Joint Institute for Wood Products Innovation:

Evaluation of Literature,

Research Gaps,

Partnerships,

and Priorities

A report submitted to the

Board of Forestry and Fire Protection

Agreement # 9CA04450

Lead Authors:

Dr. Daniel L. Sanchez, University of California-Berkeley
Teal Zimring, Galvanize Partners
Catherine Mater, Mater Engineering Ltd
Katie Harrell, Board of Forestry and Fire Protection

Contributing Authors:

Lech Muszynski, Oregon State University
Ben Edwards, University of California-Santa Barbara
Samantha Smith, University of California-Santa Barbara
Kyle Monper, University of California-Santa Barbara
AnnaClaire Marley, University of California-Santa Barbara
Max Russer, University of California-Santa Barbara

DRAFT

January 5, 2020

Executive Summary

Joint Institute for Wood Products Innovation: Evaluation of Literature, Research Gaps, Partnerships, and Priorities

Background and Justification

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. A changing climate and overstocked forests have dramatically increased the size and intensity of California wildfires and insect infestations, threatening the ability of forests to capture and clean water, serve as long-term carbon sinks, and support 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.

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 provide:

- A review of forest product innovation literature, including any associated barriers;
- Gaps in forest product innovation research as well as those areas that have yet to be examined in the context of California forests;
- Potential strategic partnerships with external stakeholders and how best to engage each; and
- Recommendations for near-term priorities and a summary of barriers to in-state production of mass timber as well as other innovative forest products to inform the ongoing operation of the Institute and support the expansion of the forest products sector in California.

This report examines these topics through three separate chapters. Below, we list our primary conclusions for each chapter.

1) A literature review and evaluation of innovative wood products with potential to be manufactured from California feedstocks (Chapter 2: "*Innovative wood products and key market indicators*");
2) A review of recent trends in forest biomass harvesting and projections of supply availability in 25 Tier 1 High Hazard Zone California counties (Chapter 3: "*Trends and projections of timber and biomass supply for wood product innovation*"); and
3) Prioritization of recommended partnerships and actions to be undertaken by the Institute (Chapter 4: "*Strategic partnership landscape, gaps, and recommendations*")

Innovative wood products and key market indicators

1. Laminated timber, including mass timber panels, holds substantial promise as a new California product made from merchantable, in-state lumber. The Institute can undertake market formation activities to promote development of manufacturing capacity.
2. Some California tree species have not been investigated for laminated timber products, presenting a barrier to near-term adoption.
3. Ideal mass timber products derived from California's non-merchantable biomass (e.g. OSB, mass plywood) are unclear. More research is needed in this area.
4. 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.
5. There are relatively few export opportunities for innovative wood products manufactured in California, with the exception of biocoal/torrefied wood.
6. 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 to entrepreneurs and academics could facilitate these technologies.

Trends and projections of timber and biomass supply for wood product innovation

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 supplies;
    b. Dramatic supply variability from year to year;
    c. High cost to access low-grade wood supplies;
    d. Lack of adaptability of both under-utilized and young growth species for use in innovative value-added wood products;
    e. Lack of primary processing infrastructure for non-energy wood products (especially small log processing and dry kiln infrastructure); and
    f. Lack of environmentally appropriate options to harvest fuelwood in 25 primarily forested High Hazard Zone (HHZ) counties.
2. California should convene public and private landowners in a strategy to prioritize removal areas, and support year-round forest maintenance operations that could produce sustainable roadside-ready small log and wood biomass supplies to facilities operating within defined working circles.
3. Over the last 10 years (2009 - 2018) there was an increase in cumulative sawlog volume sold, but not harvested from national forests in analyzed counties. Over that same period, there was an increase in cumulative fuelwood harvested, but not sold off of the same forests.
4. US Forest Service annual harvest volumes have declined over the last five years compared to private land forest restoration in the majority of analyzed counties.
5. Based on an approximate 50-mile-radius from the center of a bufferwood working circle, eight bufferwood 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.
6. Tree mortality in the Sierra Nevada range has most recently been highest in red and white fir stands. Analysis of new innovative forest products for California should address how these species can be used as product supply.
7. Further recommendations for continued intrastate supply analysis include:
    a. Determine the type, size, and volume of forest vegetation that would be harvested and processed within roadside working circles;
    b. Investigate additional options for small diameter log processing, including the applicability of HewSaw technologies; and
    c. Evaluate preferