most common model is integrating the engineering detailing services and a level of project management, while other services are outsourced to closely allied partner companies familiar with the technology. However, there are companies that offer architectural design offices, transportation, construction services, customized connectors, pre-installation, and in one case, custom manufacturing of own windows/doors, floor finishes, insulation and external sidings. Some companies own forestlands, and sawmills [8]. On the other extremes, there are also few small-scale companies focusing exclusively on fabricating panels for external orders, outsourcing all other functions to external partners.

Annual per-shift capacities of CLT plants across the globe vary from less than 5000 m3 (2.1 MMbf) to 110,000 m3 (46 MMbf). Press types and sizes vary greatly (there is no size standard for CLT panels, typical width is around 10ft and length between 30 – 60 ft). Many companies had their presses and other special equipment designed and fabricated specifically for their needs. However, over the past 3 years, as markets matured, an increasing number of new CLT plants opt for specialized off-the-shelf equipment solutions, characterized by high capacity, high level of automation and an option for full integration of entire lines. Currently, about 75% of all presses installed are fabricated by one of just three EU manufacturers. Nearly 80% of all installed CNC centers we know about are fabricated by one of three leading EU manufacturers. As a result, the new production lines have become more alike. That trend applies to the oldest and largest CLT companies as they upgrade their lines to keep up with the demand.

Nail-bonded CLT: Most of the nail-bonded CLT plants currently in operation are small scale turn-key three-step MHM production lines licensed by Hundegger company. In contrast to the adhesive-bonded CLT, there is not much space for diversity in terms of the production process, levels of automation, scales of operation, and products. MHM is intended mainly for walls and roof elements but inappropriate for floors. Therefore, the manufacturers cannot offer complete MHM-based building solutions. However, not much is currently known about the market strategies or degrees of vertical integration in MHM producing companies. There are more than 30 licensed MHM plants across Europe, and the latest assessment of their total output in 2018 was about 73,000 m^3 (or over 30 MMBF).

Dowel bonded CLT: To our knowledge, there are 10 operating commercial dowel-bonded CLT lines, 8 of which are turn-key automated lines installed by Swiss hardware company TechnoWood. That does not leave much space for diversity. Since the dowel-bonded CLT can be used for walls and floors, the manufacturers can offer complete building solutions, which is a strong motivation for integrating design and construction services. Some companies mount windows and doors in prefabricated panels before sending them out to the construction site. The actual level of vertical integration is not known for the moment. The rough estimate of total production in 2019 is about 30,000 cubic meters (or nearly 13 MMBF).

Research gaps

Sufficient research is available to commercialize any of the discussed products, but most of it is outside of US. These industries do exist and sell projects as we speak. Wood species of interest for California fire prevention and forest restoration efforts (red fir, white fir and Ponderosa pine) are already used in commercial CLT products in North America. Pending projects at Oregon State University develop design values for all-Ponderosa pine lauyps for CLT.

Both *adhesive- and dowel-bonded CLT* would definitely benefit from applied research focused on market development and code recognition in California, improvement in production efficiency, cost competitiveness against steel and concrete, development of connectors enabling rapid deployment and deconstruction, durability and, last but not least, conceptualizing the end-of-life scenarios for structures executed in these technologies.

We are not aware of any specific research needs for panels marketed as access mats.

Substitution

CLT and dowel-bonded CLT **compete primarily with mortar, steel and concrete in construction.**

Nail-bonded CLT may compete with light frame timber construction. The product is also marketed on superior thermal insulation properties (even compared with the other two massive cross-laminated timber products) and, as such, may be reducing market for some insulating materials used in small-scale timber structures.

Investment potential/scalability

Anecdotal evidence based on the new plant announcements in trade literature (admittedly, not the most accurate source) suggests that building a new reasonably automated CLT manufacturing line is not an overwhelming investment compared to a modern sawmill or traditional structural panel plant (like OSB or MDF). In 2013 a large capacity (25 MMBF/year) fully-automated facility was built in Europe at the cost equivalent to $30 million (2012 US dollars). In the same year $13 million (2012 US dollars) was sufficient to build and equip a medium capacity line (12 MMBF/year).

<u>The supply chain</u> for the CLT industry consists mostly of elements already serving allied industries and sectors in North America (including one offering special equipment for CLT lines).

<u>Waste streams and byproducts:</u> Forest products in general became masters in recycling and other forms of utilization of “waste streams,” to the point that in general the forest products sector is considered “waste-free.” Waste generated in one place becomes raw material for other products or burned for energy consumed by the industry and/or sold to the communities. Massive cross-laminated timber panel

companies are no different. However, prefabrication of panels generates large format massive cutouts (windows, doors etc.) that seem too good for milling into chips or sawdust. Companies actively seek avenues for utilization of these cutouts in ways that would make good use of the high-quality massive laminates. An example may be utilization of cutout material as stairs.

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4.2 Other engineered wood products

Engineered wood products (EWPs) come in many forms (Table 5) and have the potential to replace steel and concrete in residential and non-residential construction in the US. We have reached the following conclusions following a review of U.S. market data:

- Prior published data on US market demand for new key EWPs such as cross laminated timbers (CLT) and mass plywood panels (MPP) were largely based on 2016 construction trends particularly in residential housing. The projected upward construction trends did not materialize in the US or in California. Prior published projections may be useful again once construction trends upward, but investors are likely to be currently cautious as the latest (2019) American Plywood Association Economic Report for EWPs shows stagnation or decline in US market demand across all existing structural panel and EWP product sectors (Table 6). California market demand is not expected to change until 2022 or 2023 (First Tuesday Journal, 2019). ***Regardless, securing early stage market positioning by aggressively resolving issues around use of California targeted deadwood species (red fire, white fir, and Ponderosa pine) in CLT production, small diameter log supply, and dry kiln infrastructure challenges during this market lag period is essential. Similarly, pursuing manufacturing partner and investor connections during this period of time is equally essential.***

- Many EWPs are sold in California in over 50 locations (Table 7). None (with the exception of one glulam producer) are manufactured in the state. Most EWP suppliers to California markets are located in Oregon or BC Canada. Current market conditions suggest product development strategy for the state should focus on partnering with existing producers. ***In particular, examining the potential for parallel strand lumber (PSL) manufacturing in the State and possible partnering with Weyerhaeuser should be immediately explored.***

- Cross laminated timber (CLT) production potential in California looks promising for use of white fir, but ***testing needs to be***

done on red fir and Jeffrey pine, and re-testing needs to be done on Ponderosa pine (Table 8). Funded in 2015 by a USFS Wood Innovation grant and funding from the OSU College of Forestry and Oregon Department of Forestry, a research project looking at utilization of low-value white fir and ponderosa pine lumber from small-diameter PNW restoration timber for use in CLT core layers was conducted. Results were published in 2017 (Lawrence, 2017). Processed lumber was suppled from two producers, but only one provided lumber dried at the required 12% moisture content for CLT manufacturing (the other dried to 15% moisture content). White fir performed relatively well in both 3-ply and 5-ply CLT product, but Ponderosa pine showed distinguishing low performance in both shear block and delamination testing. It is unclear whether differing moisture content in lumber supply affected study results as the CLT manufacturer (DR Johnson) was discovered to have major technical problems with their CLT lamination line. This lamination issue was not discovered until March of 2018 and likely affected species testing performance in the research study conducted in 2016-2017.

- Product environmental branding for CLT investment potential in California. Table 9 shows that seven of the 10 CLT manufacturers currently operating in North America specifically highlight using wood supply independently certified as coming from sustainably-managed forests from either the Sustainable Forestry Initiative (SFI), the Forest Stewardship Council (FSC), and or the Pan-European Forest Certification system (PEFC). This may prove a distinct advantage for California as, for example, the State has the largest volume of FSC-certified forests of all western states in the US (at 1,730,391 forested acres certified as of 2018). ***An important JIWI contribution in research would be to analyze where these certified acres are located, who owns them, and ascertain projected harvest volumes that might be realized within supply working circles.***

- State-funded carbon investment potential: Beginning January 2021, the State of California Air Resources Board (CARB) will place into effect a limitation on out-of-state carbon projects allowed for offset credits. Currently 90% of CARB offset credits come from improved forest management (IFM) projects and 80% of those IFM credits come from projects outside California (the bulk come from Alaska and southern US states). Starting 2021 only 2% of offset credits will be allowed from out-of-state projects; the remainder must come from projects which directly benefit California. No analysis has been conducted on how much long-term emissions occur during in-state wildfires and how much 'lost opportunity' future carbon storage due to growth is compromised due to wildfires. Similarly, treatment goals set forth in the California Forest Carbon Plan with regard to rate of hazard fuel treatments on both federal and private forestlands may well be served by a CARB-financed bufferwood initiative directly tied to supply for mass timber and other EWPs projects, producing substantial acres treated and wood product carbon stores. Within the bufferwood 300' setback from open road centerline in 25 bufferwood counties, almost 160,000 acres of federal lands and over 310,000 acres of private forestlands would be treated. ***As an important JIWI research contribution, it may be possible to craft an entire offset project around a bufferwood initiative that would then provide direct financing to the State from CARB offset revenue. This would be a new type of carbon offset project for CARB, but not necessarily impossible to design and implement.***

Table 5. List of engineered wood products

Engineered Wood Products (EWP)	Description	Currently used in:
Laminated veneer lumber (LVL)	A composite of wood veneer sheets whose fibers are primarily oriented along the length of the member. Veneer thickness does not exceed .25 inches.	I-Joists flanges, beams, headers, studs
Glulam	An engineered machine stress-rated (MSR) product created by adhesively bonding individual pieces of lumber or structural composite lumber having a thickness 2 inches or less.	columns, beams, rafters, purlins, braces
Parallel Strand Lumber (PSL)	A composite of wood veneer strand elements whose fibers are primarily oriented along the length of the member. Veneer thickness does not exceed .25 inches, and the average length is a minimum of 300 times the least dimension.	beams, columns
Oriented Stand Board (OSB)	A structural performance-rated panel product consisting of wood strands. The strands are layered and oriented for maximum strength and stability.	replacement for plywood
I-Joists	A structural member using sawn or structural composite lumber flanges and structural panel webs, bonded together with exterior exposure adhesives forming an "I" cross-sectional shape	floor and roof applications
Mass Plywood Panels (MPP)	A massive, large scale, structural composite lumber based panel designed as an alternative to concrete and steel, and to Cross Laminated Timbers (CLT). Dimensions can be up to 12 feet wide and 48 feet long with thicknesses up to 24 inches. Thickness may be constructed in 1 inch increments to provide superior strength and performance.	CLT replacement for roof, floor, wall applications
Cross laminated timber (CLT)	A pre-fabricated solid engineered wood panel made of at least three orthogonally bonded layers of solid sawn lumber that are laminated by gluing longitudinal and transverse layers to form a solid rectangular-shaped, straight, and plane timber.	Structural core for roof, floor, wall applications in buildings ranging from 1 – 20 stories
nano.CLT	A thin version of CLT, sold in three laminate layers starting at ¾" (19mm) in thickness.	Often used in tandem with CLT to create consistency in appearance between structural CLT elements and decorative interior walls.
free.CLT	Curved Cross Laminated Timber(CLT)	Freeform roofs, pavilions, furniture, sculpture.

Engineered Wood Products (EWP)	**Description**	**Currently used in:**
Nail Laminated Timber (NLT)	An alternative to CLT but is less uniform in appearance and spans in only a single direction. Assembled in combination with plywood, it forms a diaphragm but with less strength than CLT and ICLTs.	Alternative to CLT
Dowel Laminated Timber (DLT)	An alternative to NLT. Wood dowells replace use of nails in panel production	Replacing NLT
Interlocking CLT (ICLT)	Similar to CLT in that it comprises layers of smaller pieces of timber but relies on a complex array of tongue and groove and dovetail connections to lock the individual pieces in the panels together -and similar systems to connect the panels themselves. ICLT requires no adhesives (and therefore has no volatile organic compound - VOC - emissions) and no expensive connections. The product was developed in Utah to use intermediate layers of low cost wood from trees killed by infestations of red pine beetles.	

Table 6. U.S. demand and production for engineered wood products

	Source: American Plywood Association 2019 Economic Report		
EWP	**Current US market demand**	**Current US Production**	**Market activity**
Laminated veneer lumber (LVL)	78 million cubic feet	71 million cubic feet	Declining since 2017
Glulam	285 million board feet: 59% residential construction 36% non-residential construction 5% industrial construction	281 million board feet	Stagnant since 2018
Parallel Strand Lumber (PSL)	Unreported due to single supplier status (Weyerhaeuser) Sold as Parallam		
Oriented Strand Board (OSB)	20,829 million sq feet 3/8" basis: 55% residential construction 22% remodel 14% industrial construction 9% non-residential construction	15,181 million sq feet 3/8" basis	Stagnant since 2018
I-Joists	636 million linear feet: 87% residential construction 7% non-residential construction 6% repair and remodel	510 million linear feet	Declining since 2018
Mass Plywood Panels (MPP)	Early market stage; volume unknown	Only one producer in US Freres Lbr (OR)	Unknown
Cross laminated timber (CLT)	Early market stage; no actual volume data available	12 manufacturers in North America: 9 in US; 3 in Canada	Unknown
nano.CLT	Unknown		
free.CLT			
Nail Laminated Timber (NLT)			

Table 7. Production, sales, buyers and suppliers of engineered wood products in California

EWP in CA	Produced in CA?	Sold in CA?	Who buys in CA? (Lumber and harware stores)	Who supplies buyers (production location) as stated in store published product data
LVL	No	Yes	21 unique stores 51 locations 24 counties	Boise Cascade (White City, OR) Louisiana Pacific (BC) Murphy Engineered Wood (Sutherlin, OR) Pacific Wood Laminates (Brookings OR) Roseburg Forest Products (Riddle, OR) Weyerhaeuser (Millersburg, OR)
Glulam	Yes RedBuilt (Chino, CA)	Yes	14 unique stores 36 locations 20 counties	Boise Cascade (Homedale, ID) Rosboro Lumber (Springfield, Vaughn, Eugene; all in OR)
PSL	No	Yes	20 unique stores 49 locations 23 counties	Weyerhaeuser (Vancouver, BC)
MPP	No	Early market stage but primarily subject to growth in multi-family residential and commercial construction.		
CLT	No			
nano.CLT	No	Specialty product/early market stage/currently limited producers:		
free.CLT	No	For nano.CLT, free.CLT - one producer in Canada (Element5)		
NLT	No	For ICLT: one producer in Utah (Euclid Timber Frames)		
ICLT	No	For NLT and DLT: one producer in Canada (StructureLam); recently phased out of NLT.		
DLT	No			

Table 8. North American CLT production by species

North American CLT producers who advertise softwood species in CLT production	Species	specific gravity (PRG-320)	MOR	MOE	crushing strength
		12% mc	lbf/sq in		
Smartlam, Vaagen Timbers, Element5	Hem-fir including: white fir CA red fir	 0.42 0.43	 9700 10,370	 1485000 1,483,000	 5740 5410
Smartlam, DR Johnson, Vaagen Timbers, Element5, Katerra	Douglas-fir	0.51	12500	1,765,000	6950
International Beams, Sterling Site Access Solutions Texas CLT LLC Sterling Lumber Company	slash pine*	0.66	16300	1,980,000	8140
	shortleaf pine*	0.57	13100	1,750,000	7270
	longleaf pine*	0.65	14,500	1,980,000	8470
	loblolly pine*	0.57	12800	1,790,000	7130
Smartlam	Englemann Spruce	0.39	9010	1,369,000	4560
Smartlam, Structurlam, Katerra	Sitka spruce	0.42	10,150	1,600,000	5550
Smartlam, Element5	white spruce	0.43	8,640	1,325,000	4730
Smartlam, Vaagen Timbers	western larch	0.58	13,000	1,870,000	7620
	ponderosa pine	0.45	9400	1,290,000	5320
Smartlam, Vaagen Timbers, Element5	western hemlock	0.47	11300	1,630,000	7200
	Jeffrey pine	0.45	9300	1,240,000	5530
Smartlam	noble fir	0.42	10790	1,619,000	5730
Nordic Structures	black spruce	0.45	10100	1,523,000	5410
Smartlam	lodgepole pine	0.47	9400	1,340,000	5370
DR Johnson	Alaska yellow cedar	0.50	11100	1,420,000	6310
Structurlam, Katerra	western white pine	0.43	9700	1,460,000	5040
StructureCraft	sugar pine	0.4	8200	1,190	4460
StructureCraft	sub-alpine fir	0.53	8420	1,324,000	4910
European CLT producers who advertise hardwood species in CLT production	Species				
Hess Timber (Switzerland)	European beech	0.71	15970	2,075,000	8270
Comparable California harwoods	Tan Oak	0.67	16650	2,071,000	8250
	Pacific Madrone	0.79	10100	1,230,999	6880

*aka "southern yellow pine"

Table 9. Advertised environmental forest certification for CLT products

Company	SFI	FSC	PEFC	Not Stated	Website where certification referenced
Smartlam	1				https://www.smartlam.com/index.php/press-release/
Vaagen Timbers				1	http://www.vaagenbros.com/sustainability/
Element5		1			https://elementfive.co/new-clt-plant/
DR Johnson		1			https://archello.com/news/nature-conservancy-hq-is-first-in-america-to-use-locally-sourced-fsc-certified-cross-laminated-timber
Katerra	1	1	1		https://www.katerra.com/2019/09/23/katerra-mass-timber-factory-opens/
International Beams		1			http://atlasway.ca/uploads/files/International%20Beams%20-%20I%20joists%20-%20Residential%20Design%20Manual.pdf
Sterling Site Access Solutions				1	https://www.chicagobusiness.com/innovators/running-out-hardwood-lumber-heres-solution
Texas CLT LLC				1	http://texasclt.com/
Structurlam	1	1			https://www.structurlam.com/whats-new/news/structurlam-first-canadian-cross-laminated-timber-manufacturer-earn-sfi-chain-custody-certification/
Nordic Structures		1			https://www.nordic.ca/en/sustainable-construction/certifications

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4.3 Pyrolysis: non-energy products

Introduction

Pyrolysis is a thermochemical conversion process that decomposes woody biomass into liquid, gaseous, and solid products under inert or low oxygen conditions. The temperature and residence time of the pyrolysis process affect the proportion of each type of product produced. Higher operation temperatures decompose more biomass into gaseous products. Conversely, lower operation temperatures produce a greater proportion of solid products, like biochar (Bridgewater et al., 1999). Fast pyrolysis is a sub-category of pyrolysis that utilizes higher temperatures. Fast pyrolysis rapidly decomposes biomass at approximately 500 ˚C in order to maximize liquid yield (Pollard et al., 2012). Slow pyrolysis is also performed in the absence of oxygen but at lower temperatures of about 300 ˚C. The process is considered "slow" because the residence time for vapors ranges from 5-30 minutes compared to an order of a few seconds during fast pyrolysis (Gerewal et al, 2018).

Given its range of products, pyrolysis is a promising technological platform for wood product innovation. As discussed previously, if markets for pyrolysis products are developed, they may incentivize the removal of woody biomass from California forests.

The matrix is an overview of the current and potential landscape for each product in California. To support this preliminary assessment, this chapter summarizes existing literature to evaluate the technological and commercial readiness of each pyrolysis product. Also discussed is the potential influence that the Institute may have in product development.

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PRODUCT: PYRO-LIGNEOUS ACID

Product Description

One of the common by-products of slow pyrolysis is pyroligneous acid (PLA). PLA is an oxygenated, crude organic liquid at room temperature and is produced following the capture and condensation of pyrolysis gases (Grewal et al., 2018). During slow pyrolysis, cellulose and lignins from wood or agricultural feedstock are carbonized at roughly 300 ˚C (Grewal et al., 2018). Once the gases are captured, the condensed liquid undergoes a three-month purification process to produce three layers of liquid: light oil, crude brown PLA, and wood tar (Grewal et al., 2018).

PLA is often referred to as wood vinegar, liquid smoke, bio-oil, or wood distillate (Grewal et al., 2018). Wood vinegar has potential applications as a natural alternative herbicide, pesticide, and insecticide as well as plant growth supplement (Grewal et al., 2018; Luo et al., 2019; Mohan et al., 2006; Simma et al., 2017). In California, one patented wood vinegar product is certified by the State as an organic input suitable for organic farming (Corigin Solutions, LLC, 2019). Novel applications include food additives and flavoring (Grewal et al., 2018), an animal feed supplement to reduce bacterial growth (Kupittayanant and Kupittayanant, 2017), and an application to facilitate compost decomposition (Nurhayati et al., 2006).

Several variables impact wood vinegar production quality and consistency. Temperature in particular can impact PLA use and effectiveness. For example, a study of bamboo and spruce PLA application found that vegetable seed germination and subsequent growth were promoted at PLA produced with temperatures of up to 250 ˚C (Fagernas et al,. 2015). However, there was a strong inhibition on germination and radicle growth using vinegar produced at 250 to 400 ˚C (Fagernas et al,. 2015). Feedstock moisture content and hardness also impact quality (Truesdall, 2019). In addition, the residence time of vapors during the slow pyrolysis process (ranging between 5-30 minutes) contribute to product consistency (Grewal et al., 2018).

Existing Capacity

Currently, there are no commercial-scale facilities producing wood vinegar in California. One Merced-based company, Corigin Solutions LLC, produces a wood vinegar product called "Coriphol," but not yet at a commercial scale (Truesdall, 2019). The facility is capable of processing 10 tons of feedstock per hour of agricultural biomass. Almond shells and other fruit orchard debris are the most common feedstock (Truesdall, 2019).

Justification

The multiple uses of wood vinegar highlight its potential to spur growth in numerous high-value markets. Should California, which is already dominant in organic agriculture, invest in PLA, it may develop a competitive advantage for natural pesticides, herbicides, and insecticides, as well as growth enhancers.

Market Indicators

The multiple uses of wood vinegar—many of which of are hypothetical at present—complicate any analysis of market size for PLA.

Existing uses of PLA include wood vinegar and liquid smoke. These markets are generally small, with total market values on the order of $10-100 million. The wood vinegar market has potential to expand as farmers seek to reduce usage of fossil chemical inputs to agriculture, lucrative pharmaceutical uses are developed, and its efficacy for plant growth ability is solidified (Bauer, 2017).

We are not able to quantify the market size for other potential applications of PLA.

Barriers to product or process innovation and growth

As discussed elsewhere in this report, PLA is produced alongside other products, such as biochar. As described in a 2015 study, PLA production may only be economical if integrated into sawmills or combined with production of other pyrolysis products, such as wood pellets (Fagernäs et al., 2015).

There are also a myriad of regulations that complicate production. U.S food and agricultural regulations are different and more restrictive than European regulations (Bauer, 2017). Efficacy concerns also abound, and there remains the fact that a potential market favors "smaller-scale farmers that favor green practices" (Robb and Joseph, 2019).

Research Gaps

There is a considerable need for research into the use and efficacy of conifer feedstock for wood vinegar production, especially using species native to California forests. Most research to date has concentrated on bamboo PLA production due to its popularity in Asia. In Nordic countries, spruce feedstock has also been examined. However, there is a lack of research regarding the use of softwoods found in California. This is a critical research gap because different tree species have different chemical and structural compositions that influence the specifics of a pyrolysis operation, and the Institute is primarily focused on non-merchantable conifer feedstock for pyrolysis applications.

There also is a need to research less well-known (but potentially high value) uses of wood vinegar. Currently, it is not clear how effective PLA is when applied to animal feed or homeopathic medicine (Mohan et al., 2006; Theapparat et al., 2018). Thus, efficacy studies would be useful to understand the liquid's impact on high-value California crops like almonds and avocados. Research is also needed to understand if California tree species are suitable in terms of flavoring and preservation for liquid smoke production.

Product Substitution

The use of wood vinegar in limited markets in the developing world may displace limited amounts of fossil-fuel derived chemical pesticides, herbicides, and insecticides. Commercial markets, however, are slowly developing in China and Australia, especially with organic farmers who prefer or require natural approaches to pest control and/or utilize wood vinegar for its seed germination enhancement properties (Robb and Joseph, 2019). This presents a large opportunity: although wood vinegar does not store or sequester carbon, it theoretically could displace a sizeable number of fossil-fuel derived products.

Additionally, wood vinegar application for plant growth has the potential to displace fertilizers, pesticides, and insecticides. Wood vinegar could potentially reduce the need for certain types of antibiotics as an animal feed additive.

Opportunities for Institute Influence

- Conduct conifer feedstock studies to determine suitability for PLA production.
- Conduct PLA efficacy trials using conifer feedstock for fertilizer, pesticide, insecticide, and liquid smoke applications.
- Develop a demonstration-scale facility that produces PLA in combination with other pyrolysis products.
- Streamline or advance favorable statewide waste diversion regulations to reduce forest biomass feedstock costs for PLA production.
- Consider certification programs for PLA derived from California forest biomass, which could command premium pricing.

MATRIX EXPLANATION

- **Minimum feedstock required:** *35,000 BDT/year*. Facilities focused on PLA production can process 10 tons of feedstock/hour with the potential for more to operate at full capacity. We assume that facility operates 85% of the year.
- **Carbon storage** *No.*Wood vinegar does not store or sequester carbon since it is a volatile liquid and dissipates into the atmosphere when applied in agricultural or other settings.
- **Technology readiness level** *5.*Engineering and pilot scale production is ongoing, and PLA produced from agricultural biomass is sold in small-scale operations. Technological research in terms of product efficacy using wood feedstock is still needed to support commercial-scale production.
- **Commercial readiness level** *3.* There are no yet commercial-scale production facilities in California, although some small operations like Corigin Solutions, LLC are producing wood vinegar in combination with other pyrolysis products like biochar. Large-scale markets, such as agriculture, are still poorly understood.
- **Feedstock use** *Non-merchantable wood.* Limited technical studies (Fagernas et al., 2015, Theapparat et al., 2018) cite the use of small-diameter woody biomass as suitable for production, but the majority utilize agricultural biomass.
- **International markets** *Yes.* Wood vinegar application in small-scale agriculture is common across Asia and is growing in popularity among some organic farmers in Australia, New Zealand, Chile, and many other countries.
- **Potential market size** *Uncertain.*multiple uses of wood vinegar—many of which of are hypothetical at present—complicate any analysis of market size
- **Research or analysis need** *High.*Although limited technical studies exist, significant research is still needed to determine PLA's efficacy on plants and crops grown in California. Similarly, technical studies of PLA production using forest species common to California are also necessary to determine feasibility. Permitting for use in conventional or organic agriculture needs examination.
- **Can the Institute influence outcomes?** *Low.* The Institute may support research into using conifer feedstock for PLA production, but markets are still poorly understoodß.

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PRODUCT: CARBON BLACK

Product Description

Carbon black is a form of manufactured carbon that is conventionally produced through the incomplete combustion of fossil fuels. A majority of carbon black produced is utilized as a filler and strengthening component in rubber tires, while it is also used as a filler and strengthening component in other various rubber and plastic products. Carbon black can be derived from woody biomass, as well as other forms of biomass such as agricultural waste. Research has shown that carbon black can be derived from biomass pyrolysis oil as well as from bio-derived chars (Fan and Fowler, 2018; Toth et al., 2018).

Existing capacity

There are no known commercial facilities in California or globally that are producing carbon black from woody biomass.

Justification

Although carbon black derived from woody biomass is in the research and development stage, the potential to partially displace conventionally produced carbon black is large. Scaled production of bio-derived carbon black would add an additional demand for small-diameter woody biomass within California, thereby assisting in creating a market for currently unmerchantable wood. Additionally, carbon black derived from biomass results in less carbon emissions than conventionally produced carbon black. Studies indicate that biomass derived carbon black is composed of between 60 and 85 percent carbon (McCaffrey, 2019).

Market indicators

The production of carbon black from woody biomass is still in the research and development stage. Recent research suggests that carbon black produced from woody biomass pyrolysis oil is equivalent to medium grade carbon black produced from fossil fuels (Toth et al., 2018) and, therefore, can be utilized as an additive in numerous products that use conventionally produced carbon black. Further scaling of production is necessary to identify if woody biomass derived carbon black can compete in the conventional market. The price of conventionally produced carbon black is tied to the price of oil.

Barriers to product or process innovation and growth

Barriers to growing the woody-biomass carbon black market are related to both its technological and commercial immaturity. Only small-scale, research studies have successfully produced carbon black derived from woody biomass. Scaled production needs to be proven before the product can become commercially viable. Additionally, although there is a large existing market for conventional carbon black, there is no guarantee that consumers will switch to biomass derived carbon black, even if it is competitively priced, due to uncertainty regarding product quality. However, studies indicating that biomass derived carbon black can be produced at commercial grade are promising (Toth et al., 2018).

Research gaps

As previously discussed, the production of carbon black from woody biomass (as well as other biomass feedstocks) is limited to small-scale research (Fan and Fowler, 2018; Toth et al., 2018). Large-scale studies as well as operational experience with large-scale processing facilities are necessary to confirm that production can be successful and competitive at a commercial scale. Additionally, the lowering of the oxygen content of biomass pyrolysis oil is essential to scale woody biomass-derived carbon black production (Toth et al., 2018).

Product substitution

In 2018, the world market size for carbon black was approximately $17.2 billion USD. Additionally, the market is expected to increase in size by six percent over the next six years. In terms of products, a majority of this demand is coming from tire manufacturing. Regionally, Asia Pacific has the greatest demand for carbon black (Grand View Research, 2019).

With a large and increasing demand for conventionally-produced carbon black, carbon black derived from woody biomass has the potential to tap into a thriving global market. Existing companies that utilize carbon black and other conventional carbon products are trying to switch to bio-derived carbon alternatives. Goodyear Tires recently announced that they would replace all of their fossil-fuel derived processing oils with oil derived from soybeans by 2040 (Manly, 2019).

Opportunities for JIWPI Influence

- Partner with research institution(s) to develop a trial, commercial scale carbon black production facility to prove scalability.
- Partner with transportation research centers (The UC Berkeley / Davis Institute for Transportation Studies) and CalTrans to prove markets.
- Introduce carbon black derived from woody biomass pyrolysis oil as a low-carbon alternative to carbon black conventionally produced from fossil fuels, including through legislation, procurement, or testing
- Other market development activities including policy, finance and/or technology incubation.

MATRIX EXPLANATION

- **Minimum feedstock required** *Unknown.* Carbon black produced from woody biomass has only been completed at the small-scale, rather than for commercial production.
- **Carbon storage** *Yes.* Carbon black produced from agricultural biomass has been shown to be composed of between 60 and 80 percent carbon (McCaffrey, 2019). Additionally, carbon black stays in products for a relatively long amount of time. For example, rubber tires (the product for which the majority of carbon black is used) take between approximately 80 and 100 years to decompose in a landfill (Alsaleh & Sattler, 2014).

- **Technology readiness level** *4-5.*Carbon black produced from woody biomass has yet to be scaled to commercial level.
- **Commercial readiness level** *3.* Although the conventional market for carbon black in rubber tires and other rubber products is robust, carbon black derived from woody biomass is not yet commercially produced and there is more research needed to determine whether it would be seen as a viable substitute in the market.
- **Feedstock use:** *Non-merchantable wood.*
- **International markets** *Yes.* Carbon black is used in a variety of rubber and plastic products worldwide. In 2018, the global market size for carbon black was approximately $17.2 billion USD (Grand View Research, 2019).
- **Potential market size** *Large.* If carbon black derived from woody biomass was scaled to commercial production, there is a large conventional market in which it could play a role. Therefore, it could substantially increase demand for small-diameter woody biomass within California.
- **Research or analysis need** *High.*Research needed to prove scaled production can produce carbon black at the same quality as smaller research studies (Toth et al., 2018).
- **Can JIWPI influence outcomes?** *Medium.* A lack of technical maturity hinders JIWPI's ability to promote or develop markets.

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PRODUCT: BIOCHAR

Product Description

Biochar is a recalcitrant charcoal created from pyrolysis of biomass at high temperatures (300 to 700 degrees Celsius) (Anderson et al., 2013). Biochar can be used in many capacities. In the agriculture sector, its most prominent uses have been as an animal feed and as a soil amendment. When biochar is added to agricultural soils, it can increase crop yield by enhancing soil hydrological and nutrient properties (Pourhashem et al., 2019).

There are numerous emerging applications for biochar outside of the agricultural sector. For instance, biochar has potential application in the transportation (concrete filler), water treatment (filtration), building (filtration, insulation), electronics, cosmetics, textiles, and medical sectors.

Existing capacity

There are several companies producing and selling biochar from forest biomass in California. North America is currently the largest consumer of biochar and is where more than 80 percent of medium and large scale manufacturers are located (Grand View Research, 2019).

Key industry players include BSEI (Oregon and China), Airex Energy Inc. (Canada), and Diacarbon Energy (Canada), which all use forest biomass as a feedstock (Grand View Research, 2019).

Justification

The economic and environmental benefits provided by biochar justify further research into methods to help scale this nascent market. Biochar has the capacity to improve crop yields in agricultural soil, reduce nutrient runoff and fertilizer application, increase water retention, and sequester carbon (Pourhashem et al., 2019). Biochar has also been demonstrated to reduce the release of nitrogenous gases from fertilizers as well as carbon dioxide emissions from tilling (Pourhashem et al., 2019).

Market indicators

Although still in its nascent stages, a market for biochar in the US is steadily growing. The USBI estimated that 200,000 bone dry tons of biomass are consumed yearly to create biochar and that 35,000-70,000 tons per year of biochar are currently produced in the US (USBI, 2018). Another market report estimated a global market size of $1.3 billion in 2018, with demand estimated at 395.3 kilo-tons a year (Grand View Research, 2019).

Barriers to product or process innovation and growth

The large amount of capital required to construct a new pyrolysis facility is one of the main barriers to growth in the biochar industry. According to Pourhashem et al. (2019), the total investment costs for a large-scale biochar facility (2,000 tons/day) can be more than $400 million. Additionally, uncertainty surrounding future biochar prices make it difficult for market establishment (Campbell et al., 2018). According to Kore Infrastructure, biochar is not economically viable when produced by itself. Rather, it provides an additional revenue stream for pyrolysis facilities that are coproducing higher value products such as biogas and bio-oil.

Research gaps

Standardization and certification of biochar products is a large research gap impeding market growth. Stronger definitions of biochar grades are needed to help improve industry standards (USBI, 2018). Additionally, there is limited research into policies that would facilitate payments for ecosystems services to farmers who manage their lands with biochar (Pourhashem et al., 2019). Investing in education for farmers about the benefits of biochar may help increase the scalability of biochar and help fund production of other pyrolysis products.

Product substitution

Biochar has been shown to be an effective substitute for peat, which is most commonly used as a growing media in horticulture (Steiner & Harttung, 2014). Approximately 11 MMT of peat are used for horticultural purposes each year (Steiner & Harttung, 2014). Peat bogs are important ecosystems and are valuable carbon stores. However, when harvested and used for horticulture, peat decomposes quickly and becomes a source of greenhouse gases (Steiner & Harttung, 2014). Replacing peat with biochar, a stable form of carbon, would reduce the amount of carbon emissions in the horticulture industry.

However, biochar can be created from a range of feedstocks, most of which are existing waste streams. According to Kore Infrastructure, although wood pellets would be an ideal feedstock, agricultural and sewage waste is abundant for use and much less cost prohibitive.

Opportunities for JIWPI Influence

- Contributing to efforts to integrate biochar into California's climate policy in order to help subsidize the high cost of biochar production. For example, integration of biochar into the carbon offsets market would help provide financial subsidies for the product and drive market growth. In a number of interviews in the viticulture industry, many growers were aware of the benefits of using biochar, but that the product was too expensive. Subsidizing biochar through climate policies could help engage this uncaptured share of the market.

- Promoting biochar to increase soil water capacity in agricultural soils, in conjunction with California's Sustainable Groundwater Management Act

- Developing other markets and uses for biochar, including exports and transportation

MATRIX EXPLANATION

- **Minimum feedstock required:** *150,000 BDT/yr.* National Carbon Technologies operates a biochar production facility in Michigan that processes 300,000 tons of wood per year (40 tons per hour).

- **Carbon storage** *Yes.* Biochar can have a carbon content of around 60-70 percent and has the capacity to remain sequestered in soils for thousands of years (Granastein et al., 2009; Laird et al., 2009).

- **Technology readiness level** *9.*Biochar is currently produced at commercial scale, with at least two dozen globally recognized operating companies (Pourhashem et al., 2019; Polaris Market Research, 2019).

- **Commercial readiness level** *5.* Currently, markets for biochar are not well established as there is substantial volatility and uncertainty surrounding biochar prices (Campbell et al., 2018). Additionally, while farmers are considered the primary customers of biochar, wide adoption of biochar into agricultural practices has not yet been achieved (Polaris Market Research, 2019). Industry participants are now focusing on educating farmers to help scale the industry.

- **Feedstock use** *Non-merchantable wood.* Various types of feedstocks can be used to create biochar, including non-merchantable wood.

- **International markets** *Yes.* According to Grand View Research (2019), most biochar is manufactured in North America (80 percent) and in Europe. Large amounts of biochar are produced in collaboration with research groups and institutions in rural areas in China, Japan, Brazil, and Mexico.

- **Potential market size** *Uncertain.* It is notoriously hard to estimate market size for biochar given the absence of markets. For instance, Polaris Market Research (2019) estimates the global biochar market will reach $3.23 billion by 2026, growing at a compound annual growth rate of 9.1%. At a biochar value of $400/ton, this is equivalent to 8 million tons of biochar product, likely produced from over 25 million BDT of woody biomass. However, current market size is likely very small, on the order of tens of thousands of tons per year.

- **Research or analysis need** *High.* Standardization and certification of biochar products is a large research gap impeding market growth (USBI, 2018).

- **Can JIWPI influence outcomes?** *Medium.*Contributing to efforts to integrate biochar into California's climate policy can help subsidize the high cost of biochar and further spur the market.

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PRODUCT: ACTIVATED CARBON

Product Description

Activated carbon is a form of carbon that has been processed to make it extremely porous (Adeleke, 2018). This high porosity gives activated carbon a large surface area which increases its adsorption capacity. Activated carbon is used for a range of purposes, most commonly in potable water purification and sewage treatment (Grand View Research, 2019). In 2018, 40% of the total volume manufactured in the world was used for water treatment applications (Grand View Research, 2019).

Existing capacity

Although 10.8% of activated carbon business establishments are located in California (Adeleke, 2018), no commercial scale activated carbon facilities located in state were identified. However, Calgon Corporation has a reactivation manufacturing site located in Blue Lake, CA which recycles spent activated carbon.

Three companies dominate global market share: Kuraray Company Limited (50%), Cabot Corporation (20%), and Ingevity Corporation (8%) (Adeleke, 2018). Other key companies include Carbon Activated Corporation, Jacobi Carbons AB, Calgon Carbon Corp., Osaka Gas Chemical Co. Ltd., and Evoqua Water Technologies LLC (Grand View Research, 2019).

Justification

Activated carbon is an existing mature industry that utilizes woody material as a feedstock. Thus, there is a high potential for the integration of non-merchantable wood feedstock.

Market indicators

Activated carbon is a mature global market (Adeleke, 2018). In 2019, the global market amounted to 2.4 MMT and is projected to grow to approximately 5 MMT by 2021, growing at a CAGR of 8.2 percent (Beroe, 2018). The global industry is also projected to reach $353.5 million by 2023, growing at an annualized rate of 1.0 percent (Adeleke, 2018).

The production capacity in the US amounted to 0.256 MMT in 2018 (Beroe, 2018). Intensifying emission standards are anticipated to create a boon for the industry, as filtration for air and water pollution increases in demand (Adeleke, 2018). However, currently, in the US, exports account for 91% of industry revenue (Adeleke, 2018).

Currently, China is the biggest exporter of activated carbon, accounting for 18 percent of the current market, followed by the US (16 percent), Belgium (7 percent), and the Netherlands (6 percent) (Beroe, 2018). The Asia-Pacific region is also expected to have the fastest market growth, with a CAGR of 11.1 percent through 2022 (Shukla, 2016). All other regions are expected to experience market decline in response to the growth of the Asia-Pacific supply (Grand View Research, 2019).

Barriers to product or process innovation and growth

Activated carbon growth is largely confined by its high capital requirements. IBISWorld classified the activated carbon manufacturing industry as “moderately capital intensive” (Adeleke, 2018). They estimate that for every $1.00 spent on labor, manufacturers spend $0.15 on capital machinery and equipment. The price of feedstock is also a potentially large barrier to growth, as raw materials account for 68-72 percent of the final price (Market Reports World, 2019). Additionally, substitute products such as silica gel and super sand are expected to slow market growth (Market Reports World, 2019).

Environmental laws are another barrier to growth and may provide a reason for the absence of activated carbon producers in California. For example, manufacturers are subject to the Clean Air Act as well as the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation and Liability Act for handling and disposal of hazardous substances created during the production process (Adeleke, 2018). Additionally, as activated carbon is used in drinking water treatment facilities, manufacturers must adhere to the American Water Works Association standards. California environmental laws are commonly regarded as relatively strict compared to other states, which may be disincentivizing production in California.

Research gaps

Most research and development in the industry surrounds emerging end-uses in downstream markets, with emphasis currently placed on applications that can remove pathogens and contaminants (Adeleke, 2018). More research is needed to assess how California can encourage activated carbon production in state.

Product substitution

Activated carbon is most commonly used for water purification and water treatment, making up 49% of end user industries (Beroe, 2018). It is projected that by 2020 activated carbon feedstock will consist mainly of wood/coal (57%) and coconut shells (37%) (Beroe, 2018). The availability of coconut shells as a feedstock is highly vulnerable to adverse environmental conditions that affect coconut production. Common product substitutes for activated carbon filtration includes sand filtration and silica gel filters. Additional substitutes, such as granular rubber and coke breeze have been tested as substitutes for activated carbon but have not been used at a commercial scale (Beroe, 2018).

Opportunities for JIWPI Influence

- Investigate avenues for woody biomass to replace feedstocks currently being used in California facilities
- Research opportunities for in-state production of activated carbon from woody biomass to compete with international supply

MATRIX EXPLANATION

- **Minimum feedstock required** *150,000 BDT/yr.* National Carbon Technologies operates a biochar production facility in Michigan that processes 300,000 tons of wood per year (40 tons per hour). However, we were not able to determine how much of their product was biochar vs. activated carbon.
- **Carbon storage** *Yes.* Carbon storage in long-lived products.
- **Technology readiness level** *8-9.* Technological readiness is high as the level of research and development invested in technology change is low (Adeleke, 2018). Most research and development investment is driven by end uses in downstream markets.
- **Commercial readiness level** *9.* Activated carbon is a highly mature and globalized industry currently sold for a range of different end uses (Adeleke, 2018). Global market size is expected to reach $5.12 billion by 2022 (Shukla, 2016).
- **Feedstock use** *Non-merchantable.*
- **International markets** *Yes.* The activated carbon manufacturing industry is highly globalized (Adeleke, 2018). Key exporting countries include China (18 percent), US (16 percent), Belgium (7 percent), and the Netherlands (6 percent). The market across the Asia-Pacific region is expected to grow the fastest, at a compound annual growth rate (CAGR) of 11.1 percent through 2022 (Beroe, 2018; Shukla, 2016).
- **Potential market size** *Large.* Global market size is projected to reach 2.5-5 MMT by 2021 growing at a CAGR of 8.2 percent and $5.12 billion by 2022 at a CAGR of 9.3 percent (Beroe, 2018; Shukla, 2016).
- **Research or analysis need** *Medium.*Market research on how to integrate non-merchantable wood from California forests into a mature global market is necessary.
- **Can JIWPI influence outcomes?** *Low.*It is unclear if in-state production of activated carbon from woody biomass can compete with international supply.

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4.4 Pyrolysis: Solid & gaseous fuels

PRODUCT: BIOCOAL/TORREFIED WOOD

Definitions

Torrefied wood, also known as biocoal, is a product of partial pyrolysis. In this process, raw woody biomass is burned in an oxygenless environment at 250 to 300 degrees Celsius. Torrefaction removes much of the moisture and volatile compounds from biomass resulting in a product that has a higher energy density per unit mass compared to the raw feedstock. This higher density has the benefit of reducing the per Joule transportation cost of biomass. Additionally, one of the notable innovations within torrefaction technology is that the displaced volatile compounds are recaptured and burned as syngas, thus creating a more thermally efficient heating process that requires less energy input for production. The resulting biomass can be condensed and pelletized, creating a fuel with a similar energy density and handling properties as coal (Thrän et al., 2017). Because of this similarity, a common use for biocoal is to co-fire it within existing coal power plants since biocoal is considered a low-carbon fuel that lacks the heavy metal and sulfur emissions that come from coal.

Existing capacity

Several hundred thousand tons of torrified wood pellets are produced worldwide. For instance, one torrefied pellets production plant, owned by OAO Bionet, Onega, Arkhangelsk Oblast, produces 150,000 tons of torrefied pellets per year.

Torrefied pellets would compete with traditional wood pellets to meet demand for solid, biomass energy feedstocks. In 2015 approximately 26 Mt of wood pellets was produced globally; 5 Mt of which came from US exports (Thrän et al., 2017). Production demand came primarily from Europe: European Union countries subsidize biomass for use as carbon-neutral bioenergy towards meeting their Paris Agreement goals. East Asian countries like China, Japan, and South Korea also make up a large portion of global demand.

In Oregon, the Restoration Fuels facility in John Day, Oregon (construction to be completed in Q1 2020), is expected to produce 100,000 tons of product from 149,000 BDT/year.

In California, while some of the state's energy comes from woody biomass as a result of policies like SB 1122, the added cost of torrefaction to the high cost of forest woody biomass means that these facilities rely solely on raw materials rather than biocoal. That said, it is possible that a distributed network of satellite torrefaction facilities could, despite upfront costs, lead to overall cost savings at scale in California due to decreased transportation costs.

Justification

Torrefied wood has numerous benefits over raw biomass as a bioenergy source. Torrefaction creates a product that is roughly 50% more energy dense, absent of most volatiles, and is mostly hydrophobic – meaning it can be stored with minimal risk of decay and carbon monoxide off-gassing (Thrän et al., 2017). The decreased moisture content and increased density also help reduce the often prohibitively high cost of transportation associated with forest residuals. Additionally, compared to the fossil fuels that it can displace, torrefied wood has relatively lower GHG emissions associated with its use.

Market indicators

Interest and research into torrefaction has seen a steady rise in the past decade as indicated by the number of scholarly papers on the topic (Ribeiro et al. 2018). This research has focused on technological advancements as well as market research into supply chains and consumer demand (Fritsche et al., 2019). Coupled with the large and quickly growing international markets for biocoal, this indicates a potentially bright future for the product. In particular, there are a number of large commercial scale facilities (producing > 50,000 tons/year) operating internationally (Ribeiro et al. 2018, Cremers et al. 2015). However, it is important to recognize that demand for torrefied wood is in part subsidized by government demand for green energy – often in the form of feed-in tariffs and feed-in premiums, though the exact schemes vary between EU countries (Banja et al., 2019).

Barriers to product or process innovation and growth

One of the primary concerns expressed by biocoal consumers is product consistency. Energy facilities would benefit from quality assurances regarding grindability, moisture content and energy balance as a means of increasing consumer trust (Wild et al., 2016).

Research gaps

Much of the ongoing research on torrefied wood relates to product consistency for end-users. Different feedstock sources (e.g. pine versus spruce) can lead to small but important differences in certain characteristics such as minimum ignition energy or biological degradation (Fritsche et al., 2019). Additionally, various preheating and densification techniques can also lead to differences in product quality and consistency (Fengler et al., 2017).

Product substitution

As mentioned above, torrefied wood has a similar energy density and handling properties as coal, allowing it to be co-fired within existing coal facilities. Promising research also demonstrates potential for full-scale coal substitution within steam powered trains using a process that requires minimal retrofitting of steam engines (Fengler et al., 2017). There is also potential for use of biocoal within high temperature industrial heat processes such as paper, cement, glass, ceramics and steel and iron production (Fritsche et al., 2019). Once again, limitations do remain in terms of inconsistency of biocoal pellets and the inability to fully match the energy density of coal.

Opportunities for JIWPI Influence

- The JIWPI should steer market research towards the potential for California derived torrefied wood to meet the growing demand from East Asian countries like Japan and South Korea. This could come in the form of seeking out Asian business partners and researching the potential demand quantity and price points for the type and quality of pellets that could be produced in California.
- Invest in research regarding the cost and benefits of constructing satellite torrefaction facilities in California as a means reducing the cost of transportation to biomass energy facilities.

MATRIX EXPLANATION

- **Minimum feedstock required**: *149,000 BDT/year.* In the United States, the Restoration Fuels facility in John Day, Oregon (construction to be completed in Q1 2020), is expected to produce 100,000 tons of product from 149,000 BDT/year. In Europe where markets for torrefied wood are boosted via government subsidies for green energy, the smallest commercial facilities require approximately 90,000 BDT/year (Cremers et al. 2015).
- **Carbon storage:** *No.* No long-lived carbon storage possible.
- **Technology readiness level:** *8.* The John Day facility will be capable of producing >250 tons/day of torrefied wood from softwood lumber residues. A few European facilities also have similar production levels.
- **Commercial readiness level:** *6.* While numerous commercial facilities exist worldwide (primarily in Europe) the market is largely fueled by European government subsidy. Even despite the subsidies, many European facilities have been decommissioned or mothballed due to high production costs and unstable markets.
- **Feedstock use:** *Non-merchantable.* Can use various non-merchantable woody biomass feedstocks, from forest residues to sawdust.
- **International markets:** *Yes.* Large, growing demand particularly from European and East Asian countries expected. Market has grown globally from 6 Mt in 2006 to 26 Mt in 2015, with continued growth expected (Thrän et al., 2017).
- **Potential market size:** *Large.* Domestically there may be potential for conversion of local biomass electric facilities toward use of torrefied pellets. However, the greatest potential market lies from Asian countries like Japan and Korean, which combined are expected to have a demand of over 20 Mt of wood pellets per year by the mid-2020s (Thrän et al., 2017). Much of this demand is expected to be met by China and South East Asia countries, however there may still be a great deal of potential for California biomass within these markets. Torrefied pellets would compete with traditional wood pellets to satisfy this demand.
- **Research or analysis need:** *Medium.* Need for more research into means of maintaining high levels of product quality across a range of feedstock sources including very small diameter forest residues.
- **Can JIWPI influence outcomes?** *Yes.* We see potential to facilitate in-state use and international export of biocoal.

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PRODUCT: RENEWABLE NATURAL GAS

Product Description

Deployment of fuels having a lower carbon intensity can help the state reach its goals for aggressive greenhouse gas emissions reduction.

One pathway to substantially reduce GHG and criteria pollutant emissions is by expanded use of renewable natural gas (RNG). RNG can be produced from a number of sources, such as digesters, wastewater treatment facilities, landfills and from thermal conversion of renewable carbonaceous materials like woody biomass.

Here, we target the thermal conversation of woody biomass to RNG via gasification and subsequent catalytic conversion. This is broadly known as methanation, or the Sabatier process. Commercial suppliers of these technologies include Andritz and Haldor Topsoe A/S (GTI, 2019).

RNG is distinguished from biogas by its quality. RNG can be produced by upgrading biogas or syngas to be of an appropriate quality and make-up to supplement or replace natural gas. Most RNG being used in California and throughout the rest of the United States is produced from landfills (GTI, 2019).

Existing Capacity

We are not aware of any existing demonstrations of this technology using forest biomass. However, there have been at least two proposals for facilities producing RNG in California:

(1) The Gas Technology Institute has produced an engineering design for RNG production in Stockton, CA. The facility would operate at the DTE biomass power plant in Stockton, producing 3 BCF/yr RNG and displacing approx 170,000 tons of CO2/yr (GTI, 2019).

(2) San Joaquin Renewables has announced intentions to develop a RNG production facility employing methanation on agricultural wood waste in McFarland, California (San Joaquin Renewables, 2019).

Justification

Renewable natural gas production and consumption has expanded dramatically in the United States in recent years, based on policy support by the U.S. Renewable Fuel Standard and California's low-carbon fuel standard. While much of this RNG is sourced from the anaerobic digestion of wet biomass (e.g. manure), it is possible to convert woody biomass to RNG using thermochemical processing.

Market Indicators

Several electricity and gas utilities in California, namely SoCalGas, have expressed an interest in the production and procurement of RNG as part of California's climate policy (SoCalGas, 2019).

Further, California has also passed a renewable gas standard (SB 1440), calling for an increasing share of RNG to be produced from biomass. The law was signed in 2018 by then-Governor Brown.

Barriers to product or process innovation and growth

The primary barrier to growth of RNG from forest biomass is the lack of a large-scale demonstration facility operating on woody biomass feedstock.

Research Gaps

See 'Barriers' above.

Product Substitution

RNG is a direct substitute for fossil-derived natural gas. Natural gas is a hydrocarbon gas mixture consisting primarily of methane. California is a large producer and consumer of natural gas, consuming over 2,000 BCF/yr.

Opportunities for JIWPI Influence

- Facilitate development of a demonstration facility.
- Development of pro-forma or other standards for RNG produced via gasification, facilitating pipeline injection.
- Other market development activities, including policy, finance, or technology incubation.

MATRIX EXPLANATION

- **Minimum feedstock required:** ***250,000 BDT/yr.*** The Gas Technology Institute has based their engineering design on a renewable natural gas (RNG) facility that would convert wood waste on a feedstock demand of 310,000 tons of biomass at 17% moisture. This is roughly 250,000 BDT (GTI, 2019).
- **Carbon storage:** *Possible.* The Gas Technology Institute included carbon capture and sequestration (CCS) as a possibility in their engineering design study.
- **Technology readiness level:** *6.* According to the Gas Technology Institute, there has been previous pilot-scale testing in the United States and commercial scale design work performed in Europe of RNG technologies using woody biomass as a feedstock. We are not aware of the demonstration of an actual system prototype in a relevant environment. (GTI, 2019)
- **Commercial readiness level:** *5.* A deep understanding of the target application and market (low-carbon fuels in California) has been achieved. However, we are not aware of any companies developing a facility in California that operates on forest biomass.
- **Feedstock use:** *Non-merchantable wood.* All lignocellulosic biomass, including forest and agricultural wastes, can be used.
- **International markets**: *Yes.* In Europe there is currently a large demand for locally produced RNG and biogas, however, we do not expect California to enter into the European market.
- **Potential market size:** *Large.* The National Renewable Energy Laboratory has estimated California's potential natural gas demand as a transportation fuel to be ~110 trillion Btu/year by 2030 (Penev, 2016). This is a market size of 110 BCF/yr, or roughly 9.5 million BDT/yr of wood demand.
- **Research or analysis need:** *High.* We are not aware of the demonstration of an actual system prototype in a relevant environment. As such, JIWPI could help facilitate the demonstration of this technology in CA.
- **Can JIWPI influence outcomes?** *High.* JIWPI could facilitate the development of a demonstration facility, or perform other market development activities, including policy, finance, or technology incubation.

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PRODUCT: RENEWABLE HYDROGEN

Product Description

Deployment of fuels having a lower carbon intensity can help the state reach its goals for aggressive greenhouse gas emissions reduction. One pathway to substantially reduce GHG and criteria pollutant emissions is by expanded use of renewable hydrogen. Hydrogen (H_2) can be produced from a number of processes, such as electrolysis of water or steam-methane reforming of natural gas.

Here, we target the thermal conversation of woody biomass to hydrogen via gasification and subsequent catalytic conversion. This catalytic conversion is known as water-gas shift, which converts carbon monoxide and water vapor to form carbon dioxide and hydrogen. This mixture of hydrogen and carbon dioxide can then be separated into high-purity streams using existing technology. Gasification, catalytic conversion, and gas separation is widely practiced at commercial scale in ammonia, hydrocarbon, methanol, and hydrogen production.

H_2 has many uses in energy and manufacturing, including as a transportation fuel and electricity generation via combustion or fuel cells. Hydrogen is considered an important fuel for the replacement of fossil hydrocarbons, as part of aggressive greenhouse gas emissions reduction. Here, we focus on hydrogen use as a transportation fuel in California.

Existing Capacity

The vast majority of hydrogen produced worldwide, and in California, rely two primary pathways: 1) steam-methane reforming (SMR) of natural gas or biogas, or 2) electrolysis of water. Neither of these pathways are relevant for conversion of woody biomass to hydrogen.

Large-scale hydrogen production from wood via gasification is relatively rare. Nevertheless, gasification of woody biomass is practiced at commercial scale. For instance, the McNeil generating station, near Burlington, VT, uses biomass gasification for electricity production. This facility produces 50 MW of power from 76 tons of wood chips per hour (Burlington Electric Department, 2019).

Proposed hydrogen production plants in CA process agricultural biomass, rather than wood. For instance, Clean Energy Systems plans to develop a facility producing hydrogen from 300 tons per day of orchard wastes near Kimberlina, CA (Clean Energy Systems, 2019). Clean Energy Systems hopes to retrofit a number of existing biomass power plants to produce hydrogen for use as a transportation fuel.

There has been at least one demonstration of hydrogen and electricity production from forest biomass in California. Unfortunately, this demonstration proved unsuccessful. Blue Lake Rancheria, in Humboldt County, CA, aimed to produce hydrogen from mill residues, for electricity generation via fuel cells (West, 2015). The fuel cell system had stringent gas quality standards that were not met.

Hydrogen must be sold as a transportation fuel in order to qualify for subsidies through the State's Low Carbon Fuel Standard. Thus, future development of hydrogen infrastructure will likely be limited by hydrogen fuel cell vehicle adoption. As of December 2019, there are 44 open hydrogen fueling stations in California (California Fuel Cell Partnership, 2019). There are over 10,000 retail fuel stations in California.

Justification

Hydrogen is a gaseous, carbon-free fuel that has many purposes in energy production. H_2 has many uses in energy and manufacturing, including as a transportation fuel and electricity generation via combustion or fuel cells. Hydrogen use as a transportation fuel in California qualifies for subsidies under the State's LCFS.

Market Indicators

Hydrogen must be sold as a transportation fuel in order to qualify for subsidies through the State's Low Carbon Fuel Standard. Thus, future development of hydrogen infrastructure will likely be limited by hydrogen fuel cell vehicle adoption. As of December 2019, there are 44 open hydrogen fueling stations in California (California Fuel Cell Partnership, 2019). There are over 10,000 retail fuel stations in California.

Barriers to product or process innovation and growth

The primary barrier to growth of hydrogen from forest biomass is the lack of a successful demonstration facility operating on woody biomass feedstock.

An additional barrier is the lack of enabling infrastructure for hydrogen distribution to vehicles. Future development of hydrogen infrastructure will likely be limited by hydrogen fuel cell vehicle adoption

Research Gaps

See 'Barriers' above.

Product Substitution

Hydrogen can substitute for numerous fossil-derived hydrocarbon fuels.

Opportunities for JIWPI Influence

- Facilitate development of a demonstration facility.
- Other market development activities, including policy, finance, or technology incubation.

MATRIX EXPLANATION

- **Minimum feedstock required:** *45,000 BDT/yr.* Clean Energy Systems plans to process 300 tons per day of agricultural biomass at their first facility.
- **Carbon storage:** *Possible.* Clean Energy Systems plans to geologically sequester CO_2 at their commercial-scale facility.
- **Technology readiness level:** *5.* We are not aware of a successful demonstration of an actual system prototype in a relevant environment. However, bench-scale components and/or system has been developed and validated in the laboratory environment.
- **Commercial readiness level:** *5.*A deep understanding of the target application and market (low-carbon fuels in California) has been achieved. However, we are not aware of any companies developing a facility in California that operates on forest biomass.
- **Feedstock use:** *Non-merchantable wood.* All lignocellulosic biomass, including forest and agricultural wastes, can be used.
- **International markets**: *Yes.* There is large demand for hydrogen both domestically and internationally. However, we do not expect California to enter into these markets without low-carbon fuel policies.
- **Potential market size:** *Uncertain.* The future development of hydrogen infrastructure will likely be limited by hydrogen fuel cell vehicle adoption.
- **Research or analysis need:** *High.* We are not aware of the demonstration of an actual system prototype in a relevant environment. As such, JIWPI could help facilitate the demonstration of this technology in CA.
- **Can JIWPI influence outcomes?** *High.* JIWPI could facilitate the development of a demonstration facility, or perform other market development activities, including policy, finance, or technology incubation.

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4.5 Liquid Fuels

Introduction

Liquid fuels can be produced from forest biomass, including non-merchantable wood. These fuels can reduce consumption of fossil fuels via substitution of low-carbon or carbon-negative fuels. Biofuel production techniques using lignocellulosic biomass typically can be classified into one of two categories:

- *Biochemical processes*, which harness biological organisms such as yeast and microbes to convert biomass constituents to fuel. For example, lignocellulosic ethanol can be produced by the pretreatment, hydrolysis, and fermentation of sugars derived from biomass.
- *Thermochemical processes,* which harness heat and catalysts to convert biomass constituents into fuel. For example, drop-in biofuels can be produced via gasification, gas cleaning, and catalytic conversion of syngas derived from biomass.

Conversion methods for biomass entail different infrastructure, costs, efficiencies, and carbon (CO_2) emissions reduction, and technical risk.

Biofuel production typically produces multiple products from biomass, whether using biochemical and thermochemical processes. In particular, commercial thermochemical processes always produce a mixture of gases, liquids and solids. As a result, any commercial system will need to sell multiple products, or use them for process heat. Biofuels production is better conceptualized as a biorefinery, whereby biomass is processed into a spectrum of bio-based products (e.g. food, feed, chemicals, materials) and energy.

Commercial production of biofuels faces a number of risks. Issues include:

- **Scale:** biofuel plants are relatively small relative to a pulp mill, are very expensive in terms of capital costs per production volume.
- **Feedstock handing:** Handling and processing biomass at scale presents major logistical challenges.
- **Feedstock-process interactions:** Ash, lignin, and trace contaminant levels in forest biomass can reduce the yield of processes compared to agricultural biomass.
- **Margins:** Fuels have a low margin and are produced at large scale, challenging the profitability of biofuels production. Only with significant subsidies, or a reliable signal sent through climate policy, will allow biofuels to be profitable at scale.

Both biochemical and thermochemical processes face technical barriers related to feedstock-process interactions. Biochemical processes for liquid fuel production have typically employed agricultural biomass, such as corn stover or perennial grasses, rather than forest biomass. The major differences between woody and agricultural biomass are their physical properties and chemical compositions. Woody biomass is larger, stronger and denser, and has higher lignin content than agricultural biomass. As a result, woody biomass is more recalcitrant to microbial and enzymatic actions than non woody biomass. This is particularly true for softwood species (Zhu, 2010). Thermochemical processes are also sensitive to ash and trace contaminants found in forest biomass, reducing process yield. Range Fuels and Kior, described below, both failed to commercialize liquid fuel production from forest biomass due to these barriers.

Review of commercial production of liquid fuels from lignocellulosic biomass

Innovation necessarily entails risk. There are currently 13 plants around the world that convert 'biomass' to fuels or chemicals. In 2017 there were reported to be an additional 20 projects in various stages of development or even initial construction. There are also several plants that have been constructed and closed, and are not included in this list. It is worth noting that many of the under-performing or failed ventures were implemented by large, well-resourced companies who have decades of experience with operating traditional biomass processing plants, e.g., corn dry mills or pulp and paper operations.

Table 10. Partial List of Commercial Biomass to Fuels Production Plants

Currently Operating, 2018					
Company, Location	**Feedstock**	**Production Capacity (Mil lit/yr and Mil Gal/yr)**	**Estimated Biomass Consumption Mt/yr (see Note 1)**	**Technology**	**Startup**
Borregaard, Norway	Wood	20/52	NA - Dilute black liquor sugars	Fermentation of Spent Sulfite liquor	1938
Domsjo Fabriker AB, Sweden	Wood	22/58	NA - Dilute black liquor sugars	Fermentation of Spent Sulfite liquor	1938
Shandond Longlive, China	Ag residues (corn cobs)	63/16	205,000	Fermentation of sugars	2012
Henan Tianguan, China	Ag residues (corn and wheat stalks)	38/10	125,000	Fermentation of sugars	2012
GranBio, Brazil	Straw and bagasse	82/22	270,000	Fermentation of sugars	2014
Beta Renewables, Italy	Ag residues (straw) and energy crops	50/13	165,000	Fermentation of sugars	2012
Raizen/logen, Brazil	Straw and bagasse	40/11	130,000	Fermentation of sugars	2014
St1/SOK, Finland	Sawdust	10/2.5	30,000	Fermentation of sugars	2014
Enerkem, CAN	MSW	38/10		Gasification, chemical catalysis	2016

Operated, but closed					
Kior, MS	Clean pine chips			Catalytic fast pyrolysis, hydrotreating	
Range Fuels, GA	Clean pine chips			Gasification, chemical catalysis	
INEOS, FL	Ag wastes	30/8	100,000	Fermentation of syngas	2013
Abengoa, KS	Corn Stover, wheat straw	95/25	310,000	Fermentation of sugars	2014
POET-DSM, IA	Corn Stover	76/20	250,000	Fermentation of sugars	2014
DuPont, IA	Corn Stover	114/30	375,000	Fermentation of sugars	2014

Note 1: Conversion for biomass to ethanol via fermentation is assumed to be 80 gal/ODT. Gasification and fast pyrolysis producing hydrocarbon fuel or blend stock is assumed to be 60 gal/ODT.

In the case of deployment of 'innovative' biomass technologies the landscape is littered with projects that failed out right, or are operating below expectations (1,2). There are also promising successes (3) Examples include:

Biochemical Fermentation of Biomass to Ethanol

Abengoa, Hugoton, KS - The Abengoa facility was designed as an integrated biorefinery (4). Consumed 325,000 ODT of corn stover and produced 25 million gal of ethanol, generated 21 MW of power and heat from combustion of the lignin and process residues, and methane from the waste water treatment system. The total plant costs exceeded $225 mil with almost $100 mil coming in the form a DOE grant. Construction was completed in August of 2014 and closed in December 2015, when the parent company filed for bankruptcy. While the Biorefinery was a very small part of the Abengoa portfilo which totaled $10 billion in assets. The plant was sold to Synata Bio for $49 mil at the end of 2016 (5).

DuPont, Neveda, IA - The Dupont cellulose ethanol plant was designed to product 30 mil gal of ethanol (6). The total cost was $225 million with $51 mil from a DOE grant. It operated for 2 years until the merger of DuPont and Dow lead to changes in the business priorities, and shutdown of the plant. In November of 2018 the plant was sold to Verbio North America Corp who plan to convert it to production of renewable natural gas. (7)

POET-DSM, Emmetburg, IA - The POET-DSM Project Liberty biorefinery is designed to produce 20-25 mil gallons of ethanol from 285,000 ODT of corn strover delivered from a 45 mile radius of the plant (8). The plant is co-located and shares infrastructure with a POET corn starch to ethanol plant. It reported a number of issues with the quality and feeding of the feedstock. The construction costs were reported to total $260 mil with $88 mil from a DOE grant. In November 2019 POET announced that production was being scaled back, and that it would quite buying addition feedstock (9).

Beta Renewable, Crescentino, Italy – The Beta Renewables Prosea low severity pretreatment technology was the basis of cellulose ethanol plants built in Italy and Brazil (10). The Italian plant with a nameplate capacity of 17 mil gal started construction in 2014, and required considerable rework to the feedstock handling and cleaning systems. The plant runs on wheat straw and Anrundo Donax or Giant Reed, dedicated energy crop. It is worth noting the Anrundo Donax is cultivated in Italy but considered an invasive plant in many US states. The plant was closed in 2017 when the parent M&G company filled for bankruptcy. The Crescentino Biorefinery was a very small part of the total M&G total portfolio.

Thermochemical Production of Hydrocarbon Blend Stocks or Fuels

Range Fuels, Soperton, GA This biomass gasification plant was designed to convert pine chips into syngas, and convert the syngas liquid fuels. Project investments totaled $320 million, with half coming from government grants and half from private investors (11). The government grants included $76 million from US DOE for technology and pilot plants, and $6.25 million from the state of GA for construction of the commercial plant. The plant design was based on technology that had been piloted for many thousands of hours. Many of the syngas clean-up operations were well known in the petrochemical industry. Nevertheless, the plant as constructed had numerous problems with feeding woody chips into the gasifier while limiting the amount of air that was also fed into the reactor, and it had problems with the performance of the catalysts used to convert the syngas to fuels. The plant only operated for a few months.

Kior, Columbus, MS This plant was designed to convert pine chips into an intermediate 'bio-oil' and then convert bio-oil to a hydrocarbon blend stock suitable for refining in a petroleum refinery (12). Again, there were significant feeding and catalyst deactivation problems. Originally advertised to produce 97 gal. of blend stock for everyone ODT of pine, the target yield was lowered to 67 gal per ODT, but the plant was typically only producing 20-40 gal per ODT of clean pine wood. The catalyst deactivation was blamed on very low levels of sulfur, chlorine and alkaline earth minerals that are present in even the cleanest of wood, but that build up over time. With total cost in excess of $300 million the plant was closed after one year of operations. Several company officials were charged with fraud (13). Investors included the State of Mississippi ($75 mil), Bill Gates ($15 mil) and Vinod Khosla ($85 mil) (13). The plant has been closed and completely disassembled.

Enerkem, Edmonton, CAN Enerkem is a notable exception to most of the prior projects (14). Specifically its gasification technology uses municipal solid wastes (MSW), which has a significant cost advantage over biomass, and the plastics in MSW can product syngas with a more attractive CO/H_2 ratio for production of chemicals and fuels. A second advantage is the Enerkem developed their first commercial project in small steps, building and operating the gasifier to make heat and power, then starting to product methanol, and finally producing ethanol (14). This approach reduced the initial capital costs and increased investor confidence. Finally, as a Canadian company it benefited from a number of large national and provincial grants. The total investments in the company for development of the technology, and construction of several pilot plants, a commercial production plant, and initial construction of two additional commercial plants, are reported to be $750 mil (15).

Thermochemical Conversion of Black Liquor to Heat and Power

Georgia-Pacific Corp, Big Island, VA and Weyerhaeuser, New Bern NC Both these black liquor gasifiers were intended to debottleneck the Kraft recovery boilers and increase the efficiency of the mill (16). The GP Big Island gasifier had a nameplate capacity of 200 tpd of black liquor solids, and construction costs of $66 million. They also had the long-term goal of producing a clean syngas that could ultimately be used to product liquid fuels. The projects used two different gasifiers, and both designs suffered from severe corrosion problems. Even with ceramic brick liners there were persistent problems with crack in the refractory lining the gasifier that lead to numerous unscheduled shutdowns (16). After 3-4 years of periodic operation, both projects were shutdown permanently.

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PRODUCT: RENEWABLE HYDROGEN

Product Description

Fischer-Tropsch fuels are derived from biomass through gasification, gas cleaning, and catalytic treatment. Solid biomass is first gasified in oxygen and steam, with subsequent gas conditioning that includes cleaning of the raw synthesis gas and in some cases adjusting the composition of the syngas in preparation for downstream synthesis of Fischer-Tropsch liquids (FTL). Prior to synthesis, CO2 and sulfur compounds are removed in the acid gas removal step. The CO2 may be vented or captured and stored underground. Fischer-tropsch liquids typically contain a mixture of hydrocarbons, including gasoline and diesel substitutes (Kreutz, 2008).

Existing Capacity

There is a long history of attempts to commercialize Fischer-Tropsch fuels and other processes employing gasification, gas cleaning, and catalytic treatment. As discussed above, there have been several notable failures, alongside a few successes. For instance, Range Fuels was unable to successfully commercialize ethanol production from southern pine via gasification and catalysis. In contrast, Emerkem has successfully produced ethanol via gasification of municipal solid waste (MSW).

Red Rocks Biofuels has proposed a facility in Lakeview, Oregon in part to serve California markets. This facility will consume 68,000 BDT/yr of biomass to produce 7.2 million gallons a year of jet fuel, 7.2 million gallons a year of diesel fuel, and 3.6 million gallons a year of naphtha (Red Rocks Biofuels, 2018). This facility has not yet been placed in service. Numerous observers have questioned the technical viability of Red Rocks Biofuels' gasification technology.

Velocys plans on taking woody biomass forest residue from lumber industries and convert using proprietary Fischer Tropsch processes into aviation or heavy duty road transportation fuels. Of particular interest is Velocys integration of carbon capture utilization and storage (CCUS) technology into the process, generating net negative carbon intensity fuels (Stratmann, 2019).

Justification

Among low-carbon transportation fuels, the production of FTL from lignocellulosic biomass has been given considerable attention.

FTL offers logistical advantages over other biomass-derived fuels, including: (i) it is an energy-dense liquid fuel, (ii) no significant transportation fuel infrastructure changes would be required for widespread use, (iii) it can accommodate more easily the wide range of biomass feedstocks that are likely to characterize the lignocellulosic biomass supply—because gasification-based processes tend to more tolerant of feedstock heterogeneity than biochemical processes (Kreutz, 2008).

Market Indicators

There is an active international market for low-carbon liquid fuels. California currently uses liquid hydrocarbon fuels in the vast majority of its nearly 30 million vehicles.

Barriers to FTL from biomass are primarily financial, rather than technical. Renewed commercial interest in these fuels has been driven, in part, by low-carbon fuels policy in the Western United States, including California's LCFS. The LCFS provides subsidies for low-carbon fuels derived from lignocellulosic biomass.

Barriers to product or process innovation and growth

FTL plants exhibit large economies of scale, which increases the minimum viable capital investment necessary to construct a commercial facility (Sanchez and Kammen, 2016). Compared to other low-carbon fuels facilities (e.g. RNG, lignocellulosic ethanol), FTL plants face considerably higher capital requirements.

Furthermore, large feedstock requirements can create challenges with respect to security of supply of forest biomass in California.

Research Gaps

Barriers to F-T fuels from biomass are primarily financial, rather than technical. Several market formation activities, such as identification of candidate facility locations or preliminary front end engineering and design (pre-FEED) studies, could contribute to technology scale up. Additional barriers may be related to social opposition to large, capital-intensive facilities.

Product Substitution

FTL is a direct substitute for fossil-derived liquid transportation fuels, including gasoline and diesel. FTL is a hydrocarbon liquid mixture that can be separated into drop-in fuels replacements. California is a large producer and consumer of petroleum, consuming over 15 billion gallons of gasoline in 2015. (State of California, 2019)

Opportunities for JIWPI Influence

- Should Red Rocks Biofuels proposed facility overcome key technical and financial hurdles, the JIWPI could undertake market formation activities, including policy, finance, or technology incubation.

MATRIX EXPLANATION

- **Representative feedstock required:** *68,000 BDT/yr.* Red Rocks Biofuels has proposed a facility in Lakeview, Oregon in part to serve California markets. This facility will consume 68,000 BDT/yr of biomass to produce 7.2 million gallons a year of jet fuel, 7.2 million gallons a year of diesel fuel, and 3.6 million gallons a year of naphtha (Red Rock Biofuels, 2019).
- **Carbon storage:** *Possible.*CO2 capture and sequestration (CCS) is achievable on high-purity streams of CO2 produced during F-T fuels synthesis (Sanchez and Kammen, 2016).
- **Technology readiness level:** *7.* There have been several successful demonstrations of fuels synthesis via gasification and fischer-tropsch conversion of woody biomass. Full-scale demonstration, including startup and testing, has not yet been completed.
- **Commercial readiness level:** *6-7.* A deep understanding of the target application and market (low-carbon fuels in California) has been achieved. Product design is complete. Supply, customer agreements, and regulatory compliance are in process.
- **Feedstock use:** *Non-merchantable wood.* All lignocellulosic biomass, including forest and agricultural wastes, can be used.

- **International markets**: *Yes.* There is an active international market for low-carbon liquid fuels.
- **Potential market size:** *Large.* California currently uses liquid hydrocarbon fuels in the vast majority of its nearly 30 million vehicles.
- **Research or analysis need:** *Medium.* Barriers to F-T fuels from biomass are primarily financial, rather than technical. Several market formation activities could contribute to technology scale up.
- **Can JIWPI influence outcomes?** *High.* Should Red Rocks Biofuels proposed facility overcome key technical and financial hurdles, the JIWPI could undertake market formation activities.

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PRODUCT: GAS FERMENTATION FOR FUELS

Product Description

Low-carbon cellulosic ethanol can be produced from lignocellulosic biomass through gasification, gas cleaning, and gas fermentation. The resulting syngas from gasification and gas cleaning is converted into cellulosic ethanol using gas fermentation technologies. Gas fermentation typically employs engineered bacteria to biologically process syngas into ethanol.

Existing Capacity

Lanzatech has successfully commercialized syngas fermentation processes. Their technology has been used in multiple demonstration projects at varying scales (Holmgren, 2018).

Aemetis has proposed a facility in Riverbank, CA that will produce 12 million gallons per year of cellulosic ethanol from 133,000 BDT/yr of agricultural wood waste from orchards, using Lanzatech's gas fermentation processes. This facility has successfully secured a USDA loan guarantee, a 20-year feedstock supply agreement, and a 55-year land lease (Shaver, 2018). Aemetis plans to open the facility in 2020 and an integrated demonstration unit has operated for 120 days. Future expansion at 3 other locations would bring total production to 160 million gallons of cellulosic ethanol (Aemetis, 2019).

Justification

Cellulosic ethanol is a low-carbon liquid transportation fuel that can be produced from lignocellulosic biomass. However, traditional biological processes to produce ethanol from lignocellulosic biomass, such as pretreatment, enzymatic hydrolysis, and fermentation of sugars, are not presently commercial viable in the United States. Gas fermentation is an alternative process that has recently found commercial markets. Large-scale technology producers, such as LanzaTech, are actively exploring market development in California and elsewhere.

Market Indicators

There is an active international market for low-carbon liquid fuels. California currently uses liquid hydrocarbon fuels in the vast majority of its nearly 30 million vehicles. Renewed commercial interest in these fuels has been driven, in part, by low-carbon fuels policy in the Western United States, including California's LCFS. The LCFS provides subsidies for low-carbon fuels derived from lignocellulosic biomass.

Barriers to product or process innovation and growth

The primary barrier to growth of cellulosic ethanol from forest biomass via gas fermentation is the lack of a demonstration facility operating on woody biomass feedstocks.

Research Gaps

See 'Barriers' above

Product Substitution

Ethanol derived from biomass is a transportation fuel already consumed at large scale in the United States (>15 billion gallons / yr). It is primarily used in light-duty vehicles as a source of transportation energy, and fuel octane enhancement. California currently consumes 1 billion gallons/yr of ethanol, which could be made from ~11 million BDT/yr biomass.

Opportunities for JIWPI Influence

- Should the Aemetis Riverbank facility achieve commercial viability, the JIWPI could undertake market formation activities, including policy, finance, or technology incubation.

MATRIX EXPLANATION

- **Representative feedstock required:** *130,000 BDT/yr.* Aemetis, Inc is constructing a commercial scale facility producing 12 million gallons of ethanol per year from waste agricultural biomass in Riverbank, CA. (Shaver, 2018).
- **Carbon storage:** *No.*Cellulosic ethanol derived from gas fermentation is a low-carbon fuel.
- **Technology readiness level:** *8.* Gas fermentation to produce ethanol is proven at a commercial scale, but not using woody biomass as a feedstock. Aemetis, Inc has successfully built and operated an integrated demonstration unit in California, and is constructing a full-scale facility in California operating on waste agricultural woody biomass (Aemetis, 2019).
- **Commercial readiness level:** *6.*A deep understanding of the target application and market (low-carbon fuels in California) has been achieved. However, we are not aware of any companies developing a facility in California that operates on forest woody biomass.
- **Feedstock use:** *Non-merchantable wood.* All lignocellulosic biomass, including forest and agricultural wastes, can be used.
- **International markets**: *Yes.* LanzaTech has developed several commercial gas fermentation facilities in international markets.
- **Potential market size:** *Large.* California currently consumes 1 billion gallons/yr of ethanol, which could be made from ~11 million BDT/yr biomass.
- **Research or analysis need:** *Medium.* JIWPI could perform market facilitation for gas fermentation processes operating on forest biomass.
- **Can JIWPI influence outcomes?** *High.* Should the Aemetis Riverbank facility be successful, JIWPI could commercialize this process using forest biomass. LanzaTech technology makes this more likely.

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PRODUCT: TRANSPORTATION FUELS VIA FAST PYROLYSIS AND HYDROPROCESSING

Product Description

Fast pyrolysis and upgrading is a thermochemical pathway that produces pyrolysis oil that can be upgraded via hydroprocessing into hydrocarbon-based transportation fuels.

This process includes fast pyrolysis of biomass at high temperatures, decomposing biomass feedstock into gas (syngas), solid (char), and liquid (pyrolysis oil) products. Pyrolysis oil is a viscous, oxygenated, and corrosive mixture of polymeric chemical compounds that has little immediate commercial value. Pyrolysis oil must be upgraded via a combination of hydrotreating and either hydrocracking or fluid catalytic cracking before high-value biobased hydrocarbons can be derived from it. Char can serve as a low-value coal substitute, soil amendment agent, or used for long-term carbon sequestration.

Existing Capacity

Kior represents a high-profile failure to commercialize transportation fuels production via fast pyrolysis of woody biomass. As noted above, catalyst deactivation at Kior's facility was blamed on very low levels of sulfur, chlorine and alkaline earth minerals that are present in even the cleanest of wood.

Lawrence Livermore National Laboratory, Sierra Pacific Industries (SPI), and Frontline Bionergy are in the process of testing a 50 ton per day autothermal pyrolysis unit operating on forest biomass at SPI's Camino mill in El Dorado County, CA (McCoy, 2018). The project is supported by the California Energy Commission.

Justification

Biobased hydrocarbons produced via fast pyrolysis and upgrading can be blended into fuels commonly known as "drop-in biofuels" due to their chemical similarity to petroleum-based fuels

such as gasoline and diesel. Indistinguishable from their petroleum-based counterparts, these biobased hydrocarbons can be used to create a variety of products that have heretofore been the sole domain of the petroleum industry. While several pathways within the biochemical and thermochemical routes exist for the production of biobased hydrocarbons, fast pyrolysis is an economically attractive option (Brown, 2013)(Anex, 2010).

Market Indicators

There is an active international market for low-carbon liquid fuels. California currently uses liquid hydrocarbon fuels in the vast majority of its nearly 30 million vehicles. Renewed commercial interest in these fuels has been driven, in part, by low-carbon fuels policy in the Western United States, including California's LCFS. The LCFS provides subsidies for low-carbon fuels derived from lignocellulosic biomass.

Barriers to product or process innovation and growth

Processes for upgrading pyrolysis oil require substantial quantities of hydrogen and existing analyses of the pyrolysis oil upgrading and refining processes highlight the impact that hydrogen procurement strategy has on the project's economic feasibility. Producers may encounter anticompetitive behavior or high prices for hydrogen, should upgrading occur at existing oil refineries.

The other primary barrier to growth of transportation fuels from forest biomass via fast pyrolysis and hydroprocessing is the lack of a demonstration facility operating on woody biomass feedstocks.

Research Gaps

See 'Barriers' above

Product Substitution

Transportation fuels produced by this process are a direct substitute for fossil-derived liquid transportation fuels, including gasoline and diesel. California is a large producer and consumer of petroleum, consuming over 15 billion gallons of gasoline in 2015.

Opportunities for JIWPI Influence

- Should the current pilot-scale facilities produce promising results, the JIWPI could undertake market formation activities, including policy, finance, or technology incubation.

MATRIX EXPLANATION

- **Minimum feedstock required:** *300,000 BDT/yr.* Prior process engineering studies have focused on a autothermal pyrolysis at the scale of 2000 tons biomass / day, producing 57 million gallons per year of transportation fuel (Brown, 2013).
- **Carbon storage:** *Yes.* Autothermal fast pyrolysis can produce recalcitrant biochar byproduct, contributing to carbon storage.
- **Technology readiness level:** *5.* Commercialization of fast pyrolysis using woody biomass faces technical issues with catalyst deactivation, as demonstrated by Kior. Work has begun to demonstrate pilot-scale prototype system in a relevant environment in California.
- **Commercial readiness level:** *5.* A deep understanding of the target application and market (low-carbon fuels in California) has been achieved. Lawrence Livermore National Laboratory, Sierra Pacific Industries (SPI), and Frontline Bionergy are in the process of testing a 50 ton per day autothermal pyrolysis unit operating on forest biomass at SPI's Camino mill in El Dorado County, CA.
- **Feedstock use:** *Non-merchantable wood.* All lignocellulosic biomass, including forest and agricultural wastes, can be used.
- **International markets:** *Yes.* There is an active international market for low-carbon liquid fuels.
- **Potential market size:** *Large.* California currently uses liquid hydrocarbon fuels in the vast majority of its nearly 30 million vehicles.
- **Research or analysis need:** *Medium.* JIWPI could perform market facilitation for bio-oil and hydrotreatment processes operating on forest biomass.
- **Can JIWPI influence outcomes?** *Medium.* Should existing pilot-scale facilities produce promising results, the JIWPI could undertake market formation activities.

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PRODUCT: LIGNOCELLULOSIC ETHANOL

Product Description

Ethanol derived from forest biomass is a second generation cellulosic biofuel that can be used as a transportation fuel. Production generally occurs in the following steps:

1. Size reduction and pretreatment to increase the porosity of biomass particles and to increase the accessibility of cellulose and other polysaccharides to enzymes
2. Hydrolysis to produce sugars, typically catalyzed by enzymes that can collectively hydrolyze cellulose and hemicellulose to free sugars
3. Fermentation of sugars to ethanol, typically by yeast

Several pioneer facilities producing ethanol from lignocellulosic agricultural residues with capacity >10 million gallons per year have been built over the last few years. These include facilities in both Kansas and Iowa (Carroll, 2009).

Existing Capacity

Currently, there are no commercial scale facilities producing bioethanol in California. The proposed Axens/Anderson project will utilize the existing infrastructure at the Anderson, Ca complex. The facility will be capable of processing 100,000 BDT of feedstock per year.

Justification

Cellulosic ethanol is a low-carbon liquid transportation fuel that can be produced from lignocellulosic biomass.

Market Indicators

There is an active international market for low-carbon liquid fuels. California currently uses liquid hydrocarbon fuels in the vast majority of its nearly 30 million vehicles. Renewed commercial interest in these fuels has been driven, in part, by low-carbon fuels policy in the Western United States, including California’s LCFS. The LCFS provides subsidies for low-carbon fuels derived from lignocellulosic biomass.

Barriers to product or process innovation and growth

Barriers to lignocellulosic ethanol production from agricultural biomass are primarily financial, rather than technical. A lack of commercially available processes for pretreatment and hydrolysis of woody biomass is also a large barrier, as explained below.

Research Gaps

As discussed above, woody biomass is more recalcitrant to microbial and enzymatic actions than non woody biomass. This is particularly true for softwood species (Zhu, 2010). Particular attention needs to be paid to (1) the effectiveness of pretreatment for complete wood cellulose saccharification and (2) the energy consumption for woody biomass pretreatment, in particular for wood-size reduction to the level for effective enzymatic saccharification.

Further, existing cellulosic biorefineries producing ethanol face economic barriers (Lynd, 2017). High capital costs are an impediment to the cost-competitiveness and replication of pioneer cellulosic biofuels facilities. For example, while the capital cost per annual gallon of capacity averages $13.81 / annual gallon for the first six commercial-scale lignocellulosic ethanol facilities; the corresponding value for corn ethanol plants is on the order of $2/gallon.

Product Substitution

Ethanol derived from biomass is a transportation fuel already consumed at large scale in the United States (>15 billion gallons / yr). It is primarily used in light-duty vehicles as a source of transportation energy, and fuel octane enhancement. California currently consumes 1 billion gallons/yr of ethanol, which could be made from ~11 million BDT/yr biomass.

Opportunities for JIWPI Influence

- Evaluation of whether ligno cellullosic ethanol processes developed for agricultural biomass are amenable to California softwood species. We do not expect that the JIWPI will undertake research into woody biomass pretreatment and conversion in the near-term.
- However, JIWPI could undertake market formation activities, as they could for other wood-derived fuels.

MATRIX EXPLANATION

- **Representative feedstock required:** *100,000 BDT/Year.* Axens and Anderson Biomass have proposed an ethanol facility that will consume 100,000 BDT / yr when operating at capacity in Anderson, CA
- **Carbon storage:** *No.* Cellulosic ethanol is a low-carbon transportation fuel.
- **Technology readiness level:** *8.*Several commercial scale facilities exist that process non-forest based woody biomass, such as corn stover. Research into conversion of woody biomass feedstock is still needed to support commercial-scale production.
- **Commercial readiness level:** *6.* A deep understanding of the target application and market (low-carbon fuels in California) has been achieved. Anderson and Axens are currently developing supply agreements, CEQA permitting, and front end engineering and design.
- **Feedstock use:** *Non-merchantable wood.* Limited technical studies (Fagernas et al,. 2015, Theapparat et al., 2018) cite the use of small-diameter woody biomass as suitable for production, but the majority utilize other sources of biomass.
- **International markets**: *Yes.* There is an active international market for low-carbon liquid fuels.
- **Potential market size:** *Large.* California currently consumes 1 billion gallons/yr of ethanol, which could be made from ~10 million BDT/yr biomass.
- **Research or analysis need:** *High.* Research into conversion of woody biomass feedstock is still needed to support commercial-scale production.

- **Can JIWPI influence outcomes?** *Low.*We do not expect that the JIWPI will undertake research into woody biomass conversion. However, JIWPI could undertake market formation activities, as they could for other wood-derived fuels.

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4.6 Nanomaterials

Overview of Cellulose Nanomaterials

Cellulose nanomaterials derived from wood demonstrate great potential for meeting the need for new, sustainable approaches and products. They have a variety of unique distinguishing properties—including high strength, high absorbency, low densities, and self- assembly properties—that makes them promising for an array of commercial applications (Agenda 2020 Technology Alliance, 2016).

A 2014 Forest Service-sponsored study estimates the annual market potential for high-volume applications in the United States at around 7 million tons (oven-dried basis) of cellulose nanomaterials per year, based on current markets that are most likely to be affected. The largest-volume uses in the United States for cellulose nanomaterials are projected to be in packaging, automotive applications, cement, and paper. In addition, cellulose nanomaterials are projected to be able to compete in numerous products in other existing and emerging markets (e.g., flexible electronics, photovoltaics, filters, viscosity modifiers, oil drilling fluids, and additive manufacturing). Global market potential is 35 million metric tons (Shatkin et al. 2014).

The very high strength of cellulose nanomaterials, together with low densities, allows for the development of a wide range of high-strength, lightweight composites. Likely areas of application include automotive body panels, aerospace interior materials, lightweight construction materials with thermal and acoustic barrier properties, and paper and paperboard packaging with lightweight and enhanced barrier performance.

Table 11. Commercial Applications for Cellulose Nanomaterials, based on (Andrews, 2012) (Agenda 2020 Technology Alliance, 2016)

High-volume applications	Low-volume applications	Novel & emerging applications
· Cement · Automotive body · Automotive interior · Packaging coatings · Paper coatings · Paper filler · Packaging filler · Replacement—plastic · packaging · Plastic film replacement · Hygiene and absorbent products · Textiles for clothing	· Wallboard facing · Insulation · Aerospace structure · Aerospace interiors · Aerogels for the oil and · gas industry · Paint—architectural · Paint—special purpose	· Sensors—medical, environmental, and industrial · Reinforcement fiber—construction · Water filtration · Air filtration · Viscosity modifiers · Purification · Cosmetics · Excipients · Organic LED · Flexible electronics · Photovoltaics · Recyclable electronics 3-D printing · Photonic films

Cellulose nanomaterials are the basis of the next three products we review: ultra-strong wood, transparent wood, and some kinds of wood insulation.

Production of cellulose nanomaterials typical involves the removal of lignin, which provides structural integrity to wood. As a result, production of high-value products derived from lignin could be co-located with cellulose nanomaterial manufacturing.

We do not review lignin valorization in detail due to its technical immaturity. However, we note that Stora Enso has recently made a $10 million EUR investment in a pilot facility to produce technical carbon used in energy storage technologies at their Sunila Mill in Finland (Stora Enso 2019). Readers interested in emerging technologies for lignin valorization are directed to a recent review article by Demuner and colleagues (Demuner 2019).

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PRODUCT: ULTRA-STRONG WOOD

Product Description

Ultra-strong wood is the result of combined chemical and mechanical treatment of wood. In 2018, Song et al. reported a simple and effective strategy to transform bulk natural wood directly into a high-performance structural material with a more than tenfold increase in strength, toughness and ballistic resistance and with greater dimensional stability.

This two-step process involves the partial removal of lignin and hemicellulose from the natural wood via a boiling process in an aqueous mixture of NaOH and Na_2SO_3 followed by hot-pressing, leading to the total collapse of cell walls and the complete densification of the natural wood with highly aligned cellulose nanofibres. This strategy has been demonstrated as "universally effective" for various species of wood. This processed wood has a specific strength higher than that of most structural metals and alloys, making it a low-cost, high-performance, lightweight alternative (Song et al. 2018).

Commercialization of ultra-strong wood is being led by Inventwood, LLC, under the trade name of MettleWood. Basswood ***(Tilia)***, oak *(Quercus)*, poplar *(Populus)*, western red cedar *(Thuja plicata)* and eastern white pine *(Pinus strobus)* were used for the fabrication of densified wood.

MATRIX EXPLANATION

- **Representative feedstock required:** *Unknown.*Process has not been demonstrated at commercial scale.
- **Carbon storage** *Yes.* Carbon storage through long-lived wood products.
- **Technology readiness level** *3.*Active R&D has been initiated, and technology concept has been formulated.
- **Commercial readiness level** *2.* Cursory familiarity with potential applications, markets, and existing competitive technologies/ products exists
- **Feedstock use** *Merchantable wood.* Inventwood LLC intends to use MettleWood for structural applications, which would likely require dimensional lumber.
- **International markets** *Unknown.*
- **Potential market size** *Unknown.*
- **Research or analysis need** *High.* A large amount of work will be required to commercialize these new products.
- **Can JIWPI influence outcomes?** *Low.* This product is likely too technologically and commercially immature to be the focus of JIWPI efforts at present.

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PRODUCT: TRANSPARENT WOOD

Product Description

Transparent wood composites have up to 90% transparency and high strength and durability. Transparent wood is prepared through two steps: 1) removal of lignin from wood (delignification), typically using acid and heat, and 2) additional of polymers to form a composite material. In 2016, Zhu first reported on production of transparent wood from small blocks (Zhu et al 2016). Similar methods have been developed for transparent films derived from wood (Ye et al 2019).

Development of transparent wood composites is still at a lab-scale and prototype level. Commercialization of transparent wood is being led by Inventwood, LLC.

MATRIX EXPLANATION

- **Representative feedstock required:** *Unknown.* Process has not been demonstrated at commercial scale.
- **Carbon storage** *Yes.* Carbon storage through long-lived wood products.
- **Technology readiness level** *3.* Active R&D has been initiated, and technology concept has been formulated.
- **Commercial readiness level** *2.* Cursory familiarity with potential applications, markets, and existing competitive technologies/ products exists.
- **Feedstock use** *Non-merchantable wood.* Transparent wood can be made from small blocks of wood, which is likely non-merchantable. Films can also be made from non-merchantable wood.
- **International markets** *Unknown.*
- **Potential market size** *Unknown.*
- **Research or analysis need** *High.* A large amount of work will be required to commercialize these new products.
- **Can JIWPI influence outcomes?** *Low.* This product is likely too technologically and commercially immature to be the focus of JIWPI efforts at present.

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PRODUCT: WOOD FIBER INSULATION BOARD

Product Description

Low-density fiberboard (LDF) made from wood can serve as an effective insulation for residential construction. Wood fiber insulation board has moderate insulating properties, is water-resistant, allows vapor transfer, and has low or no VOC emissions. Unlike traditional insulation materials, it does not cause irritation, is made from renewable materials, and has a low carbon footprint.

Wood fiber insulation board is manufactured primarily in Europe, by manufacturers including Gutex, STEICO, and Best Wood SCHNEIDER. GO Labs, based in Maine, is leading commercialization efforts in the United States (Turkel 2017).

LDF, however, may not provide performance necessary to meet California's stringent building codes and energy efficiency standards. Gutex has an R-value of 3.7 per inch. In the United States, it's common to see exterior walls sheathed in the pink, extruded polystyrene foam made by Owens Corning, which is rated at R-5 per inch, or rigid foam sheets from Dow Chemical, which boast an R-value of 6.5 per inch (Turkel 2017).

Advanced wood insulation, based on nanomaterials, are in active development (Li et al 2018). InventWood, for example, is developing anisotropic, lightweight, strong, and super thermally insulating nanowood. These products are less technically and commercially mature than their LDF counterparts. In additional to boards, nanomaterial foams are also being developed (Wicklein et al 2015).

JIWPI could undertake activities to develop highly thermally insulating wood insulation. They could also work with Bureau of Household Goods and Services in the California Department of Consumer Affairs to expedite licensing, and ensure that wood insulation meet's State insulation quality standards.

MATRIX EXPLANATION

- **Representative feedstock required:** *90,000 BDT/year.* GO Lab in developing a plat in Madison, ME to consume 180,000 green tons of wood chips / year (McCarthy, 2019)
- **Carbon storage** *Yes.* Carbon storage through long-lived wood products.
- **Technology readiness level** *8.* Low-density fiberboard is manufactured and sold in Europe by Gutex, STEICO, and Best Wood SCHNEIDER.
- **Commercial readiness level** *5.* While a deep understanding of the target application and market has been achieved, there are uncertainties about consumer adoption in California and the United States.
- **Feedstock use** *Non-merchantable wood.*
- **International markets** *Yes.* Robust markets exist in Germany.
- **Potential market size** *Unknown.*
- **Research or analysis need** *High*. Advanced wood insulation with higher performance would give wood-based products a competitive advantage in California.
- **Can JIWPI influence outcomes?** *Medium*. JIWPI can fund research or market development for highly thermally insulating products. They could also work with CA Bureau of Household Goods and Services on licensing. Nevertheless, performance enhancements must occur.

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PRODUCT: ACETYLATED WOOD

Product Description

The main target of applying chemical modifications onto wood is to alter the molecular structure of the cell wall polymers. This way, the cell wall of wood is in a permanently swollen situation and attracts no or very little moisture. At the same time, the chemically modified wood is not recognized by the degrading fungi, since the lower moisture content does not promote decay. Researchers have mostly studied the reaction of hydroxyls groups with acetic anhydride, a process that is called acetylation.

Numerous laboratories worldwide have tried to acetylate wood with a variety of ways. The first attempts, however, to commercialize the process was not successful in the USA (1961), Russia (1977) and Japan (1984). On the semi-industrial level, the first successful scaled-up acetylation was performed at Stichting Hout Research (the Netherlands), by Prof. Militz and coworkers. Today, acetylated wood is scaled-up in the Netherlands, under the commercial name Accoya, which utilizes radiata pine and alder wood with a 20% acetyl weight gain. Accoya wood undergoes a nontoxic acetylation process which modifies wood permanently. (Papadoupolous et al. 2019)

Photo by James Lee on Unsplash

MATRIX EXPLANATION

- **Representative feedstock required:** *7,000 BDT/year.* Accys Techonologies PLC reports their product output as 40,000 m^3/yr in 2016. (Accys Techonologies PLC, 2016)
- **Carbon storage** *Yes.* Carbon storage is achieved through medium- and long-lived wood products.
- **Technology readiness level** *8.* The technology has been proven to work in its final form and under expected conditions. However, it has not been deployed using California feedstocks.
- **Commercial readiness level** *5.* A deep understanding of the target application and market has been achieved in Europe. However, additional work is necessary to understand market conditions in California.
- **Feedstock use** *Merchantable and Non-merchantable wood.* Accoya sells primarily structural wood products made from merchantable wood. Tricoya sells medium density fiberboard (MDF) derived from chipped wood.
- **International markets** *Yes.* There are well-established European markets for these products.
- **Potential market size** *Medium.* The market for Accoya and Tricoya has been estimated as in excess of 2.5 million m3 annually, or nearly 450,000 BDT/yr (Accys Techonologies PLC, 2016).
- **Research or analysis need** *High.* Application of acetylation to California tree species has not been investigated in detail.
- **Can JIWPI influence outcomes?** *High.* JIWPI can investigate the suitability of this technology to California-based wood product manufacturing. If suitable, it can undertake market formation activities.

References

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PRODUCT: FURFURYLATED WOOD

Product Description

Chemical modification with furfuryl alcohol is known as furfurylation. Furfuryl alcohol is a liquid produced from agricultural wastes, such as sugar cane and corn cobs. Furfurylation is executed by impregnating wood with a mixture of furfuryl alcohol and catalysts and then heating it to cause polymerization. The purpose of furfurylation is to improve the resistance to biological degradation and dimensional stability by applying a nontoxic, proprietary, furfuryl alcohol polymer. The Norwegian company Kebony AS, applies the technology and produces two distinct products: (i) Kebony Clear, which is a hard furfurylated wood with a typical weight gain of 35%, and (ii) Kebony Character, a light furfurylated wood with a typical weight gain of 20% (Papadoupolous et al. 2019).

MATRIX EXPLANATION

- **Representative feedstock required:** *1,750 BDT/year*. Kebony AS reported 10,000 m^3/yr output from their facility in Norway in 2018 (Kebony 2018)
- **Carbon storage** *Yes.* Carbon storage is achieved through medium- and long-lived wood products.
- **Technology readiness level** *8.*The technology has been proven to work in its final form and under expected conditions. However, it has not been deployed using California feedstocks.
- **Commercial readiness level** *5.* A deep understanding of the target application and market has been achieved in Europe. However, additional work is necessary to understand market conditions in California.
- **Feedstock use** *Merchantable wood.* Kebony has focused on treatment of dimensional lumber.
- **International markets** *Yes.* There are well-established European markets for these products.
- **Potential market size** *Medium.* Market size for furfurylated wood is likely similar to that for acetylated wood.
- **Research or analysis need** *High.* Application of furfurylation to California tree species has not been investigated in detail.
- **Can JIWPI influence outcomes?** *High.* JIWPI can investigate the suitability of this technology to California-based wood product manufacturing. If suitable, it can undertake market formation activities.

References

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PRODUCT: THERMALLY MODIFIED WOOD

Product Description

Thermal modification is a process where wood is heated to high temperatures (170°C and above) in the absence of oxygen. The thermal modification process breaks down the hemicelluloses, which lose some of their hydroxyl (OH) groups so water is less able to attach to the wood. There is also a reduction of the chain lengths of the cellulose microfibrils. The moisture content of the wood is lower after modification and the wood is less responsive to moisture change, giving improved stability and durability. This process also breaks down some of these hemicelluloses, so the wood becomes darker in color (Dunning and Sargent, 2015).

Thermal modification processes can be applied to a wide range of wood species, but need to be optimized for each species (Navi & Sandberg 2012). The property improvements gained are highly dependent on process conditions, treatment intensity (temperature, duration), wood species and thickness of samples.

The most common commercial TMT, ThermoWood®, started in Finland and is licensed from there via the International ThermoWood Association, with many operations throughout Europe and a growing number outside Europe. For example, over the ten years from 2003 to 2013, ThermoWood® global production grew nearly 6 fold. Key applications in Europe have been cladding, decking and window joinery (ThermoWood Association, 2013).

There is one commercial facility producing thermally modified wood in California. Sunset Moulding in Chico, CA produces Pakari thermally modified wood for decking and exterior siding. Pakari is derived from Radiata Pine, also known as Monterey Pine. The natural range of Monterey pine is extremely limited. On the United States mainland it is confined to three localities on the central California, and is not harvested commercially. Radiata Pine processed in California is instead imported from abroad, notably New Zealand and Chile.

MATRIX EXPLANATION

- **Representative feedstock required:** *35,000- 1,750,000 ft^3/yr (420-21,000 BDT/yr) .* There is a range of commercially available ThermoWood® kilns, ranging in size from 2000-3000 m3/yr (small), 5,000-10,000 m3/yr (medium), and 10,000-15,000 m3/yr (large). There is also a continuous process available which has the capacity of 30,000-50,000 m3/yr (Dunningham and Sargent, 2015). In BDT/yr, the range is.

- **Carbon storage** *Yes.* Carbon storage is achieved through medium- and long-lived wood products.

- **Technology readiness level** *8.* The technology has been proven to work in its final form and under expected conditions. However, it has not been deployed using California feedstocks, as Radiata Pine is not grown in-state.

- **Commercial readiness level** *8.* Pakari thermally modified wood is produced and sold in California.

- **Feedstock use** *Merchantable wood.* Dimensional lumber is typically processed in thermal wood modification.

- **International markets** *Yes.* There are well-established European markets for these products.

- **Potential market size** *Medium.* Market size for thermally modified wood is likely similar to that for chemically modified wood.

- **Research or analysis need** *High.* Application of thermal modification to California tree species has not been investigated in detail. Radiata Pine is not harvested commercially in California.

- **Can JIWPI influence outcomes?** *High* JIWPI can investigate the suitability of this technology to California-based wood product manufacturing. If suitable, it can undertake market formation activities.

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4.8 Chemicals and extractives

Introduction

The Competitive Advantage for Woody Biomass: When considering alterative biomass feedstocks all companies recognize that while many feedstocks *could* be used as the feedstock for a particular process, after considering both capital and operating costs one feedstock will be preferred over others. This 'preference' may vary in different locations. For biomass there are generally four broad classes of non-food feedstocks, 1) crop residues, 2) dedicated perennial crops, 3) short rotation woody crops and 4) trees. All four classes of feedstocks are composed of cellulose, hemicellulose, lignin and extractives, albeit in different proportions. The arrangement of these four common biomass components, and their local costs determines their competitive advantage. It is clear that the lowest cost feedstock based on $/ODT is not always the preferred feedstock if its chemical properties are not a good match for the process or products being developed.

Biobased Chemicals and Extractives: When biomass is used for production of chemicals, extractives or fuels there is always a separation step (Cardona-Alzate et al., 2020). Separations are may be required

1) at the 'front end' to remove lignin and extractives from the cellulose and hemicellulose sugars, prior to the production of fermentable sugar, or the removal of ash prior to pyrolysis

2) in middle of the process such as the fractionation of liquid pyrolysis oil or the removal of 'contaminants' such as sulfur, chlorine, or higher hydrocarbons from a syngas stream, or

3) at the end of the process to isolate the target chemical in high purity.

Separations have implications for costs and environmental burdens associated with any chemical process. Separations are expensive, with both capital and operating costs. Tools such as Techoeconomic Assessments (TEA) and Life Cycle Analysis (LCA) are needed to understand the trade-offs between lower costs feedstocks, product yield and the environmental footprint of the overall process (Julio et al., 2016). The environmental burdens for separations can also be significant. All separations require power, and the most common separation technology, distillation, requires process heat. Separations also create waste streams that must be treated by incineration or in a wastewater treatment plant, emitting biogenic carbon.

Biobased chemicals are commonly envisioned as value-added, side streams produced at a large biorefinery. This follows the model of an oil refinery, which converts 80-90 % of the crude oil into a fuel product, and 10-20 % into value-added chemicals. As highlighted in the Biorefinery Inventory (Anon, 2017) even a modest-sized biorefinery, making a single product, will cost $150-200 million. Adding more complex chemical manufacturing will increase the capital costs significantly, but also create an opportunity for higher revenue and profits.

In a biorefinery, value-added chemicals can produced from many different routes, but four categories can be identified, 1) fermentable sugars to chemicals, 2) lignin to chemicals, 3) pyrolysis oil to chemicals, and 4) direct extractions of woody biomass to produce chemicals.

Fermentable Sugars to Chemicals - Product Description: Currently a number of commodity chemicals are made from corn or sugarcane derived sugars including butanol, lactic acid, xylitol and succinic acid (Lindorfer et al., 2019). All of these chemicals use sugars, preferably glucose, as a starting material, although in some cases xylose, mannose and galactose can also be used. All cases these commercial process require careful separation steps to remove unreacted materials or side products, which add significant capital and operating costs.

It is clear that low cost, clean sugars can be effectively used for production of biobased chemicals. Glucose from starch, primarily corn, or sugar cane, is a relatively clean, and low cost source of fermentable sugars (Reeb et al., 2015; Reeb et al., 2016). Non-food lignocellulosic biomass, in particular woody biomass, which may initially have lower costs ($/ODT), but in the case of fermentable sugars the pretreatment is complex and expensive, and has yet to be demonstrated commercially. Thus, the sugars derived from lignocellulosic biomass are more expensive than sugars from cornstarch. Softwoods are particularly challenging due to the details of the lignin structure that the make the pretreatment more complex, and soluble lignin residues that inhibit many of the subsequent processes.

Examples of current commercial products derived from corn-based fermentable sugars include

- Sugar to Polylactic acid – This product has been commercialized by Nature Works.
- Sugar to ethanol to ethylene to BioPolyethyene– Process is commercial in Brazil using sugarcane glucose (Anon, 2011)
- Glucose to butanol – Several large chemical companies have developed routes for fermenting glucose, from either cornstarch or sugarcane, into butanol (DOE EERE, 2020).

If low cost sugars from lignocellulosic biomass were available, these chemical production routes could be modified to use this new source of sugar.

Lignin to Chemicals - Product Description: Lignin has a long and challenging history of serving as a feedstock for production of value-added chemicals and polymers. The dominate process, Kraft pulping significantly modifies the structure of the lignin, which lowers its value for the vast majority of applications (Bajpai, 2018). In Kraft pulping valuable pulping chemicals are mixed with the lignin, and must be separated from the lignin stream and returned to the pulping process. Nonetheless, several processes for recovery of Kraft lignin have recently been commercialized (Valmet, 2015).

The complexities associated with deleterious changes in the lignin structure due to Kraft pulping has led to the concept of the 'Lignin First" biorefinery (Renders et al., 2019). This concept uses organic solvents to remove some or all the lignin, and then, depending on the process, uses additional chemical or enzymes to convert the carbohydrate fraction into high quality cellulose or low cost sugars. None of these processes have been demonstrated at more than the bench scale. It is important to note that all these schemes require large amounts of process heat for drying or solvent recovery.

There are a series of value-added products that are consistently evaluated for lignins isolated from different processes, including 1) fuels and power, 2) macromolecules, and 3) aromatic chemicals.

- Fuels and Power - Lignin can be directly pyrolized to produce liquid fuel intermediates
- Macromolecules - Lignin is currently used commercially as a low value additive for phenol formaldehyde resins and other polymers
- Aromatic Chemicals – Given the highly aromatic nature of lignin, production of aromatic chemicals such as benzene, toluene and xylene (BTX), or monomeric phenol and substituted phenols has attracted great interest.

Pyrolysis Oil to Chemicals - Product Description: There are a wide variety of different pyrolysis oil production processes, but all of them produce 'oxygenates' and 'aromatics' (Pires et al., 2019). The oxygenates can be used for wood vinegar, or food additives, while the aromatics can be used to make commodity chemicals. The intermediate pyrolysis oil is acidic and corrosive, and will solidify over a period of a few weeks, and is not a direct replacement for petroleum.

There are three common classes of chemical products derived from fast pyrolysis processes, 1) food and flavor additives, 2) aqueous products, known as wood vinegar or PLA, and 3) aromatic chemicals.

- Food and Flavor - Red Arrow, and its technology partner Ensyn, have been producing food and flavor additives for more than 25 years (Biofuels Digest, 2019).
- Wood vinegar is isolated from the same aqueous fraction of pyrolysis oil as liquid smoke and has been tested for uses in organic agriculture and horticulture. (Grewal et al., 2018).
- Aromatic chemicals - Benzene, toluene and xylene (BTX), or monomeric phenol are an obvious target for chemicals derived from pyrolysis oil.

Wood Extractives to Chemicals - Product Description: Wood extractives have been used in the US for production of chemicals for more than 200 years. Extractives derived from softwoods, in particular pines, continues to be a viable and profitable industry (Bhatia, 2016; Swift, 2011). The pulp and paper industry is the dominate route for producing pine chemicals. Worldwide production of pine chemicals exceeds 1.2 million tons, valued in excess of $4 billion (Ukkonen, 2016).

Virtually every pine pulp mill products crude pine chemicals that are easily recovered from the pulping process. Since the volumes of extractives is modest relative to pulp production, and the markets for the products are small and fragmented, most pulp mills sell the crude products to a pine chemical refiner. This pine chemical refiner aggregate the products from multiple mills, and combines them to create the volumes that can justify the capital infrastructure needed for the chemical modifications and refining of the pine extractives.

Existing capacity:

- **Sugars to Chemicals -** The Nature Works polylactic acid plant in Blair Nebraska has a reported production capacity of 150,000 tons per year (NatureWorks, 2007). The production of BioPE is reported in be in the tens of thousands of tons (Mohsenzadah, 2017). Production of biobutanol is reported to be 40,000 tonnes per year (RosalesCalderon and Arantes, 2019)
- **Lignin to Chemicals**: LignoBoost (Valmet, 2015) and variations of this process have been installed at five commercial pulp mills worldwide with a total installed capacity of 100,000 ODT per year.

- **Pyrolysis oil to Chemicals:** There are five to six small-scale commercial fast pyrolysis plants ranging in size between 25,000 and 84,000 ODT per yr. if they were operated continuously (PyroWiki, 2019). Red Arrow and Ensyn have been operating pyrolysis oil plants for more than 25 years (Biofuels Digest, 2019).

- **Pine Extractives to Chemicals:** Virtually every pine pulp mill products crude pine chemicals, since there are easily recovered in the pulping process, and their removal is required for production of high quality pulps. Worldwide production of pine chemicals exceeds 1.2 million tons, and is valued in excess of $4 billion. The Pinova plant in Brunswick GA, uses a unique organic solvents process to extractive pine chemicals from aged pine stumps.

Justification: One major reason for the interest in the production of value-added chemicals in a biorefinery is the potential to increase the overall profitability of the biorefinery. This is because fuels have a very low profit margin, even with price supports. There are promising examples of long-term, profitable operations producing chemicals from woody feedstocks, but all of these operations require large manufacturing infrastructure. California no longer has an operating pulp mill that could serve as an anchor for these types of biobased chemical products.

Market indicators: Judging market demand for these biobased products is complex. Most of them are more expensive to produce than their fossil based alternatives. However, there is a growing willingness of consumers to pay more for a 'sustainable' or 'green' product (Global News Wire, 2019). One recent study indicated that 2/3 of respondents consider sustainability when making a purchase, and 1/3 were willing to pay up to 25% more for a sustainable product. Other reports show similar trends (Curtin, 2018). A recent report from the McKinsey Group showed similar trends, and a surprising 80% were willing to pay a 5% premium for a sustainable product (Miremadi, et al., 2018).

Barriers to product or process innovation and growth: There are host of barriers, including a lack of policies that provide more reliable supply of feedstocks, new financial structures to de-risk first-of-a-kind processes, new concepts for small-scale integrated biorefinery processes, more demonstration of market performance and LCA tools that can be used to accurately measure the climate change impacts of these complex biochemical production systems from cradle to grave.

Research gaps: Given the wide variety of individual chemicals that can be made from biomass it is not possible to summarize all specific research gaps, but in general there is a need for improved technology for separations and catalysts, and concepts for small-scale integrated biorefinery processes (RosalesCalderon and Arantes, 2019; Bozell and Petersen, 2010, Lindorfer, et al., 2019).

Product Substitution: The vast majority of the biobased chemicals compete head-on with the identical molecule made from fossil fuels sources, and in the vast majority of cases, the fossil fuel based route is lower cost. Thus, there is a constant pressure on the biobased process to lower costs and reduce the 'biobased/green' premium.

Opportunities for JIWPI Influence: Low. JIWPI can help develop tools for measuring the environmental life cycle benefits, or costs, of different biobased chemicals, and may help develop public information literature to highlight the most promising materials. JIWPI does not have the resources to have an impact on the development of any specific commercial products.

Estimation of market size for chemicals and extractives

Estimating the amounts of woody biomass needed to supply the production of chemicals requires a series of steps, and assumptions on the yield for each step including,

1. the total volume of chemical products, which in this work is a combination of several different individual molecules, e.g., commodity chemicals such as benzene, toluene, xylene (BTX), and phenol, also alternatives such as methoxy phenols that can replace cresols, that are valued in the market,

2. the recovery of these chemicals at high purity, generally at 98-99% purity, from a complex intermediary reaction mixture. Again, using BTX and phenol, and also methoxy phenols as an example, these chemicals are present complex mixtures of monomeric and dimeric aromatics, along with other hydrocarbons, and must be isolated using a combination of solvent extractions and distillation,

3. the 'upgrading' of the original biomass intermediate, in this case pyrolysis oils, using an enzymatic or chemical catalyst. In the case of BTX and phenol, and methoxy phenols, the original pyrolysis oil will have an array of dimeric and oligomeric aromatic structures, that may be converted to valuable monomer with chemical catalysts, and
4. the yield of the original intermediate from woody biomass. This step is dependent on both the process, e.g., time, temperature, chemical treatments, and also the source of the biomass, hardwood vs. softwoods, or clean wood vs forest residues with high bark and ash contents.

In all four steps, there are a multitude of secondary technical details. The scale and potential co-location of the process will also impact the relationship between the volume of woody biomass needed to produce a specific chemical product.

Based on these considerations and complexities it is nonetheless useful to try and estimate the volumes of woody biomass that would be consumed in the production of chemicals. Table 12 shows these relationships, and highlights key assumptions on the yield at each step in the process. The yield of an individual chemical or intermediate can vary widely based on specific manufacturing processes.

Table 12. Estimation of feedstock demand for chemicals and extractives

Process and Chemical products	Final Chemical Product(s) (Tons/yr.)	Isolation of products from upgraded reaction mixture (Ton/yr.)	Yield from catalytic upgrading (Ton/yr.)	Crude reaction produce (Ton/yr.)	Woody biomass feedstock (ODT/yr. and Million BF/yr)
Biomass to sugars used to make PLA (based on Natureworks plant)	150,000	187,000 (80% recovery)	234,000 (80% average yield of lactic acid from monomeric sugar)	468,000 (50% average production of monomeric sugar from woody biomass)	940,000 tons of wood or 300 million BF
Biomass to sugars to butanol	131,000	145,000 (90% recovery)	441,000 (33% average yield of product from monomeric sugar)	551,000 (50% average production of monomeric sugar from woody biomass)	690,000 tons of wood or 220 million BF
Lignin isolated by fractionation without additional chemical modification	25,000 Used for additives to plastics, resins and surfactants	31,000 – 80% isolated from precipitation and filtration process	31,000 – no catalytic modification so 100% yield	156,000 – 20% yield of lignin from pulping process	625,000 tons No additional wood needed, only additional isolation capacity
BTX and phenol, cresol replacements (based on Kior biomass capacity)	17,000	21,000 - 80% recovery of target chemicals from crude, upgraded reaction mixture	26,300 – 50% production of target molecules from catalytic treatment of crude reaction product	52,500 – 20% yield of aromatic fraction from original biomass fractionation	175,000 tons of wood, or 56 million BF
Pine chemicals (Based on Pinova plant, GA)	1,570 pine chemicals	1,960 – 80% recovery of salable product from crude reaction mixtures	2,450 – 70% of crude pine extract that can be used for chemical production	3,500 – (5% pine chemicals from biomass)	70,000 tons of wood or 22 million BF

MATRIX EXPLANATION

- **Representative feedstock required:** All these chemical products rely on an initial ‘pretreatment, and softwood trees are not a preferred biomass for many of these pretreatments.
- **Carbon storage:** No. These chemicals will displace petrochemical derived chemicals, but a detailed life cycle analysis is needed to understand the carbon implications.
- **Technology readiness level:** 8-9. All these processes have commercial examples, but only a few, e.g., pine chemicals, LignoBoost, Red Arrow/Ensyn rely on woody biomass.
- **Commercial readiness level:** 7-8. All these processes have commercial examples, but replication is challenging.
- **Feedstock use:** Woody biomass can be used for these processes, but is not currently preferred for production of fermentable sugars.
- **International markets: Yes.** Interest in biobased chemicals is greater in international markets.
- **Potential market size:** Highly varied, and specific to the chemical. See estimation above.
- **Research or analysis need:** High. There needs to be improved processes for separation specific products, and catalysts for converting intermediates to products, and for life cycle tools for better understand the sustainability (cradle to grave) of these processes.
- **Can JIWPI influence outcomes?** Low. JIWPI does not have the resources to have an impact on the development of any specific commercial products. JIWPI could help develop tools for measuring the environmental life cycle benefits, or costs, of different biobased chemicals, and limit greenwashing. It could also help develop public literature to highlight the most promising materials, and increase public confidence.

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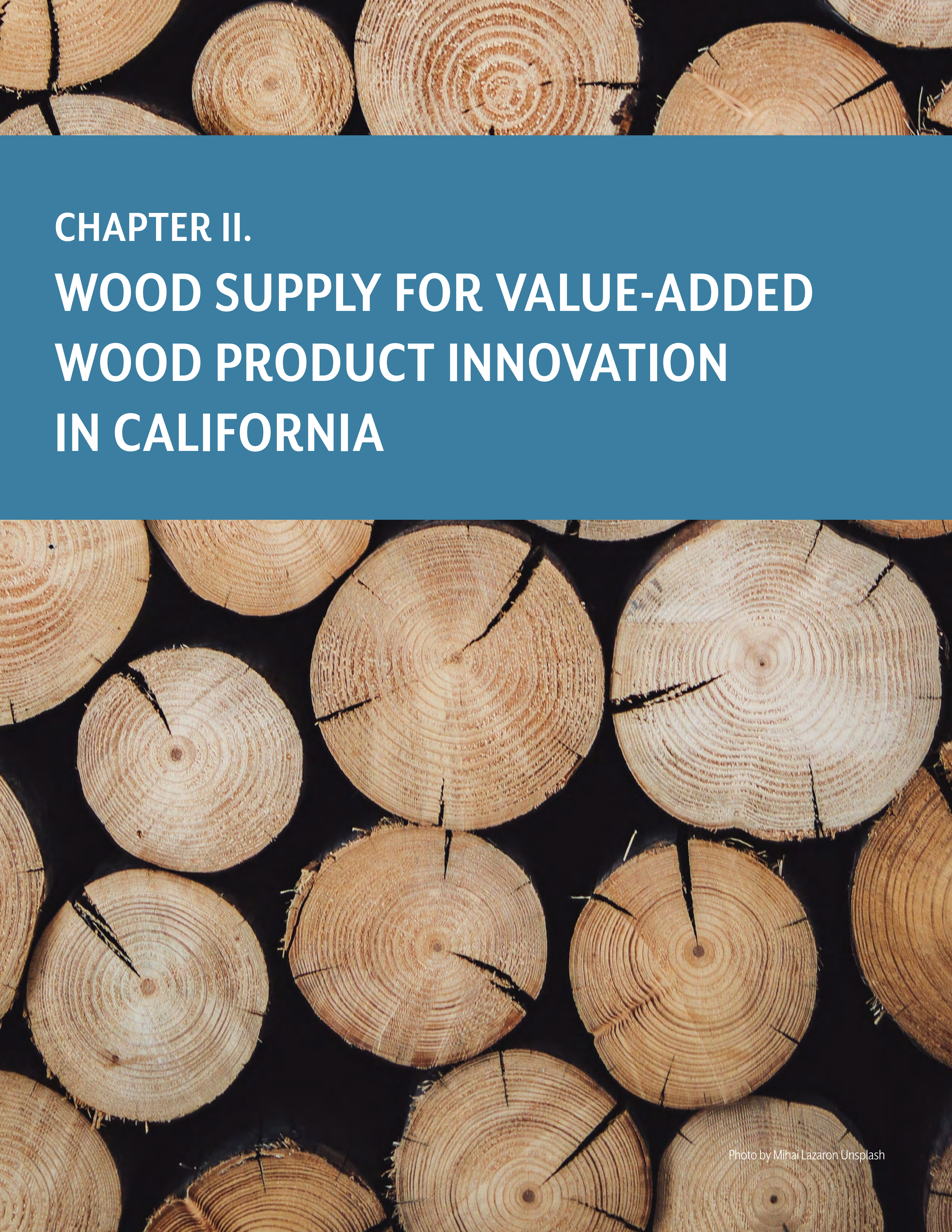
CHAPTER II.

WOOD SUPPLY FOR VALUE-ADDED WOOD PRODUCT INNOVATION IN CALIFORNIA



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1. SUMMARY

Information contained in chapter:

- Summary of supply-based barriers to innovative wood products
- Develops strategy that merges small-diameter forest fuels reduction with value-added innovative forest products
- Develops a California "bufferwood" concept, which encompasses hazard fuel removal and fire breaks within rights of way
- Analysis of wood supply data for 25 primarily-forested Tier 1 High Hazard Zone counties
- Exploration of the key elements of a proposed "bufferwood" initiative to ensure reliable wood supply from public and private lands

Methodologies:

- Literature review
- Geospatial analysis

Conclusions:

1. The following conditions impede efforts to develop and deploy mass timber and other innovative wood products in California
    - **a.** Lack of access to long-term wood supply
    - **b.** Dramatic supply variability from year to year (lack of consistency)
    - **c.** Lack of certainty to supply in high environmental risk acres
    - **d.** High cost to access lower-grade wood supply
    - **e.** Adaptability of both under-utilized and young growth species for use in innovative wood products, as separate from wood biomass to power generating facilities
    - **f.** Lack of primary processing infrastructure for non-energy wood products
    - **g.** Continued environmental pressures that limit harvest of fuel wood in forested High Hazard Zone (HHZ) countie
2. Over 50% of net cumulative sawtimber volume sold over the last decade by the Forest Service but not harvested through 2018 is housed (net cumulative of 180 mmbf out of 355 mmbf state-wide). This suggests availability of existing commercial sawlog volume already acquired by key California purchasers that could be made available for new wood product innovations in the State.
3. An additional average annual sawtimber supply of ~ 45 mmbf from both federal and private forestlands is conservatively projected between 2020-2024 compared to the last half decade, allowing for project development of many of the innovative wood products covered in this report without current market displacement
4. Based on an approximate 50-mile-radius from the center of a "bufferwood" working circle, eight circles could be supported. Projected overall traditional wood supplies within only four of the eight possible circles would be sufficient to accommodate a representative mass timber facility.
5. Analysis of new innovative forest products for California should address the use of red fir, white fir, ponderosa pine, and Jeffrey pine, as product supply to manage high tree mortality of these species in the Sierra Nevada range.

6. Infrastructure remains a major barrier to wood product. Two major infrastructure gaps emerge in the State:
    a. Adequate small diameter log processing, Kiln drying, which is necessary for existing CLT production standards

2. INTRODUCTION

This chapter focuses on the trends and projections of the state of wood feedstock supply in CA that could service new, value-added wood product innovation development. Numerous publications have targeted analysis on supply modeling assuming altered regulatory and legal restrictions limiting access to supply currently experienced in California (not covered in this report). Yet without failing, all publications (and business interviews undertaken for each publication) ultimately underscore seven reoccurring supply log jams to moving innovative wood product development forward[i, ii, iii, iv, v]:

1. Lack of access to long-term wood supply
2. Dramatic supply variability from year to year (lack of consistency)
3. Lack of certainty to supply in high environmental risk acres
4. High cost to access lower-grade wood supply
5. Adaptability of both under-utilized and young growth species for use in innovative value-added wood products as separate from wood biomass to power generating facilities.
6. Lack of primary processing infrastructure for non-energy wood products (especially small log processing and dry kiln infrastructure).

Continued environmental pressures that limit harvest of fuel wood in forested High Hazard Zone (HHZ) counties.

Notwithstanding the generally challenging and costly factors associated with establishing new manufacturing operations in California, the latest examination of published data does suggest unique opportunities to open access to currently underutilized sources of wood supply.

While CA continues to engage in important and urgent hazard forest fuels reduction activities, piecing together strategy that merges small-diameter forest fuels reduction with value-added innovative forest products development remains a challenge. Washington State and Alaska present examples of innovation and lessoned learned in this area:

Washington State's Vaagen Brothers Lumber has been the lead US adopter of small log processing (using HewSaw technology) for fuels reduction and restoration efforts. Now – as newly constructed Vaagen Timbers – the company will be making CLT panels specifically from small diameter (down to 4") forest restoration and fuels reduction thinnings effectively merging fuels reduction strategy with innovative engineered wood product development while working hand-in-hand with the State's environmental organizations.[vi]

Similarly, in the currently heavily-politicized and environmentally-targeted Tongass National Forest in Alaska, a somewhat similar connective transition strategy is underway. As background, Alaska is warming at 2.5 times the rate of all lower 48 states, and the Tongass NF experiences the highest levels of annual wildfires in the US: from 6.5 million acres burned in 2004 to 2.5 million acres burned in 2019.[vii] Between 1990 to 2019 (29 years) twelve of those years each recorded more than 1 million acres burned. As comparison, all acres burned in CA since 2013 totaled 1.8 million.[viii] A major transition to small diameter young growth harvesting away from old growth logging (leaving those for carbon stores) is underway with the help of the environmental community that proposed a "bufferwood" strategy similar to what is proposed for JIWPI consideration in California. Through an unusual partnership between the Alaska Region Natural Resources Defense Council (NRDC), Oregon-based GEOS Institute, and the USFS Pacific Northwest Forest Products Research Station, funding was provided to

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[i] Council of Western State Foresters; ***Mass Timber Market Analysis***; The Beck Group; November 2018
[ii] CalFire and California Tree Mortality Task Force; ***Dead Tree Utilization Assessment***; The Beck Group; May 2017
[iii] Lupien, Sandra; ***Removing Barriers to CLT Manufacture and Adoption in California***; 2018
[iv] The National Forest Foundation; ***California Assessment of Wood Business Innovation Opportunities and Markets***;The Beck Group; December 2015
[v] PG&E, High Hazard Fuel Study Committee; ***High Hazard Fuels Availability Study***; Mason, Bruce, and Gerard; The Beck Group; June 2019
[vi] Multiple C. Mater interviews with Duane and Russ Vaagen
[vii] August 2019; About 2.5 Million Acres in Alaska have burned. The State's Wildfire Seasons are getting worse, Experts Say; www.time.com/5657188/alaska-fires-long-climate-change
[viii] CalFire fire published reporting per county from 2013 through October 2019

research young growth forested acres throughout the Tongass within an 800' setback in 'suitable' (environmentally sensitive acres netted out) 'roaded' (currently open public roads) areas throughout forest industry supply working circles. The results detailed a small diameter young growth harvest volume potential (beginning 2020) that would combine forest fuels thinning efforts with conventional commercial logging to grow the forest products industry through a sustainably-managed annual harvested volume of between 50-75 mmbf log scale from federal forests alone (normal annual harvested volume over the last decade had been approximately 30 mmbf/yr). In Spring of 2019, the Forest Service initiated the young growth transition project[ix], with projected harvested volumes to be ramped up to between 50-75 mmbf by 2024 alongside investment in new small log processing technology. Forest timber cruise protocol was adapted to using 5" tops (rather than the normal 6" tops) to accommodate new small log processing technology.

3. PROPOSAL FOR BUFFERWOOD CONCEPT

A modified "bufferwood" concept, which encompasses ***hazard fuel removal and fire breaks within rights of way,*** is proposed for JIWI consideration in California, but with the following differing features:

A proposed 300' harvest setback from centerline of open, improved public roads on forest-designated lands to facilitate reduction of fire starts in roadside areas (where data shows some of the largest fires in the State started[x]) and where fuel breaks can be created.

This overall strategy could eventually be employed in 8 supply working circles in 25 forested counties (Figure 1) that house the highest volumes of hazardous forest fuels (designated by the state as 'Tier 1' acres), but initial focus is proposed for Northern California in 14 counties (Siskiyou, Shasta, Humboldt, Trinity, Mendocino, Tehama, Glenn, Colusa, Lake, Plumas, Butte, Sierra, Nevada, Yuba) where:

a) ... 55% each of smaller fires (less than 1,000 acres burned per event) and larger fires (more than 1,000 acres burned per event) have occurred in the State since 2013[x] (Figure 2).

b)... national forests in these counties house the largest amount of 'deadwood' acres in the state[xii] (Figure 3). According to 2019 USFS deadwood data,[xiii] over a half million (537,428) deadwood acres on national forests were removed from "deadwood acre" status between 2017 and 2018. Almost 8 million dead trees were harvested. Deadwood acres were reduced by 30% (from 1.7 million acres to 1.2 million acres) and dead trees across all national forests were reduced by 40% (from 19.1 million dead trees to 11.4 million dead trees). So the dynamics of fire priority areas from a national forest perspective changed significantly in a single year. Over 3 million dead trees were removed from the Sierra National Forest in 2018 (primarily red fir) followed by the Stanislaus NF with over 1.5 million trees removed (Ponderosa pine and white fir) and the Sequoia NF at 1.1 million removed dead trees (red fir, white fir, and ponderosa pine). The Shasta-Trinity NF led all 13 targeted national forests in bufferwood circles in removal of deadwood acres with a reduction of over 110,000 acres in 2018, followed by the Sierra NF at 91,000 acres and the Stanislaus NF at 84,000 acres. Conversely, in 2018 Six Rivers NF increased their number of dead trees by 20,000, followed by Mendocino NF at a 17,000, and the Modoc NF at a 10,000. More alarming, the Six Rivers NF and the Modoc NF both experienced dramatic increases in deadwood acres during the last year (160,000 acres and 370,000 acres respectively) affecting many counties in the northern part of the state.

c)... over 50% of net cumulative sawtimber volume sold over the last decade by the Forest Service but not harvested through 2018 is housed (net cumulative of 180 mmbf out of 355 mmbf state-wide)(Figure 4). Cumulative net carryovers in sold volume yet to be harvested on National Forests are typically in the 20 mmbf range, but starting between 2014 and 2016 the cumulative net volumes sold but not harvested in California have dramatically increased in five of the twelve national forests in bufferwood counties: the Klamath National Forest has a 73 mmbf sold but not harvested cumulative carryover as of the end of 2018; the Eldorado, Sierra, Stanislaus, and Modoc National Forests show cumulative net carryovers of 54 mmbf, 47 mmnf, 45 mmbf, and 32 mmbf, respectively through 2018. It is unclear why this notable rise in sold but not harvested volume exists (or how that happens within purchase

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[ix] Tongass National Forest presentation; Ketchikan Spruce Root Young Growth Summit; October 2019

[x] Fire origin reports from multiple articles and CalFire reports and C. Mater personal communication with CalFire officials.xi

[xi] CalFire fire published reporting per county from 2013 through October 2019

[xii] USFS Aerial Detection Survey, 2018

[xiii] ibid

contracts with set harvest date requirements), but nonetheless suggests availability of existing commercial sawlog volume already acquired by key California purchasers such as Sierra Pacific Industries, Siskiyou Cascade Resources, and Trinity River Lumber Company that could be made available for new wood product innovations in the State.

d)… 50% of total average annual increases of harvested sawlog volume from private forestlands in the state over the last five years has occurred[xv]

e)… the largest number of currently operating sawmills in the state are housed (18 out of 23), with at least 3 of those mills appearing to be operating below annual sawmill capacity (Figure 5)[xvi], and where the largest number of dry kiln operations exist.[xvii] Even so, the lack of dry kiln capacity throughout the state even in the Northern region is uniquely worrisome, as many mass timber and other engineered wood products have manufacturing specifications that not only require dried lumber in product development, but require moisture content levels to be below normal softwood lumber specifications. Lumber used in cross laminated timber production is an example, with PRG-320 specifications requiring lumber dried to 12% moisture content where normal softwood lumber is dried down to only 15% moisture content.

f)… over 45% of 2019 GIS-evaluated "bufferwood" forest acres in California (total of ~435,000 forested acres within 300' setbacks) are located, and where almost 35% of those Northern California "bufferwood" acres are USFS lands[xviii](Figure 6).

g)… a large portion of the State's significant forest slash piles are located[xix]

h)… an additional average annual sawtimber supply of ~ 47 mmbf in two working circles from both federal and private forestlands is conservatively projected between 2020-2024 compared to the last half decade (Figure 7), allowing for project development of many of the innovative wood products covered in this report (assuming market demand potential) without current market displacement. Future supply above current levels was calculated in each working circle after comparing average annual harvested volume in one half-decade (2009 through 2013) compared to the second half-decade (2014 through 2018). We conservatively estimated that the third half decade (2020-2024) would reach only 50% of the average annual increased volume harvested between the first half decade and the second half decade. As example, counties in working circle1 (Shasta and Siskiyou Counties) experienced an 11% increase in harvested volume off of private and national forestlands resulting in an average annual harvest volume increase of almost 42 million board feet between the first half decade and the second half decade. An 11% increase on 42 mmbf would result in average annual harvest volume of 47 mmbf for 2020-2024 with 50% of that increase conservatively projected (23 mmbf/yr). Only four of the eight working circles appear to be poised for supply increases at sufficient levels (more than 20 mmbf/yr) that would invite interest in investing in many of the innovative wood products covered in this report without disrupting current markets (Figure 8).

With respect to sawmill infrastructure concerns in bufferwood working circles, the lack of small log processing technology to process small diameter logs (from 3" tops to 10" large end diameters) needs to be highlighted. As noted in Figure 5, analysis of current sawmilling infrastructure in the bufferwood working circles shows that all currently operating mills in these working circles do not process below 6" tops with many stating preference for 9" tops.[xxi] Several equipment manufacturers offer curve-saw technology, but HewSaw technology seems to have captured the most investment choices in mills investing in fuel reduction/forest thinning efforts to reduce forest slash piles (photo to right taken in 2019 near Loyalton, California) tied to mass timber product manufacturing. HewSaw small diameter curve saw technology has been installed in 60 mills throughout North America and British Columbia. Almost 50% of installations are in Pacific Coast states and BC, with several of those installations at mills currently manufacturing cross-laminated timbers or mass plywood products using small-diameter, low-value softwoods for core applications (Freres Lumber in Oregon and Vaagen Timbers in Washington). Vaagen Timbers has stated an interest in working in California with a portable HewSaw processing unit to help address fuel reduction efforts throughout the state and ascertain future product development potential.

[xiv] USFS published Cut and Sold reports and Volume Distribution Reports; 2009 through 2018

[xv] Bureau of Business and Economic Research; California Timber Harvest by County for 2009 through 2018; Forest Industry Research Program; University of Montana

[xvi] UC Berkeley Forest Product Manufacturers Data Spreadsheets; 2019.

[xvii] 2019 Big Book; The Buyers and Sellers Directory of the Forest Products Industry; Random Lengths publications, Inc.

[xviii] Conservation Biology Institute 2019; C. Mater -directed GIS analysis of bufferwood acres; All GIS data available off DataBasin website; https://databasin.org/datasets/b6614ab4842f4641b64945c864c94e80

[xix] C. Mater personal communication with CalFire officials; 2019.

[xx] Bureau of Business and Economic Research; California Timber Harvest by County for 2009 through 2018; Forest Industry Research Program; University of Montana; CMater projections based on 2009-2013 average annual harvest volume by county compared to 2014-2018.

HewSaw small diameter curve saw technology produces ready-to-dry-and-plane lumber and wood chips from 3" to 10" diameter low-value (slash pile) logs in a single-pass in-line process that significantly increases lumber recovery (Figure 9). Specific mill testimonials[xxii] include:

A Phase 1 California "bufferwood" project focused on targeted Northern California counties could include but not be limited to:

1. GIS vegetation identification and layering in bufferwood acres in the targeted Northern California counties
2. GIS evaluation of 'suitable', roaded acres.
3. Added GIS layering of forest slash pile locations and, where available, characteristics
4. Determined impacts of harvested bufferwood with regard to fire breaks
5. Determination of small log volume assuming 5" tops
6. Possible bridging of bufferwood acres to currently targeted thinning and forest restoration acres
7. Evaluation of year-round bufferwood processing and roadside ready supply projections for both small log and woody biomass within working circles 1-4.
8. Demand analysis for roadside-ready supply within working circles.

[xxi] UC Berkeley Forest Product Manufacturers Data Spreadsheets; 2019.

[xxii] Personal interviews with Mater Engineering in May of 2000.

Table 13. Mills employing small diameter log processing technologies, such as HewSaw.

Sawmill Operation	Location	Curve saw brand	Direct mill comments
Longview Fiber	Washington	HewSaw	* recovery increased by 30%-40% * saws logs in lengths of 8' to 20' and down to 4" tops
Hampton-Willamina Lumber	Oregon	CAE/Nuenes	* recovery is up to 15% * saws logs in 17' lengths down to 4" tops * phenomenally efficient machine in all aspects
Tolko Forest Industries Ltd.	BC	HewSaw	* produces quality lumber from misshapen Lodgepole pine logs * company can now saw suppressed pine between 5" to 7" on butt down to 2.75" top * does not require log pre-sorting * processes 600 feet per minute * 2x3 lumber production has doubled since HewSaw's installation
Andrews Wood Products Ltd.	BC	HewSaw	* small log processing in Lodgepole pine * annual production is ~ 58 mmbf * processes from 2" to 7" in diameter * processing results in optimum strength and machinability characteristics with superior appearance preferred by Japanese customers
Repap BC	BC	HewSaw	* can surface chip, rip saw and edge wane boards in a distance of 3.2 feet * processes logs from 8' to 20' down to 3.5" tops * uses one of ten log sorts after scanning * runs at 335 feet per minute for lodgepole pine and 295 feet for hemlock
Vaagen Brothers	Washington BC	HewSaw	* processes logs down to 4.5" tops * annual capacity is 25-35 mmbf single shift (often does two shifts) * specifically focused on forest fuels thinnings in partnership with communities * now has portable HewSaw line to bring the mill to the forest in multiple states. Is targeting including California and Montana.

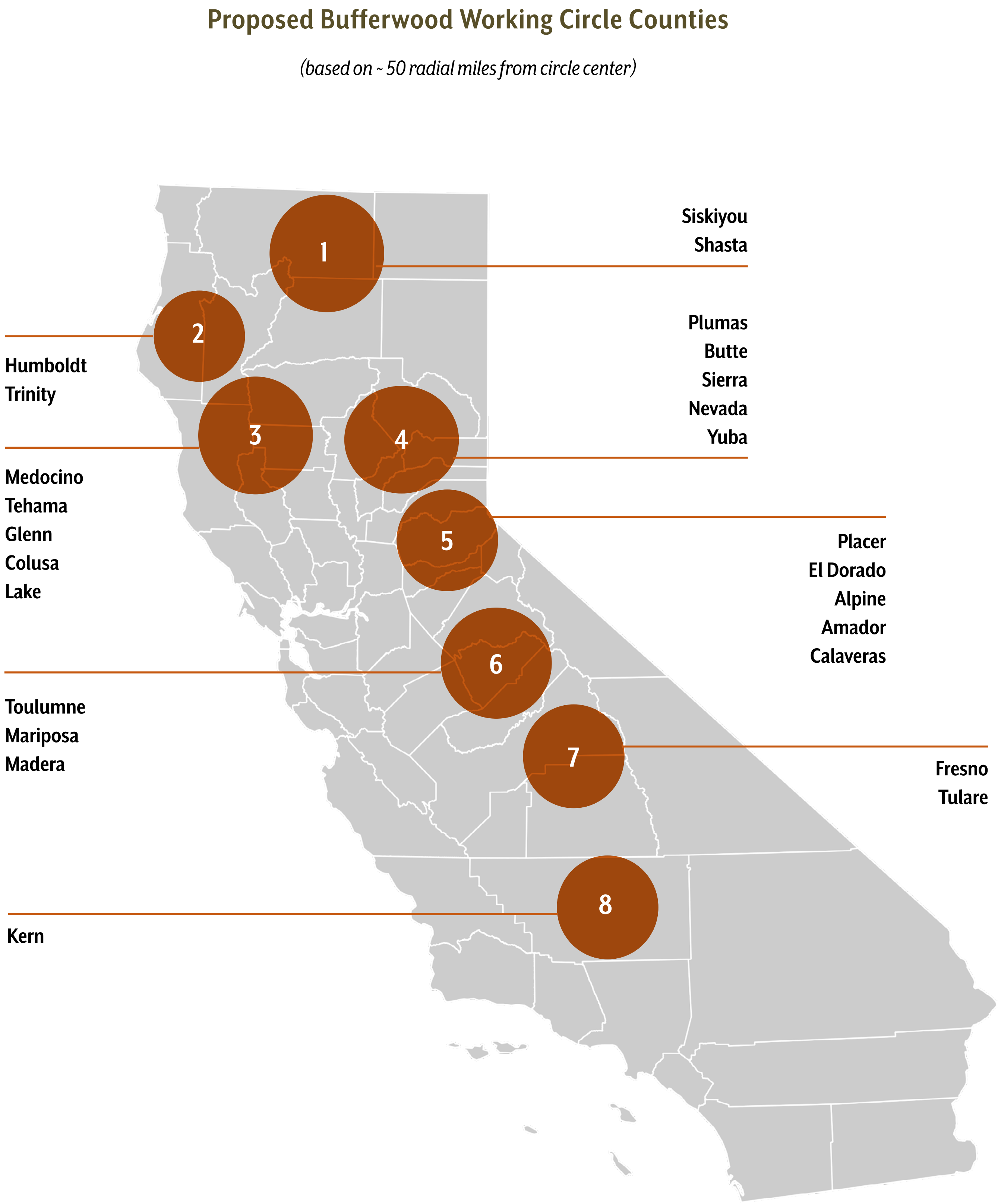


Figure 1. Proposed bufferwood working circle counties

725 Fires within California Bufferwood Counties from 2013 through October 2019:

Northern CA: working circles 1-4

Central CA: working circles 5-6

Southern CA: working circles 7-8

# of fires < 1k acres per occurence

	2013	'14	'15	'16	'17	'18	'19	Total	%
Northern Bufferwood (Counties)	33	23	37	41	77	63	51	325	55
Central Bufferwood	14	20	18	25	32	25	18	152	26
Southern Bufferwood	9	4	7	17	43	19	15	114	19

Total acres burned in: bufferwood counties: 166,590 ac non-bufferwood counties: 79,617 ac

Northern = 48% of burned acres

Central = 28% of burned acres

Southern = 24% of burned acres

# of fires > 1k acres per occurence

	2013	'14	'15	'16	'17	'18	'19	Total	%
Northern Bufferwood (Counties)	7	11	12	3	19	17	5	74	55
Central Bufferwood	4	6	2	2	5	4	2	25	18
Southern Bufferwood	3	3	2	9	16	1	1	35	26

Total acres burned in: bufferwood counties: 3,771,444 ac non-bufferwood counties: 1,845,931 ac

Northern = 67% of burned acres

Central = 20% of burned acres

Southern = 13% of burned acres

Figure 2. Fires within California bufferwood counties, 2013-October 2019

Mortality by species in “bufferwood” working circles

(2018 data)

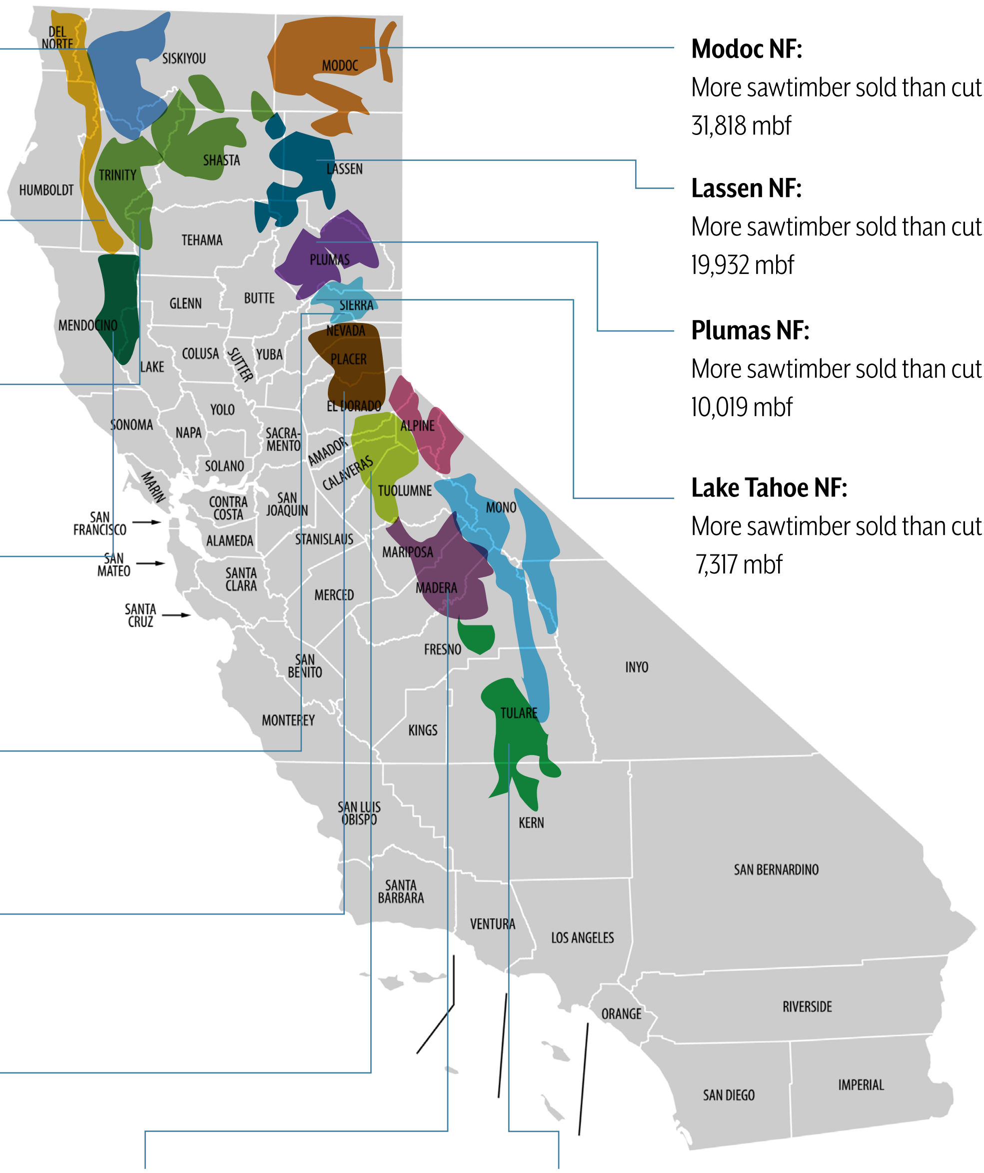
Based on mortality, key focus should be on product applications for red fir and white fir, and to a lesser extent ponderosa pine.

		Firs			Pines					
Working Circle	**Deadwood Acres 2018**	red	white	douglas	jeffrey	ponderosa	lodgepole	other	tan oak	National Forests
1	**321,314**	9%	65%	4%	13%	1%	4%	0%	3%	*Lassen, Shasta-Trinity, Six Rivers, Klamath*
2	**136,658**	10%	56%	9%	5%	12%	0%	1%	7%	*Mendocino, Shasta-Trinity, Six Rivers*
3	**216,481**	3%	78%	0%	3%	14%	1%	1%		*Lassen, Mendocino*
4	**414,684**	17%	71%		3%	8%	1%			*Lassen, Plumas, Lake Tahoe, Tahoe*
5	**178,877**	35%	58%		3%	3%	1%			*El Dorado, Lake Tahoe, Tahoe*
6	**421,552**	62%	22%		8%	6%	2%			*Sierra, Inyo, Stanislaus*
7	**390,737**	61%	17%		9%	5%	4%	4%		*Sierra, Inyo, Sequoia*
8	**141,625**	61%	16%		14%	6%	3%			*Sequoia*

Figure 3. Mortality by species in bufferwood working circles

Net cumulative Forest Service sawtimber volume (mbf) sold but not harvested over last decade as of 2018 in "bufferwood" counties.

(Total 10-yr cumulative sawtimber sold but not cut statewide = 355 mmbf)



Klamath NF:
More sawtimber sold than cut:
72,958 mbf

Rivers NF:
More sawtimber sold than cut:
26,094 mbf

Shasta-Trinity NF:
More sawtimber cut than sold:
-21,756 mbf

Mendocino NF:
More sawtimber sold than cut:
19,502 mbf

Tahoe NF:
More sawtimber sold than cut:
20,093 mbf

El Dorado NF:
More sawtimber sold than cut:
54,395 mbf

Modoc NF:
More sawtimber sold than cut:
31,818 mbf

Lassen NF:
More sawtimber sold than cut:
19,932 mbf

Plumas NF:
More sawtimber sold than cut:
10,019 mbf

Lake Tahoe NF:
More sawtimber sold than cut:
7,317 mbf

Stanislaus NF:
More sawtimber sold than cut:
45,195 mbf

Sierra NF:
More sawtimber sold than cut:
46,712 mbf

Sequoia NF:
More sawtimber sold than cut:
678 mbf

Figure 4. Cumulative Forest Service sawtimber sold but not harvested over last decade in bufferwood counties (as of 2018)

California Illustration by House1090 at English Wikipedia / CC BY-SA

Primary Production Sawmills in Operation in 2019:

- None process below 6” diameter logs
- Most appear to be producing at stated sawmill capacity

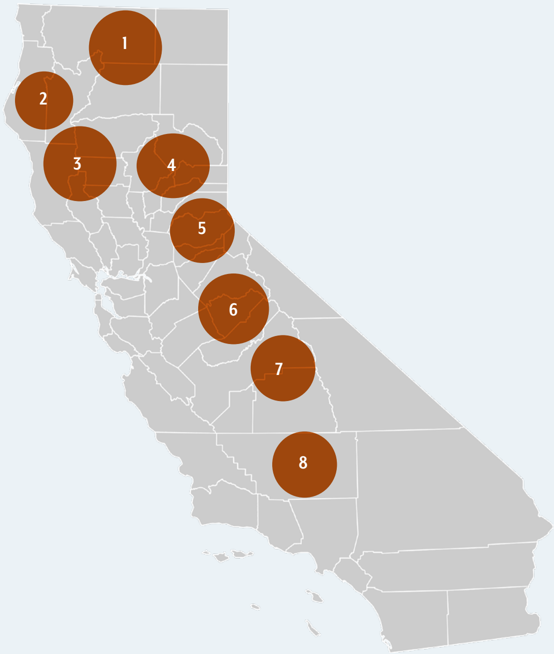


Figure 5. Primary production sawmills in operation in 2019

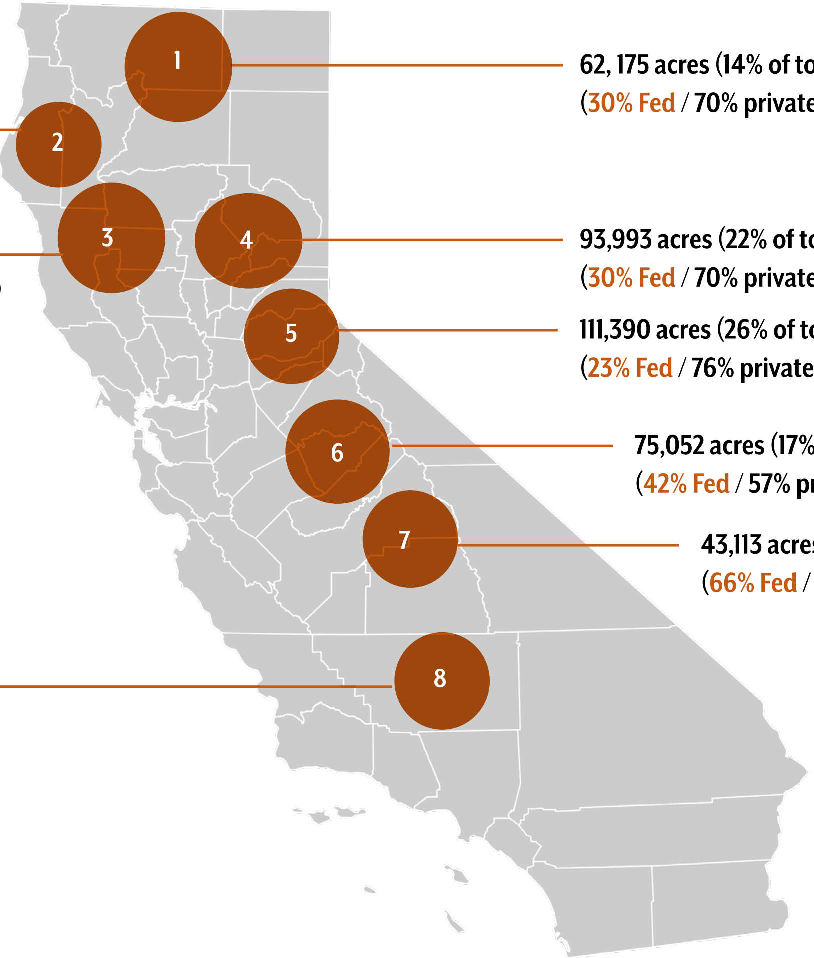
Working Circle	Company	City	Annual Production Appears at Capacity per Shift
1	Sierra Pacific	Anderson	yes
1	Shasta Green Sawmill	Burney	No
1	Sierra Pacific	Burney	yes
1	Sierra Pacific	Redding	yes
1	Alta California Roundwood	Anderson	yes
1	Roseburg Forest Products	Weed	yes
1	Timber Products	Yreka	yes
2	Schmidbauer Lumber	Eureka	No
2	Arcata Forest Products	Arcata	No
2	North Fork Lumber Co.	Korbel	yes
2	Humboldt Lumber Co	Humboldt	yes
2	Trinity Lumber Co	Weaverville	yes
3	Agwood Mill & Lumber	Ukiah	yes
3	Mendocino Forest Products	Ukiah	yes
4	Sierra Pacific	Oroville	yes
4	Apex Lumber	Oroville	yes
4	Collins Pine	Chester	yes
4	Sierra Pacific	Quincy	yes
5	Sierra Pacific	Lincoln	yes
5	California Hardwood Producers	Auburn	yes
6	Sierra Pacific	Chinese Camp	yes
6	Sierra Pacific	Sonora	yes
7	Sierra Forest Products	Terra Bella	yes

Bufferwood Acres by Working Circle

(2019 DataBasin GIS data)

Total acres = ~435,000 in 25 bufferwood counties

See DataBasin website
(www. DataBasin.org; click on data sets; click on Bufferwood: High Hazard Forests/Adjacent Roads



62, 175 acres (**14% of total**)
(**30% Fed** / **70% private**)

17, 722 acres (**4% of total**)
(**53% Fed** / **47% private**)

26,164 acres (**6% of total**)
(**34% Fed** / **65% private**)

93,993 acres (**22% of total**)
(**30% Fed** / **70% private**

111,390 acres (**26% of total**)
(**23% Fed** / **76% private**)

75,052 acres (**17% of total**)
(**42% Fed** / **57% private**)

43,113 acres (**10% of total**)
(**66% Fed** / **30% private**)

7,410 acres (**2% of total**)
(**46% Fed** / **52% private**)

Figure 6. Bufferwood acres by working circle

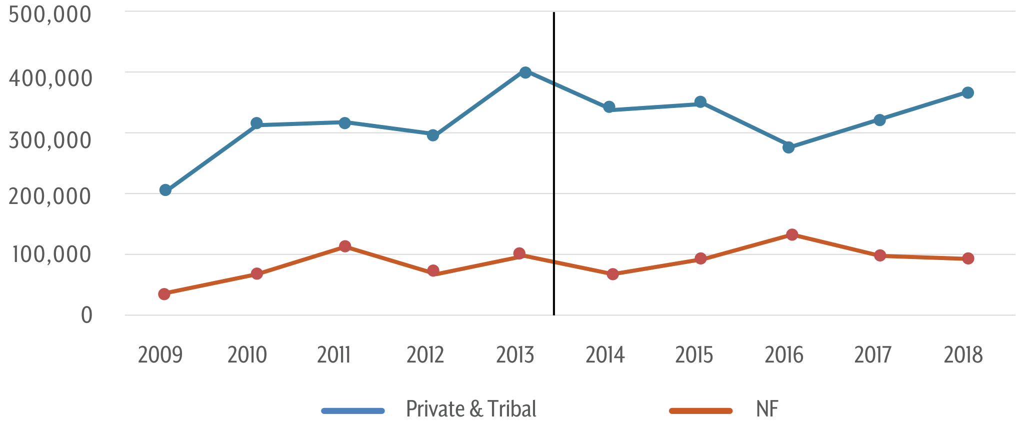
Bufferwood *Acres* by Working Circle Regions

Northern Region (working circles 1 thru 4):	68,000 federal
	132,000 private
Central Region (working circles 5 and 6):	57,000 federal
	129,000 private
Southern Region (working circles 7 and 8):	32,000 federal
	51,000 private

Best bets in Northern California "bufferwood" working circles for added future timber supply:

Working Circle 1: Timber harvest variability

(Siskiyou, Shasta Counties)



Private/Tribal: increase of avg annual harvest of 22,152 mbf

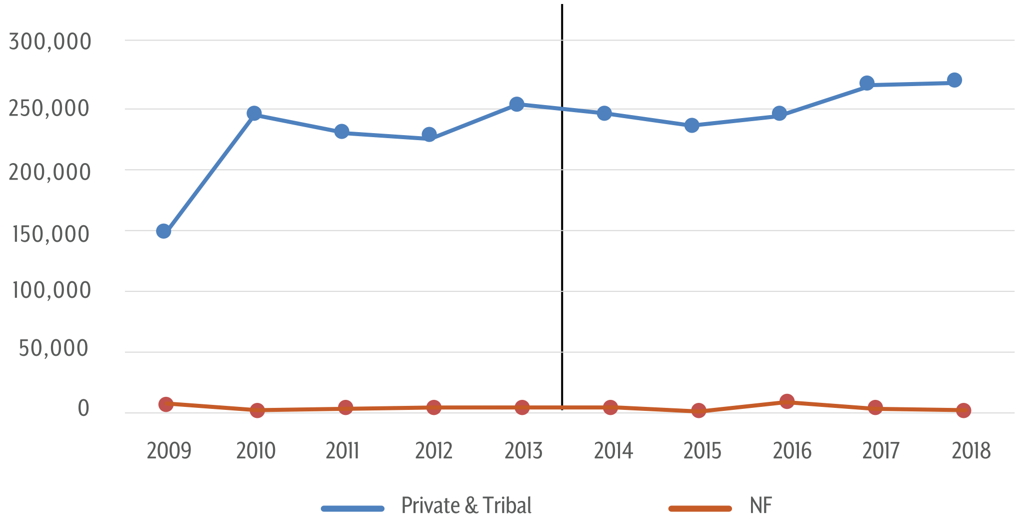
National Forests: Lassen, Shasta-Trinity, Six Rivers
increase of avg annual harvest of 19,839 mbf

Total avg annual increase:
41,990 mbf (+11%)

Projected 2020-2024:
+ 23 mmbf/yr

Working Circle 2: Timber harvest variability

(Humboldt, Trinity Counties)



Private/Tribal: increase of avg annual harvest of 41,170 mbf

National Forests: Mendocino, Shasta-Trinity, Six Rivers
decrease of avg annual 463 mbf

Total avg annual increase:
40,708 mbf (+16%)

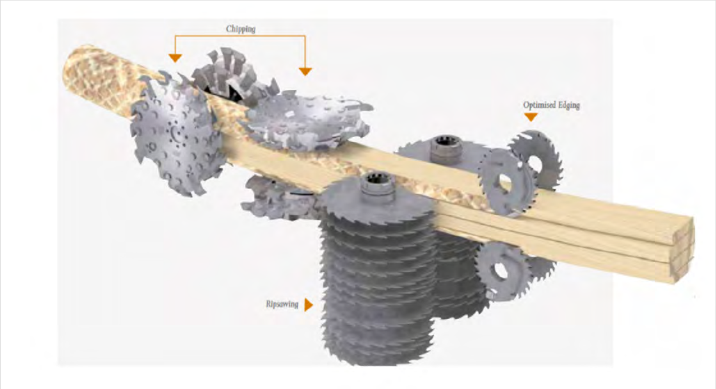
Projected 2020-2024:
+ 24 mmbf/yr

Figure 7. Categorization of most promising Northern California bufferwood working circles for additional future timber supply

Product Area	Product Type	BDT/yr	mbf/yr	Bufferwood working circles that could independently accommodate development	Working circles projected added average annual volumes in 2020-2024 over current volumes *(no current market displacement)*
Mass timber	Cross laminated timber	75,000	25,000	1,2,5,6	(approximate) Working circle # 1 = + 23 mmbf Working circle # 2 = + 24 mmbf Working circle # 3 = + 7 mmbf Working circle # 4 = + 3 mmbf Working circle # 5 = + 54 mmbf Working circle # 6 = + 48 mmbf Working circle # 7 = + 18 mmbf Working circle # 8 = 0 mmbf
other EWP	LVL	108,000	36,000	5,6	
	PSL	108,000	36,000	5,6	
	Glulam	160,000	53,000	5	
Pyrolysis: Non-energy	Pyro-ligneous acid	35,000	11,200	1,2,5,6,7	
	Biochar	150,000	48,000	5,6	
	Activated carbon	150,000	48,000	5,6	
Pyrolysis: Solid & gaseous fuels	Biocoal/torrefied wood	149,000	48,000	5,6	
	Renewable natural gas	250,000	80,000	none	
	Renewable hydrogen	45,000	14,000	1,2,5,6,7	
Liquid fuels	Fischer-Tropsch Fuels	68,000	22,000	1,2,5,6	
	Gas fermentation	300,000	96,000	none	
	Lignocellulosic ethanol	100,000	32,000	5,6	
Nanomaterials	wood fiber insulation board	90,000	29,000	5,6	
Chemically-treated wood	Acetylated wood	7,000	2,000	all working circles	
	Furfurylated wood	1,700	0.544	all working circles	

Figure 8. Supply and demand comparison for innovative wood products manufacturing in bufferwood working circles

Curve saw visualization in processing small diameter logs and location of competitors and/or potential partners



HewSaw small diameter curve saw technology has been installed in 60 mills throughout North America and British Columbia. Almost 50% of installations are in Pacific Coast states and BC, with several of those installations at mills currently manufacturung cross-laminated timber or mass timber products using small-diameter, low-value softwoods for core applications (Freres Lumber in Oregon and Vaagen Timbers in Washington). Vaagen Timbers has stated an interest in working in California with a portable HewSaw processing unit to help address fuel reduction efforts throughout the state and ascertain future product development potential.

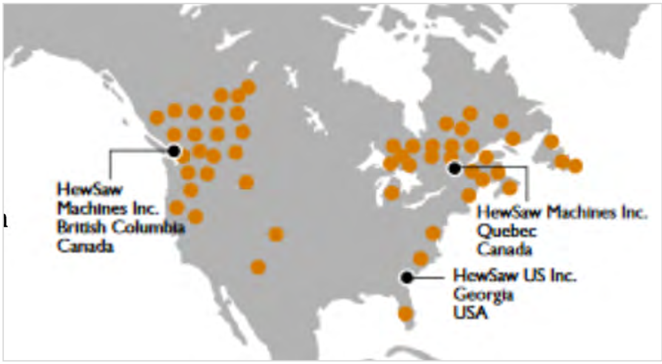


Figure 9. Small diameter curve-saw (HewSaw) installations across North America.

HewSaw small diameter curve saw technology produces ready-to-dry-and-plane lumber <u>and</u> wood chips from 3" to 10" diameter low-value (slash pile) logs in a single-pass in-line process that significantly increases lumber recovery (according to direct interviews with mill owners).

CHAPTER III.

STRATEGIC PARTNERSHIP LANDSCAPE, GAPS, AND RECOMMENDATIONS

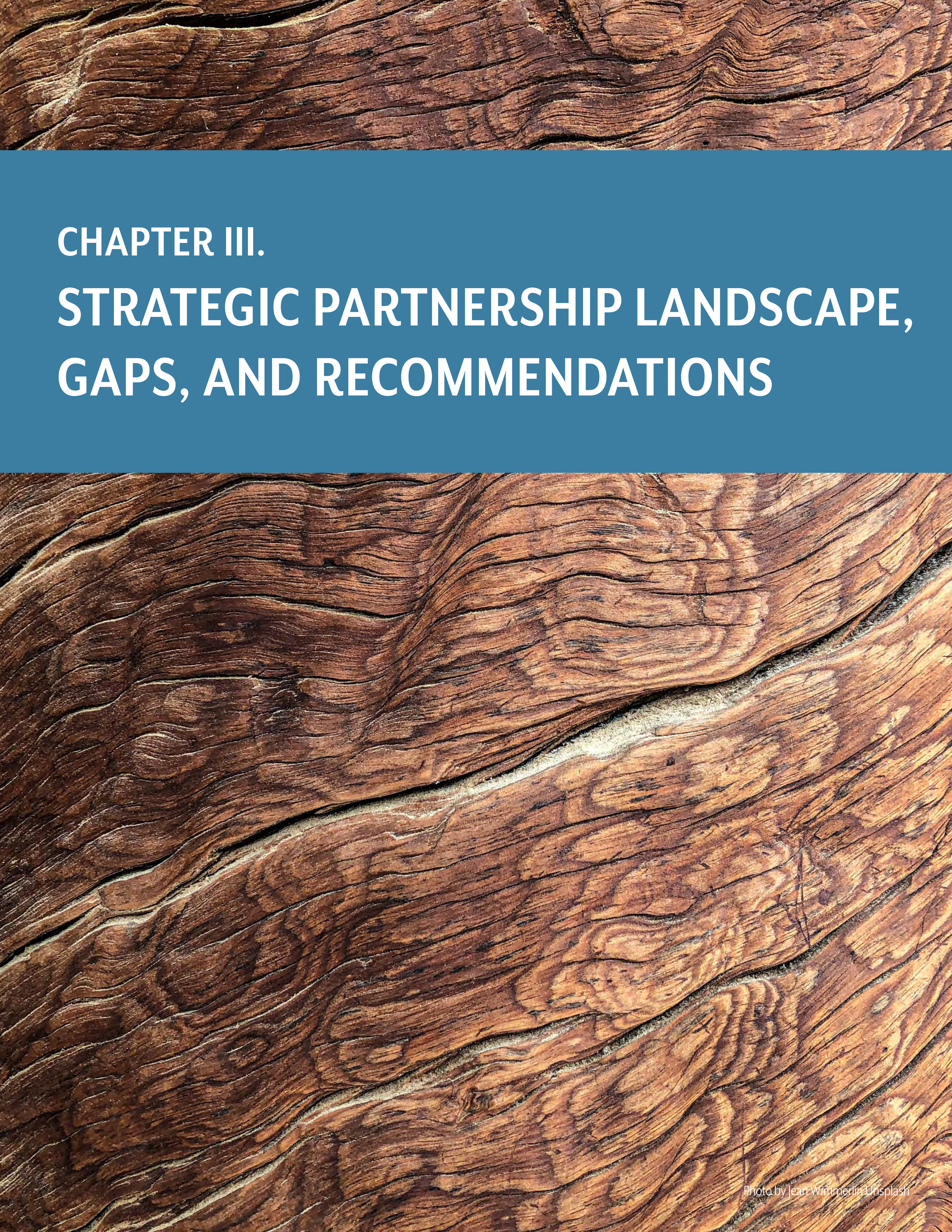


Photo by Jean Wimmerlin Unsplash

1. SUMMARY

Information contained in chapter:

1. Summary: *"Pathways forward for the Institute"* provides non-mutually exclusive approaches and partnership options for the Institute.
2. Gaps and Challenges: *"Key programmatic focus areas for the Institute"* describes some of the barriers to innovative wood products which the Institute may most directly impact.
3. Strategic Opportunities: *"What is possible today"* breaks out which partnership types and which partners directly map to each supply chain challenge and provides recommended means of engagement.

Methodologies:

1. **Literature Review and Research Gap Analysis:** to (a) identify opportunities and calls to action specifically addressable by the Institute, (b) highlight effective partnership models to consider replicating, and (c) build a well-curated wood innovation library.
2. **Interviews:** Over 50 organizations were interviewed across six key stakeholder categories.
3. **Workshops:** In mid-September, the Institute helped coordinate and facilitate a workshop in Truckee and Loyalton, CA, which gathered policy makers, public agency leadership, investors, and philanthropists to discuss the viability of a 'campus-style' wood processing facility in Sierra County.

Conclusions:

1. Innovative wood products hold the potential to drive numerous benefits in California. Development and deployment of innovative wood products can help the State of California increase the pace and scale of forest management and restoration efforts, build local capacity, strengthen regional collaboration, support innovation, and promote carbon storage in long-lived wood products.
2. The structure of the Institute provides a valuable opportunity for cross-sector partnerships among industry, philanthropy, policy, government agencies, tribal communities and inter-tribal councils, and academia.
3. Areas of focus for the Institute may include:
    - a. <u>Supply</u>: Identify solutions to achieve predictable, long-term, economical supplies of sustainably harvested forest fiber that promote California's healthy forest initiatives;
    - b. <u>Demand</u>: Identify policies and processes that establish a conducive environment for wood processors and increase end-market demand;
    - c. <u>Funding and Financing</u>: Identify public and private funds to support mass timber and innovative wood business capital requirements and ongoing operations; and
    - d. <u>Economic Development</u>: Incubate mass timber and innovative forest wood product technologies and support rural socio-economic and environmental outcomes.
4. Near-term areas of focus
    - a. Conduct applied research and analysis, and
    - b. Advance collaborative action.

    c. Programmatic focus areas
        i. Identify actions and policies that attract investment capital and expand markets for innovative wood products;
        ii. Training and education;
        iii. Stewarding innovative financing to attract private capital;
        iv. Improving stakeholder engagement and effectiveness through convening activities; and
        v. Public Education

5. Longer-term areas of focus (3-5 years)
    a. Encourage entrepreneurship and business development

Related Appendices:

(Appendix A) Organizations interviewed

(Appendix B) Domestic and international academic centers of excellence in wood product innovation

(Appendix C) Forest Futures gathering back-casting worksheet and workshop results and report-outs

2. PATHWAYS FORWARD FOR THE INSTITUTE

The structure of the Institute provides a valuable opportunity for cross-sector partnership among industry, philanthropy, policy, government agencies, tribal communities and inter-tribal councils, and academia. The Institute[xxiii] was established by Executive Order B-52-18 on May 10, 2018, to “perform wood products research, development, and testing; and to accelerate research, development, and adoption of advanced forest management and wood products manufacturing [in California].”[i]

Table 14. Activities mandated by the Joint Institute for Wood Products Innovation Charter

Priority Activities as mandated by the Charter			
Review existing analyses *of barriers and opportunities to forest product innovation and expansion.*	***Identify gaps*** *in knowledge and* ***meet with stakeholders*** *to fill gaps and identify market opportunities of specific interest to those actively pursuing market innovation and expansion.*	***Coordinate applied research projects*** *responsive to the recommendations of the Wood Utilization Working Group and/or Institute Advisory Council.*	***Develop a business incubator*** *for wood products that is coordinated with local chambers of commerce, counties, and community business incubators and leaders.*
Additional Activities as mandated by the Charter			
Conduct market research *to identify existing and emerging wood products.*	***Share market research*** *findings with “others interested in expanding innovative wood product markets.”*	***Conduct research and develop strategies*** *to reduce barriers to innovative wood products.*	***Identify new technologies to improve economic viability*** *of sustainable forest management practices and ecosystem restoration.*
Determine potential markets *with “sufficient scale and timelines” that “offer substantive assistance to reduce hazardous fuels and improve forest health in California.”*	***Provide education and outreach*** *to affected entities, interested parties, the public, media, and policy makers on forest products, innovative wood use, and the work of the Institute.*	***Initiate local, State, and federal policy design*** *for wood innovation and expanded utilization of forest biomass.*	***Identify and evaluate relevant standards*** *–implemented and operational, national, and international–for wood product innovation initiatives “as appropriate.”*

The Institute combines broad reach and skills: academic expertise, significant stakeholder networks, and, as a State entity, substantial convening power. The enabling factors for California wood innovation markets are similarly cross-sectoral and interdisciplinary in nature. Consequently, recommendations for the Institute's partnerships and programmatic structures focus on outreach, engagement, and collaborative action coupled with cross-campus and cross-discipline applied research and analysis. We identify four primary wood innovation market barriers in California: supply insecurity, insufficient demand, lack of financing and investment, and lack of effective innovative business development support in rural communities. Therefore, we recommend the following areas of focus for the Institute:

- **Supply:** Identify solutions to achieve predictable, long-term, economical supplies of sustainably harvested wood fiber that promote California's healthy forest initiatives.
- **Demand:** Identify policies and processes that establish a conducive operational environment for wood processors and increase end-market demand to pay for these facilities.
- **Funding and Financing:** Identify public and private funds to support innovative wood business capital requirements and ongoing operations.
- **Economic Development:** Incubate innovative forest wood product technologies and support rural socio-economic and environmental outcomes.

Table 15. Recommended Institute programs – a logic model and methodology for prioritizing individual projects and scopes

	Recommended Strategic Partnership Structures for the Joint Institute
CORE	**Conduct applied research and analysis:** Conduct applied research and translate findings into action – such as product layups and concise research synopses.
	Advance collaborative activities: Steward collaboration, demonstrate technologies, and advance policy solutions. (Select critical barriers best addressed through collective action and, assemble small cross-sector cohorts of decision makers within relevant stakeholder groups, identify shared priorities/outcomes and steward action).
ASPIRATIONAL	**Help to produce a pipeline of entrepreneurs, engineers, skilled laborers, designers, and architects:** Connect wood innovation projects and technical teams within schools across the State and throughout the West with existing incubators and accelerators in California.

Table 16. Strategic partnership recommendations for core and aspirational foci.

Table: Summary of core recommended strategic partnerships
(further examples and recommendations are discussed in section 4.3)

Applied research and analysis:

- **Tallwood Design Institute (TDI):** Development of an applied research and analysis partnership to undertake mutually agreed upon collaborative projects of value across arid forested regions, relying on the unique resources and skills of each partner to effectively engage manufacturing, design and harvesting industries across regions with research findings.
- **Oregon Wood Innovation Center, TDI, Wisconsin Forest Products Laboratory (FPL):** Development of a regional consortia of wood innovation centers to share research and project priorities and to mutually address challenges and opportunities in regional and national markets; each partner to focus their research contributions on encouraging markets in their priority regions.
- **WoodWorks:** Support WoodWorks in developing new and deepening existing partnerships between Woodworks and California community college (CCC) system, California state schools, and the University of California system to encourage the use of WoodWorks curricula and train-the-trainer programs in CA where of value. Develop distribution partnership whereby JIWPI research and analysis is shared through WoodWorks industry networks and CA-based opportunities are highlighted.

Engaging stakeholders to turn research into action:

- **Pacific Coast Collaborative (Collaborative):** Amplify findings through Collaborative's events & publications and provide the Collaborative with a source of cutting-edge CA-focused research to meet it's mandate.
- **Public agencies and existing industry collaboratives:** On a project by project basis, find the right partners to engage early in the project in order to effectively address cross-sector audiences, and to distribute and amplify findings most effectively through existing networks, conferences, and gatherings. Several examples are provided in section 4.3.

Encouraging workforce development, entrepreneurship and business growth: 5+ year horizon, aspirational

- **UCANR and the VINE Program:** Partner to develop a business incubator model within VINE focused on wood innovation in rural California, building upon their existing agriculture-focused rural incubators; the Joint Institute will develop the business priorities within this market, provide technical expertise to entrepreneurs, and assemble and inform additional entities to accelerate, advocate and grow these small rural businesses—such as Elemental Accelerator, among others.

Table 17. Lessons from existing wood innovation centres. Summary table based on discussions with: Oregon Wood Innovation Center, Tallwood Design Institute, WoodWorks, University of British Columbia, USDA Forest Product Laboratory, and the Washington State Composite Materials & Engineering Center.

Table: Brief overview of lessons learned from wood innovation centers
What are your most successful programs and strategies?
Industry outreach: Woodworks, Washington State University (WSU), TDI and UBC Advanced Wood Processing Center (UBC) all cited a specific, intentional focus on industry outreach, specifically: · Operating as networking hubs, providing connections & relationships among stakeholders. · Consistently seeking new ways to engage industry in their work. · Providing free insight into the regulatory and technical landscape of wood innovation markets. · Aggregating, summarizing & sharing national & global market info to curated industry networks. · Gathering industry insight on challenges and key areas for innovation to inform research priorities. · Providing creative policy recommendations and sharing industry insight with advocacy partners.
Public education, targeted stakeholder education and public database management: · Aggregating and distributing information—to the public and to key interested parties specifically—in language that translates to a variety of audiences from contractors to manufacturers to design to academia. The Oregon Forestry Industry Directive & the USFS Forest Products Laboratory Library are two examples of public and online databases intended to democratize information into what are otherwise often highly relational and opaque markets for investors, or smaller businesses.
Clearly defined objective to assist in prioritizing myriad projects: · Adhering to an over-arching approach or program strategy to guide decision making on project priorities. TDI, USFS FPL and WSU all noted challenges confronted in the past resulting from efforts to 'boil the ocean' rather than focus on a single, focused outcome.
What's challenging / what hasn't worked:
It's challenging to effectively in California: · WoodWorks cited challenges in offering existing training programs in California and concern that these will be duplicated, costing unnecessary time and money. TDI noted similar challenges in providing education programs or conducting industry outreach in CA. USFS FPL noted the need to offer small businesses, entrepreneurs & investors a known resource for CA market insights – specifically noting tech companies with an interest in water and carbon benefits of wood markets.

Table: Brief overview of lessons learned from wood innovation centers

There is no effective platform to coordinate across wood innovation centers

- OSU, WSU, TDI, UBC, USFS FPL and Woodworks all note the need to decrease duplication, share insights, and access one another's programs (where relevant). Clarifying across centers what research is taking place & where technical expertise is needed would increase the value of each research investment. OWIC noted the need for a "consortia or clustering strategy" to assist in this.

Additional opportunities this suggests for the Institute:

- **Focus on a specific, measurable outcome.** For instance, increasing net carbon storage in the state through wood product innovation in line with the CA Forest Carbon Plan.
- **Operate as a center for expertise & insight on California markets.** For instance, aggregate and distribute market lay-ups, publicize findings on technology innovations of particular relevance to CA, share expertise on California markets among existing networks.
- **Facilitate the establishment of a multi-region cooperative.** In tandem with partner centers, convene and develop an applied research and analysis cooperative to pursue collaborative projects that benefit the entire arid western region and decrease duplication of efforts among centers.
- **Network industry and stakeholders across regions to encourage mutual growth**. Collaborate with other wood innovation centers to identify the right stakeholders across design, manufacturing, construction, academia and more to encourage mutual learning and mutual growth.

3.0 KEY PROGRAMMATIC FOCUS AREAS FOR THE INSTITUTE

This section highlights critical challenges in increasing the pace and scale of forest restoration in California through wood innovation markets that are most addressable by the Institute.

3.1 Identify actions and policies that attract investment capital and expand markets for innovative wood products

Conservatively, the cost estimate for the landscape-scale restoration needed across public and private forested landscapes in California[ii] is about $10 billion over the next 10 years.[iii] Even with SB 901 set to provide $200 million annually for forest health and fire prevention,[iv] total public funds fall short of the estimated annual billion dollars needed to achieve meaningful progress. Increased market demand for by-products of sustainable forest management activities could defray costs and increase the pace of restoration. The primary challenge is not a lack of private capital, but creating the conditions under which capital will invest in opportunities that represent a reasonable probability of earning a risk-adjusted return, if executed and managed prudently.

To be successful, California must simultaneously address several key issues: ensuring access to long term feedstock supply; reducing transportation and forest access costs; reducing regulatory barriers to permitting innovate wood products - including renewable biofuels, increasing the market demand for these products. Raising awareness among stakeholders of these challenges and building support for a range of solutions is as important to achieving success as supply and capital-oriented support.

Public Funding Mechanisms

There are many paths which may contribute towards the state's climate, forest health, and economic goals. For example, Gov. Gavin Newsom recently introduced plans to include a $1 billion revolving loan program in his new budget to seed recycling, low-carbon transportation and climate-smart agriculture projects to better encourage small players with ideas to address the climate crisis. The Climate Catalyst Revolving Loan Fund, which would grow over four years, would offer low-interest lending to small businesses and organizations that have green ideas but may not be established or connected enough to compete for venture capital funding.

The following represent actions that state could pursue related to public funding:

Ensure State bond measures include forest restoration and wood product infrastructure investment. There are bond measures in the next legislative cycle directing capital to forest restoration. Communicating the importance of including wood product infrastructure investment, including bioenergy and biofuels, with the appropriate agencies and legislators is key. To reach current forest resilience goals, the state needs to employ all available funding tools, improve existing funding mechanisms[xxiv] and explore new financing models.

Develop long-term funding mechanisms and reduce transaction costs to access existing funding. Currently, almost all funding for forest wood product working capital is episodic, siloed, and project based.[xxv] Public funding for wood product markets needs to be more integrated across agencies and more focused on long-term initiatives, valuing avoided cost and public benefit of large-scale restoration and multi-stakeholder collaboration. Agencies need to consider opportunities to make grant application processes more affordable and less time consuming. Fortunately, discussions are underway to streamline access to relevant funding. There is broad recognition for the need to develop an easily navigable, well-maintained database of innovative wood market funding opportunities. There are also emerging discussions about the development of a revolving forest restoration loan fund in California, some of which could be accessible to wood product markets. Each of these efforts should be followed and informed by the Institute.

Restructure and improve the efficacy of transportation funding for forest restoration. The cost of road and rail transportation, further impacted by increases in the cost of low-Sulphur diesel represents a significant impediment to forest wood innovation market growth. California truck drivers paid an average of $.750 more per gallon of California No 2 Diesel Ultra Low Sulfur (0-15 ppm) than their competitors in nearby other states in 2019.[v] Conducting an economic analysis on the cost and benefit of various transport funding opportunities could prove beneficial to increasing the pace of forest restoration and resiliency, including subsidies,[xxvi] taxes, BioRAM reforms,[xxvi] and more. Findings could help inform the following:

- Policies which enable small business operators to transition to lower-impact machinery or new ownership structures - such as equipment lend-lease programs or exemptions from weight limits on logging trucks;
- Subsidies which decrease over distance – rewarding low-carbon transportation and decreasing competition across existing biomass and mass timber facilities;
- Programs which enable innovation in forest material transport. For example, incentivizing creative partnerships with private sector alternative energy or electric vehicle companies to develop closed-loop energy systems with onsite bioenergy fuels harvesting operations; and
- Policies which enable rail expansion to scale wood transport and connect mountain and coastal regions.

Provide information to State agencies on the versatility of existing public funding mechanisms. The scope of work for this report identified three concerns to existing forest restoration funding mechanisms in California. Those agency personnel tasked with allocating funds:

(a) do not necessarily fully understand proposed projects with complex, innovative financing concepts and are limited by the bureaucratic process in reaching out to gain a clearer understanding;

(b) do not fully understand the flexibility of the funding they are allocating and, therefore, fail to allocate it in ways that are most effective; and

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[xxiv] For example, bond measures provide the overwhelming majority of funding for forest restoration work in California (California Land Conservation Summit, Tahoe Conservancy and Sierra Business Council, 2019). Bonds are expensive for the state and require political buy-in and legislative process. This is not ideal for the ongoing and reliable capital needed to address forest restoration at scale in the state.

[xxv] A list of funds including data outlining the type of policy from which each fund stems can be found here: https://tahoe.ca.gov/wp-content/uploads/sites/257/2019/10/California-Land-Conservation-Summit-Papers-1-3.pdf

(c) often prioritize 'grey' infrastructure projects over restorative 'green infrastructure' projects. This suggests there is a need for education and training in conservation finance and the flexibility and opportunities within existing State funding.

The USDA Environmental Markets & Conservation Finance Program has tools available to educate individuals within federal and state agencies on innovative financing for sustainable land management.[vi] Utilizing and improving these tools to target California-specific concerns and provide training across relevant agencies would be worthwhile in helping to maximize the value of each State grant dollar spent on wood innovation markets.

Identify success metrics and reward systems for public land management that tie to the Forest Carbon Plan. State forest policy and planning has little direct impact on public land management, especially within the U.S. Forest Service. Redefining how we measure and reward progress and success in public land management would help incentivize restoration outcome

3.2. Training and education

Discussions with harvesting operations, small log processing mills, biomass power plants, community colleges, dimensional lumber mills, the California Department of Forestry and Fire Protection (CAL FIRE), and the US Forest Service indicate a lack of skilled workforce as a significant challenge. This gap is corroborated by State surveys and existing wood innovation market literature.[vii] The Institute may help address this gap by facilitating increased collaboration across disciplines, campuses, and academic systems in the State to streamline offerings and access to training and degree programs.

California produces one fifth of university graduates in the nation,[viii] yet it does not capitalize on the economic and workforce opportunities for wood innovation markets. California has some of the strongest basic and applied research facilities in the nation, such as the UC San Diego Shake Table,[ix] Humboldt State University Wildland Fire Laboratory and Rangeland Resource Center, California Polytechnic State University (Cal Poly) at San Luis Obispo Natural Resources and Environmental Science program and Fire Protection Engineering Master's Program, and others. California also has an extensive statewide community college (CCC) system, offering training and certification in heavy equipment operation, harvesting, contracting, and landscape management. Yet there are significant human capital gaps across the supply chain for forest wood innovation markets. Additionally, continual budget cuts to California's academic systems exacerbate competition for resources, further challenging the cross-campus curricula collaboration necessary to secure a trained forest wood-based innovation workforce.

- Industry representatives note that 'go-to' academic institutions for technical and market expertise are currently primarily located outside California, resulting in minimal perspective provided on California markets.
- In other California industries, there are partnerships between commercial companies and academic institutions through which companies provide funding for labs or degrees, collaborate with the academics on specific research questions and projects, and then hire directly from those labs and degrees on a regular basis.[xxviii] This does not exist for the timber and wood innovation industries in California. Rather, industry and academic collaborations are project based and individually motivated by an academic expert or company.
- There is minimal collaboration across academic systems within the State. Cross-campus collaborations are limited and do not specifically target forest restoration or wood markets. Rural forested regions have the greatest need for skilled workforce for heavy equipment operation, harvesting, transportation, and milling, yet, they have the least access to training, innovation, and funding.
- California universities should recruit and retain faculty members with expertise in wood products at engineering and architecture programs. Most universities do not have full time faculty with interest and expertise in wood products. Positions, programs, courses should be created to ensure that professional programs that graduate engineers and architects involved in specifying wood products have sufficient knowledge and comfort level to do so.

California has significant untapped opportunity to partner with out-of-state academic and industry expertise. Many organizations, from WoodWorks to the TallWood Design Institute to the labs at Washington State University,[xxxi] expressed interest in developing a platform to share curricula and expertise in service of kick-starting West-wide wood innovation markets.[xxxii]

The Institute could serve as the facilitator of such a partnership, bringing stakeholders together to structure collaborations, design the needs and outcomes, and implement the program. Such an interstate partnership would enable California students and workers to access state-of-the-art programs throughout the West . For example, the TallWood Design Institute is introducing a certification for Computer Numerical Control programming skills. While the labor pool for this training is too small to warrant such a program in California, the State could make this certification opportunity known and available to California students through partnerships. Similarly, University of Oregon will be offering interdisciplinary master degree in mass timber in 2021. This is also an opportunity to educate professionals in effective use of innovative wood products.

Additionally, seasonal foresters may serve as a recruitment pipeline for a forest products industry.

3.3 Stewarding innovative financing to attract private capital

Monetizing the public benefit of forest restoration would stimulate wood innovation markets. In 2018, California spent $947 million on fire suppression and emergency response, far exceeding the budgeted $450 million and prompting Governor Newsom to issue a statewide State of Emergency.[xi] The estimated cost of restoration efforts is likely to exceed $1 billion annually for the next 10 years.[xii] This is well beyond the capacity of the State to address without private investment as well as political and regulatory efforts to monetize sustainable forest restoration and resiliency public benefits. Other impacts and costs unaccounted for include uninsured losses, diminished property values, closed businesses, lost wages and tourism dollars, lost property and sales tax revenues, water cleanup, health care costs due to smoke (locally and in places far from fire sites), destruction of recreational and cultural amenities, wildlife loss, and the loss of potential carbon sequestration opportunities. Detailed examination of these externalities is essential to understanding the full value of forest resiliency and lack of it.

Demonstrated scale and reliable return across the forest products innovation sectors in California will help inform investors. Forest product industries in bordering states offer more desirable investment opportunities than California; consequently, most non-concessionary[xxxiii] asset managers don't see the value in the risk (and due diligence costs) associated with investing in California.[xiii] Those few investment opportunities which do exist in the State are generally individual and project based, with limited or no opportunity to scale. For investors, the risk-to-capital ratio is untenable, with high capital costs and significant financial risk. At present, most private finance in California's forest product sector is in the form of venture capital investments in individual businesses and concessionary capital (ranging from Community Development Financial Institution dollars to pure grants to program-related investments to impact investments) focused on specific projects in specific regions with the goal of creating models for future innovative finance models.[xxxv] In short, private finance currently has little ability to affect restoration at a scale proportionate to the challenge.

Blended finance[xxxvi] investment opportunities that aggregate capital across different risks and returns are needed. A new financial product in an emerging field is subject to a substantial development cycle. The sources of investment typically must extend beyond institutional capital, which rarely assumes early stage development risk and must include development capital from philanthropic and public sources. This requires a cohort of committed investors and funds, collaboration with regulatory agencies, and a financial vehicle which provides a variety of risk reduction tools, guarantees, debt service options, credit lines, and/or loan-loss guarantees. It would be of value to have a central clearing house or an individual, who keeps track of all innovative funding concepts which leverage private finance and helps to prioritize or sequence these for policy makers and state agencies – making it clear which opportunities to pursue and with how much time and energy. The Institute can play a role in aggregating emerging financing ideas and providing concise research briefs and recommendations to key stakeholders in wood innovation markets.

[xxiv] Any new transportation subsidy would have to be at least equal to resulting GHG emissions reductions – and it likely be a subsidy which decreases over distance – establishing the best parameters for this would be valuable policy guidance.

[xxv] BioRAM policies were intended to make a dent in this challenge but may need to expand the definition of qualifying fuels and to incentivize biomass materials to go to the closest facilities. Following these reforms, it will take more legislative endeavors like the BioRAM sealed bid auction process to bring more biomass power plants that are currently idle back into an operating capacity.

Supply predictability is a primary barrier for most investors. Innovative financing may be able to overcome supply challenges in some areas. Three examples of finance innovation which the Institute could help to further develop include:

- Pre-development financing to better leverage cross-boundary contracting. Master service agreement (MSA) and good neighbor authority (GNA) contracting options enable third-parties to implement timber and biomass removal. These authorities are often under-leveraged due to lack of financing. If third-party implementers had funding up front, contractors could be paid more timely, allowing for quicker forest restoration-based thinning and biomass removal.

- Creation of a ‘forward contracting’ option for investors in milling and processing facilities. Investors are less concerned about a set price for biomass or small-diameter timber than about locking in supply certainty. Offering a forward contract (which commits an investor to a purchase at any price) will help to address the volatility of product availability. Risk can be mitigated through a force majeure clause, releasing parties in the event of wildfire or other natural disaster.

- Establishment of a public-private partnership (PPP) focused on leveraging an existing MSA. The PPP guarantees availability of material at a given delivery point and lets the market compete for the material at that point, thus overcoming significant road, transport, and harvest costs, and increasing the likelihood that existing harvesting and processing operations will bid on and remove the biomass swiftly.

Regional financial mechanisms focused on local ecological outcomes are needed. Nearly half (46%) of all wildfire costs are borne by local communities. Further, the vast majority of federal wildfire expenses (85%) are related to short-term expenses such as emergency response, and not long-term resilience. This leaves the overwhelming burden of restoration to under-resourced rural communities. Community Choice Aggregators, like the Redwood Energy Authority or Pioneer Energy, are focused on this resource planning challenge, but do not have access to funding structures at the scale needed. Some communities are adopting voluntary taxes (such as Property Assessed Clean Energy funding) to fund regional restoration work, yet these levies are neither popular nor affordable for many communities in high-risk regions. There is a clear need for more effective regional financing strategies in wildland urban interface (WUI) areas and rural regions. Interviews with venture capital investors and philanthropists suggest that concessionary capital is often driven by a commitment to a region or geography rather than a particular methodology or outcome. This suggests an opportunity to increase the number of regional funding opportunities. The University of California Agriculture and Natural Resources’ (UCANR) Verde Innovation Network for Entrepreneurship (VINE) seeks to build rural entrepreneurial ecosystems to bring academic expertise and innovative skillsets to rural California. At present, VINE focuses much of its work on agricultural and food systems. Through partnership with the Institute, VINE and UCANR might work with rural regional collaboratives to tackle regional funding strategies and develop rural financing information and access.

Sustainable investments must be defined and widely adopted. A recent report from Goldman Sachs and JP Morgan calls for big banks to develop voluntary shared metrics for what constitutes sustainable investments. The Climate-Smart Wood Group (CSWG, a network of architects, builders, and other practitioners looking to source and promote climate-smart wood products) was created to establish ‘climate-smart wood’ definitions and standards for design and build sectors. Building upon the work of the CSWG, the Institute can identify California priorities using CSWG findings and produce applied research on California climate-smart standards which integrate with international green building codes and other relevant standards in operation today.

Wood innovation markets are unclear to most laypeople. Asset managers in the sustainable and impact investment space face challenges in raising capital, particularly as it relates to defining risk and revenue effectively to prospective investors, which ultimately constricts the flow of capital into forest products and wood innovation.[xvi] Due diligence in forestry investments includes an understanding of a variety of investment strategies, cash flow mechanisms, state and federal policy, regulations, and more; consequently, it is necessary to employ

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[xxviii] For example, the Energy Resources Engineering program at Stanford University.

[xxix] Shasta Community College and the Sierra Business Council are jointly undertaking a statewide review of workforce training programs relevant to wood innovation fields. This research will focus primarily on workforce development for harvesting, transportation, and milling. Results are expected in spring 2020.

[xxx] The University of California’s Verde Innovation for Entrepreneurship Network is attempting to address this gap via public-private partnership to offer global resources and expertise to entrepreneurs in agriculture and natural resources fields. However, their current focus areas do not include wood innovation or speeding forest restoration.

[xxxi] A full list of domestic forestry programs to consider for future collaboration is included as Appendix 5B.

[xxxii] The potential for interstate competition in developing the competitive edge of one state over another was not a concern for interviewees. Any concern that the growth of one market will slow the growth of another is not a priority for those investors focused on net carbon storage and catastrophic wildfire reduction.

staff or consultants with forestry experience. A lack of sustainable forestry investors makes new investors hesitant to invest. Asset managers interviewed for the Global Impact Investing Network's (GIIN) Scaling Impact Investment in Forestry Report nearly universally indicated that perceived risks among limited partners and potential investors are consistently higher than ***actual*** risks facing forestry investment.[xvii] Similarly, forest products companies, harvesters, and small processing operations seeking financing frequently lack the network or financial fluency necessary to engage asset managers. Organizations like the Sierra Business Council have provided ad hoc or project-based partnerships to connect investors and business owners. Providing such a forum is valuable for companies and suggests there may be a need for a third-party financial mediation partner who can facilitate communication between investors and small businesses.

Industries with a stake in forest restoration outcomes do not invest in restoration or wood innovation markets at scale. There is a significant body of literature detailing healthy forest ecosystem services in California, yet there are minimal ties between those services and the sectors which benefit most from their restoration and the cost of restoration. Meeting the 1 million-treated acres/year goal[xxxvii]will cost approximately $2,500-$3,000/acre for sustainable thinning, or close to $3 billion/year for about 10 years[xvii], not including ongoing maintenance. Opportunities to encourage industries that benefit from risk reduction to invest in restoration and resiliency work, include:

Insurance: After $24 billion in losses from two consecutive wildfire seasons (2017 and 2018), insurers began imposing significant rate hikes, or dropping customers altogether, in high-risk areas. The cost of insurance and other fire-related consequences in at-risk communities is negatively impacting property sales, values, and tax revenues.[xxxviii] California has more homes in the WUI than any state except Texas. Until enough restoration work is done to decrease risk in these areas, costs are likely to continue to rise.[xix]

> **Community funds are underleveraged.** Insurance companies have 'alternative asset classes' and community funds from which they pull for the types of investment needed in forest restoration. 'Alternative asset classes' are difficult to access and are highly risk averse. Community funds are much more flexible; however, there are presently no opportunities to aggregate community funds across insurance companies. Community development financial institutions have expressed interest in collaborating with the Institute in working toward creative solutions to leverage such funds.

Power: The California housing crisis is inextricably linked to the California wildfire crisis. Land use policies and affordability issues in California have led to nearly half of California's population living in areas of high wildfire threat.[xx] Simultaneously, the state is seeing the impacts of aging utility infrastructure. While only 5% of wildfire ignitions in California are from power lines, the resulting wildfires have been among the largest and most devastating in the State.[xxi] The October 2019 PG&E public safety power shutoff event in Northern California is estimated to have had a financial impact of approximately $65 million for residential customers and up to $2.5 billion for small commercial and industrial customers,[xxii] assuming 800,000 customers were out of power for 48 hours. As the Sierra Business Council reports,[xxiii] ***"When the Camp Fire broke out in Paradise in November of 2018, it downed the only transmission line that provided power to Lassen Municipal Utility District customers more than 100 miles away in Susanville and the surrounding area. LMUD operators were able to plug into the biomass-powered Greenleaf Honey Lake Power facility and provide power to Susanville's homes and businesses for almost three weeks while the transmission line was restored."***[xxiv] Many experts suggest that California may evolve in the direction of distributed energy resources,[xxxix] particularly as grid power becomes less reliable and more expensive. The State has an opportunity through funding and regulatory structures to support this shift and ensure it is equitable and serves populations effectively (feed-in tariffs, for example). The Institute is well poised to play an important role in research on these issues, and to provide outreach and education to the public and policy-makers.

[xxxiii] Non-concessionary investors are not willing to make any financial sacrifice to achieve their social goals. Concessionary investors are willing to make some financial sacrifice—by taking greater risks or accepting lower returns—to achieve their social goals.

[xxxiv] e.g. Katerra Cross Laminated Timber, Synova Biomass Power, American Renewable Power

[xxxv] Globally, the largest single source of private asset investment in "sustainable and impact forestry funds" are pension funds, with family offices, endowments, foundations, and, lastly, funds of funds.

[xxxvi] Generally, "blended finance" typically involves the use of public and/or philanthropic capital alongside private investment capital. It can take many forms, ranging from investing public money as subordinated debt alongside private monies to partially funding an investment with grant monies. Generally, it targets 1) delivering more attractive investment terms than would otherwise be available in the marketplace (ie: lower interest, larger loan, longer term) or access to capital where it would otherwise be deemed too risky to invest. The rationale is that there is a public benefit not recognized due to market externalities, etc. that blended finance can help to bridge the gap on. Examples in PACE financing (with loan-loss reserve from municipal bonds), or public funding of conservation easements to decrease costs for conservation entities to purchase and conserve land

Housing: There are numerous opportunities to link housing to forest restoration, including the use of mass timber products and demonstration of its seismic and fire-resistant qualities, and establishing biomass power facilities (as a backup power source or primary power source) in the WUI.

Tie new housing developments to forest restoration objectives. Many experts (policy makers, UC leadership, and scientists) have recommended the use of mass timber products, with their light carbon footprint and increased construction efficiency, in new multi-story construction to demonstrate its structural and aesthetic potential as well as increase expertise in mass timber use and design. Leveraging public capital to fund such projects would have the added benefits of meeting housing needs and sustainably restoring our forest lands. Incorporating avoided costs into the analysis would significantly improve advocacy and budgeting. America's largest mass timber building, Adohi Hall, is now open at the University of Arkansas.[xxv] [xl] With prefabricated panels, mass timber construction is approximately 25% faster than concrete, results in 90 percent less construction traffic and 75% fewer workers on the active deck, making it well-suited to urban infill sites.[xxvi] By leveraging the **Buy Clean California Act** (AB 262),[xli] California can ensure that a large proportion of the sourced raw materials for public buildings come from sustainably managed forests in the State.

Gas and fuel: Existing fuels infrastructure in the State is extensive. Harnessing the vested interest of gas and fuels companies to maintain use of this infrastructure, while meeting climate goals and renewable portfolio standards, is a significant, and largely untapped, opportunity. For example, SoCalGas is committed to replacing 5% of its traditional natural gas supply with renewable natural gas in the next 2 years and 20% by 2030. In January 2019, Calgren, a biofuel producer, began flowing renewable natural gas into the SoCalGas system from a dairy digester pipeline cluster.[xxvii] Part of the impetus for this investment in renewable natural gas (RNG) from biofuels is the result of a 2017 analysis showing that the switch to electric vehicles in California was slower than anticipated and that electrification of 'grey infrastructure' in the State is largely relegated to new buildings, not retrofits. A 2016 report to the California Energy Commission suggests SoCalGas is interested in investing in emerging opportunities and innovation development – including hydrogen and biofuels from forest materials. The growing body of scientific research on greenhouse gas emissions (GHG) from biofuels production (compared to open burning[xxviii]), as well as the carbon sequestration potential of pyrolysis byproducts, suggests this is a viable option. The Institute can play an important role in sharing emerging science and framing it in the context of the State's 2045 carbon-neutral goals.

Water: Healthy forests have increased fire resiliency, better water retention, and higher water quality. Water markets and healthy forests are directly correlated. One way to invest in the future of our forests is to access existing water markets and encourage proactive investment in forest restoration. For example, the Yuba County Water Agency has committed to a $1.5 million cost-share contribution to help fund the planned restoration in the Yuba watershed via the Blue Forest Conservation Bond. There will likely be opportunities to expand on this concept through 'down-stream' industry partnerships which aggregate large water users into shared investments for upstream restoration. The Institute can play an important role in proactively building connections between potential investment opportunities and investors in water markets, surfacing innovative ideas and briefing relevant stakeholders.

3.4 Improving stakeholder engagement and effectiveness through convening activities

Engaging diverse stakeholders and fostering dialogue around issues of common interest is fundamental to realizing adoption of major new policies, initiatives and legislation. There is a common refrain that forest product and wood innovation markets are overly reliant on social capital, networks, and the ability to navigate multiple agendas and objectives– each with their own acronyms, priorities, and timelines. Establishing a baseline of knowledge and language in an environment that allows individuals to speak frankly without attribution outside of traditional quasi-judicial and regulatory proceedings is an important element to reaching sufficient consensus (but not unanimity) for major new policies and legislation to be adopted. Organizations are needed to fill this role, which currently does not exist in the forest products sector.

Support regional collaboratives, share regional and rural data, and collaborate with rural communities. Among its mandates, the Institute Charter requires a focus on rural and regional collaboratives. Competition for resources makes sharing data across regionally focused organizations challenging. Within small and rural communities there is also a political and social balance among interested parties which means any convening entity takes on a political and financial burden to act as a "neutral" collaborator. Effective funding of rural, regional collaboratives might enable collaboration across political boundaries.[xlii] [xxix]

The Institute may develop applied research on policy design and financial structures to encourage rural and regional collaboration and partner with key rural influential entities to operate as a 'neutral' convener.

Promote the formation of industry and investment cohorts, and share critical knowledge across sectors. Currently there is little support and few resources available for investors interested in understanding opportunities and challenges in wood innovation market investments. The Institute is in a position to provide information to stakeholders, assuring easy and consistent access to critical knowledge and networks.

Connect entrepreneurs and innovators with interested investors for efficient use of all forest material: There is an opportunity to build collaboration within industry and investment as it relates to waste streams and feedstock use. As discussed in Chapter 1, multiple forest products are often manufactured from the same biomass source. Therefore, viable business are likely to have a dedicated waste stream for unused feedstock that either produces other structural or non-structural wood products onsite or sells to another business for processing offsite. A collaborative platform to connect entrepreneurs and innovators that would enable shared economic benefits and use of forest fiber would be environmentally and economically beneficial. Many of the pyrolysis methods applicable to converting forest slash to higher-value products are also applicable to agricultural and urban waste streams in California.

3.5 Public Education

Sustainable wood innovation markets offer an exciting opportunity to scale forest restoration swiftly throughout the state. As precautionary blackouts roll across the state, bioenergy markets offer a potential opportunity for back-up power and rural regional resilience. Structural products from small diameter timber may prove more earthquake resilient and fire resistant than traditional construction materials like concrete and steel. Embedded carbon in structural materials and innovative wood products may contribute significantly to our ability to meet ambitious California Forest Carbon Plan goals. And, nothing stores carbon like a healthier forest. There is a need to educate the public in order to facilitate the passage of new funding measures and generate support for regional plans to swiftly increase sustainable forest restoration practice state-wide.[xlii] Among the Institute's mandated activities, as noted in the Charter, is outreach and public education. California pioneered some of the most sweeping and important environmental policies in our nation – and now we have to shift the narrative: sometimes, tree huggers have to cut trees to save forests, sometimes the heroes are the ones to prevent the catastrophic fires, not only those standing on the ridges with blazing fires behind their backs. Gaps which the Institute might fill specifically include:

- Development of compelling education and outreach plans highlighting the benefits of products which are a byproduct of sustainable forest management;
- Effective engagement of commercial companies, highlighting the importance of mass timber and innovative wood products and their role in forest health; and
- Integration of forestry and wood innovation markets into new academic fields, including business, communications, law, and policy degrees

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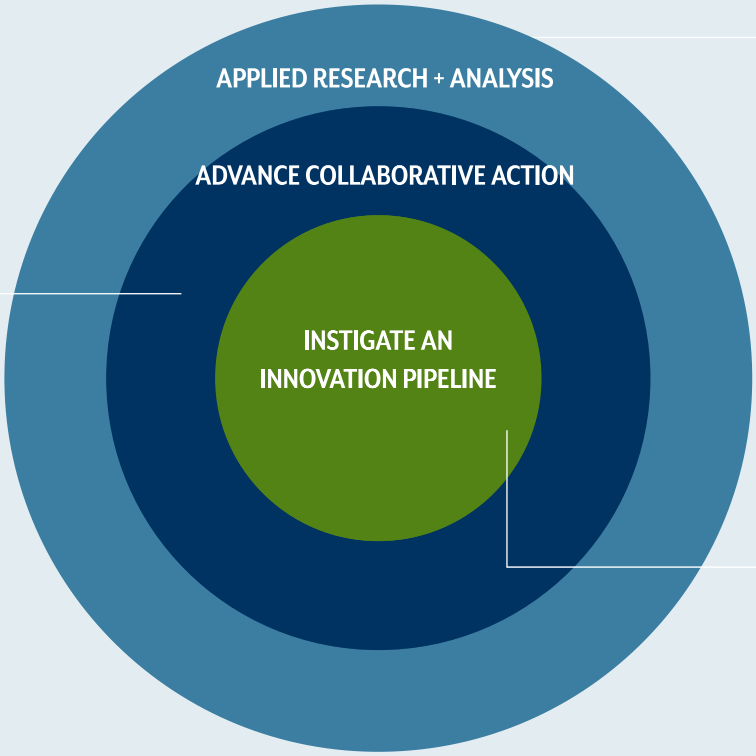
[xxxix] DERs and microgrids are more expensive than diesel generators on an upfront capital basis, but their lifetime costs are lower because they can produce valuable services, even when the larger grid is operating normally (peak shaving, T&D deferral, etc.).

[xl] The wood used was spruce, pine, and fir sourced from Europe.

[xli] AB 262 is the first bill in the US that addresses State greenhouse gas emissions purchases for public works projects. It requires the Department of General Services to establish, and publish in the State Contracting Manual, a maximum acceptable global warming potential for each category of eligible materials, in accordance with requirements set out in the bill.

4. WHAT IS POSSIBLE TODAY

The wood innovation sector, nationally – but *particularly* in California – is highly-relational and dependent on networks and access to gain insight and opportunity.[xliv] The Institute can facilitate collaboration and disseminate information to help promote the forest and carbon benefits of mass timber and wood innovation in the State. To achieve this, three programs can be developed in phases. The two-year scopes for each program will flow from this broader vision.



Focus 1:
Develop market-critical research, actionable strategy briefs, product layups, concise policy synopses and prioritize research + analysis that will foment demonstration projects in California. Curate briefings and knowledge sharing across key stakeholders & build communications that translate across sectors

Focus 2:
Tackle critical issues that require cross-sector action via curated 'action cohorts' or task forces. Build shared language and priorities, steward outcomes and action. Where appropriate, design policy solutions and public-private partnerships.

Focus 3:
Instigate an innovation pipeline through cross-campus collaboration, project + competition teams across disciplines, and formal partnership with existing incubators and accelerators.

Figure 10. Foci suggested for Institute

4.1 Applied research and analysis

Summary: The purpose of the Institute is to facilitate innovation and growth to develop and expand a robust and sustainable forest products market sector in California. In addition to funding applied research and analysis on critical market gaps, the Institute should identify and, where appropriate, organize forums to engage key audiences, promote knowledge transfer, facilitate problem solving, solicit feedback, and broaden support for the Joint Institute's research and policy recommendations.

Approach: Through research and analysis, the Institute will identify market and workforce gaps, barriers, and solutions as well as opportunities for innovation in the forest products market sector. Findings from this work will be summarized in briefing materials and provided to key stakeholders, including investors, industry representatives, environmental organizations, public agencies, the legislature, and the public. The Institute will provide materials not simply through public offerings, but also through briefings to critical actors and organizations on particular findings, including recommendations on strategic action, as relevant.

[xlii] A major theme of discussion at the 2019 California Land Conservation Summit, convened by the Tahoe Conservancy, was the need to define ecological boundaries, in addition to political boundaries, for forest restoration work. AB 2018 noted the time, money, and social capital necessary for community-based forest restoration work, but it did not mandate that funding be allocated regionally to implement such work at an ecological scale.

[xliii] For example, bioenergy markets generate a fear of clearcutting as a result of increased demand for fuels – although SB859 explicitly prohibits this – and this concern limits both policy and public engagement. Another example: During past legislative cycles, powerful steel and concrete lobbies, who stand to lose market share with the growth of mass timber, developed public relations materials depicting burning baby dolls and homes on fire – these were quite effective in lobbying the Los Angeles County Supervisors to maintain two-story height limits for mass timber buildings.

Specific initial activities might include:

1. **Academic partnerships to streamline and clarify opportunities:**
    - **a.** Collaborate in the development and maintenance of a well-curated, navigable online library of research, relevant funding streams, and public programs. Relying on this report's bibliography, curate and democratize research– providing a quick, organized gateway for wood product market insights in California.
2. **Conduct research, report on findings and solutions, develop action-oriented issue briefs, convene key stake holders to brief and drive action:**
    - **a.** Contracting mechanisms to improve supply predictability
    - **b.** Financing opportunities to kick-start innovative public funding mechanisms

Future research topic areas for the Institute might include:

3. **Economic cost-benefit analysis of subsidy designs:**
    - **a.** Conduct an economic cost-benefit analysis to assess subsidy designs – for example, determining at what threshold a transportation subsidy would be equal to GHG reductions gained through forest restoration and subsidy structures that will encourage the swiftest biomass and small diameter tree removal in California.
4. **Convene key data organizations to foment the creation of a publicly accessible models for modeling of wood innovation businesses and investments:**
    - **a.** Important to have data and models to inform linkages between industry sectors / technology and pace & scale, so we invest time and money efficiently

Potential partnerships and means of engagement:

1. **TallWood Design Institute:** The Institute can partner with TallWood to build a shared industry outreach initiative which offers a well-curated industry network database, offers interested industry players a place to go for expertise on California policy and regulation, builds networks and relationships across landowners, harvesters, millers, processors, and produces applied research and analysis targeted at west-wide industry players regarding technology, policy, and science.
2. **Pacific Coast Collaborative's *Building the Low Carbon Economy of the Future:*** This collaborative is committed to "sharing knowledge and exploring innovation" across fuels management, forest carbon planning, and fossil fuels replacement.[xxx] Partnering with this group will assist the Institute in further disseminating research findings and increasing its convening power.
3. **The TallWood Design Institute, Washington State University, and WoodWorks:** These entities expressed interest in developing a West-wide training and education platform to coordinate certificate and degree offerings. The Institute can instigate this discussion and encourage collaboration.

4.2 Engagement with key stakeholders to help translate recommendations into results

Summary: The Institute will facilitate forest product innovation and growth through demonstration, engagement of key organizations and actors in action-oriented working sessions or briefings, and provide public outreach.

Approach: Working with key stakeholders and subject matter experts, the Institute should (1) promote findings, (2) identify new near-term priorities and barriers on which to focus, and (3) assure that key cross-sector audiences, existing task forces and working groups, and other relevant stakeholders are engaged and briefed – not simply to drive consensus but to build relationships and drive discussion on strategic action in small group settings, assuring that efforts toward forest restoration and forest products and innovation continue to progress.

[xliv] The TallWood Design Institute, Oregon State University, WoodWorks, Washington State University, and others believe that one of their greatest contributions is to coordinate and facilitate wood innovation market networking.

Specific initial cohorts the Institute might convene in order to foment shared action and to provide briefs on relevant findings and solutions include:[xlvii]

On September 19, 2019, the Institute participated in and supported a gathering in Truckee and Loyalton, CA to gain insight on gaps and opportunities in wood innovation markets from a diverse group of experts. The attendee list, structure, and findings from the gathering can be found in the appendices. The Institute should focus on similar, yet smaller, highly-focused working groups who convene to understand collaboration opportunities and work toward action on a defined timeline.

1. Harvesting and transportation technologies: Curate a small group to focus on improving harvesting technologies and piloting harvesting equipment funding and financing opportunities.

2. Workforce development: Convene representatives from Shasta and Feather River Community Colleges; UC San Diego, UC Davis, and UC Berkeley forestry programs; Cal Poly San Luis Obispo; Humboldt State University; WoodWorks; and the TallWood Design Institute to discuss: (1) how to incorporate forest restoration and wood product innovation into curricula across disciplines such as architecture, design, and business schools, (2) how to create and maintain a navigable 'map' of all relevant training and education programs in the State, and (3) how to pull from expertise across organizations to create a West-wide industry outreach group that would enable students to more effectively access degrees, programs and trainings across campuses.

3. Demonstration projects: Encourage the building of demonstration projects on relevant sites, such as government buildings and academic campuses. The Institute can help to identify key partners, locations for projects, and the best technologies to demonstrate mass timber and innovative wood products. Demonstration will help highlight high-value uses for use of forest restoration material that helps to maximize carbon sequestration for industry, investors, researchers, legislators, and the public.

> **a. Possible partners include:** UCANR, VINE, Developers and build/design entities, CAL FIRE fund allocators, the Forest Management Task Force, Moore Foundation, technical specialists, and research leads for identified demonstration technologies, and Woodworks.

4. Public private partnerships to explore barriers to manufacturing: Industry representatives have expressed interest in public private collaboratives – provided they leverage what has worked from those that already exist[xlviii] and (a) also convene under very specific objectives with (b) the right cohort of organizations aimed at collective action on a short timeline. The Joint Institute can instigate a second PPP focused on land treatment to overcome supply challenges, or on regional use of forest materials in areas of particular interest: For example, consider (a) building on Lupien's recommendation to explore interest in and barriers to manufacturing mass plywood panels pending proof of materials viability,[xxxi](b) specifically on biofuels and the expanded use of biomass for heat and energy generation.

5. Insurance investment: In July 2019, the California Insurance Commissioner's Office produced a Sustainable Insurance Roadmap which prioritizes retaining home, fire, and health insurance in high-risk areas and developing financing models that utilize insurance markets and insurance investments to drive ambitious climate resilience goals in the State.[xxxii] [xlix]The Institute could provide a forum for those developing finance models (Blackrock Financial, COIN, Blue Forest Conservation, and others), to consider insurance investment mechanisms, build relationships and innovative thinking across sectors, and provide effective communication to critical stakeholders.

[xlv] For example, an 'insurance' program for processing facilities based on a futures market to secure long-term feedstock contracts for stipulated prices which would greatly ease the challenges of lenders underwriting projects.

[xlvi] For example, convene Bain Consulting, the USDA's Conservation Finance team, the Global Impact Investing Network, New Island Capital, Blue Forest Conservation, and Bank of America asset managers and institutional investors to address private financing gaps and produce public and policy-maker issue briefs.

4.3 Promote workforce development, entrepreneurship and innovation

Summary: The Institute should provide a forum for business and design schools, training centers, forestry programs, and public agencies to address workforce gaps and the disconnect between business incubators and entrepreneurs in forest products and wood innovation.

Possible Approach:

Table 18. Potential near-term and long-term actions for workforce and entrepreneurship

Near-term actions	Long-term actions
Identify challenges in technology development, building demand through design and architecture, certifications or standards, innovative financing, etc. Work with key partners West-wide to address outlined challenges.	**> Build partnerships with existing business incubators.** **> Create a pipeline for 1-3 project concepts annually to flow into these programs for funding, expertise, and growth.**
1. Develop relationships with UC, CSU, unions and trades programs, and CCC campus program leads from relevant disciplines, including business, architecture, policy, and more.	**1.** Work with an existing incubator or accelerator to develop a structure for incubating forest innovation entrepreneurs through their existing programs. Pulling from student teams and concepts that arise from the academic institutions, trades, and unions, provide 1-3 recommended project concepts annually to existing incubators and accelerators.
2. Prioritize innovation gaps within specific disciplines and devise 'challenges' or project scopes for undergraduate and graduate students.	2. The Institute can serve as the information center for statewide wood innovation market stakeholders and innovators and entrepreneurs, providing the link between industry, academia, and entrepreneurs.
3. Assemble a small team of cross-sector expertise in wood innovation markets, or rely on the Institute's Advisory Council, to provide insight and feedback to select project teams.	3. Participate in development of additional 1-2 physical locations for wood innovation technology testing & demonstration and business model innovations.

Specific opportunities and approaches:

1. **A focus on rural California:** Rural California largely lacks access to finance and academic expertise and innovation, yet will be the proving grounds for regional bio-economic models. California Economic Summit's ***Elevate Rural California*** initiative, in partnership with UCANR and Rural County Representatives of California, is specifically focused on developing targeted workforce and economic growth in rural regions. VINE already operates an accelerator cohort and is currently focused on precision agriculture using agronomy and artificial intelligence to improve nutrition targets in crops. The Institute can assemble the right players to coordinate a business incubator which is housed within VINE or the Tallwood Design Institute, for example. Additional partners might include UCANR's Elevate Rural California, and a CCC (e.g., Feather River, Sierra, or Shasta). A business incubator focused on wood innovation in rural California would meet a variety of goals, including: encouraging innovation, building a business incubation pipeline, fomenting collaboration across California academic systems, and focusing on uplifting and empowering rural California specifically.
    a. **UCANR/VINE as the portal for innovation into existing accelerators:** The Institute might create additional partnerships with accelerators such as Elemental Accelerator, Kapor Capital (Oakland), or the Nature Conservancy's partnership with TechStars. The Institute could help foster the establishment of these partnerships.

[xlvii] Of course, the research the Institute takes on under any given scope will define the relevant areas for building collective action and outreach; the below are areas that will particularly benefit from this type of convening and driving toward shared outcomes.

[xlviii] An MOU with Sierra Pacific Industries (SPI), the USFS, and several industry entities addresses prescribed burning across private and USFS land boundaries, easing permitting and enabling private and public land managers to move more swiftly in prescribed burn activities. Among the key factors that enabled the success of this partnership are: convening the right organizations to drive toward action rather than to build broad consensus and identifying a shared specific outcome objective from the outset.

    b. **UC Field Stations, Opportunity Zones, and CCCs:** Of the 56 UC Field Stations, 13 are in Opportunity Zones. Of those 13, seven are near the CCCs most active in forestry and wood innovation training (Shasta, Feather River, Columbia, and Syracuse Colleges as well as Sierra, Lake Tahoe, and Clovis Community Colleges). There may be an opportunity to encourage the UCANR VINE program to partner with Shasta Community College (as they are already committed to workforce development and engaged in statewide research on the topic) to create a physical center for the demonstration and testing of new ideas and technologies which could be funneled to existing business incubators.

1. **Harnessing the academic expertise of the Institute to support business incubators in forest products and wood innovation:**
    a. **XPRIZE for "arid forests":** XPRIZE doesn't write the technical details for the prizes that they promote and run. They currently have a rainforest prize and are interested in what they term an "arid forests" prize but would need the right technical partner to provide the appropriate language and structure for the prize. The Institute could conduct the research and design to develop such a prize.
2. **Working with California-oriented foundations to develop future programs.**

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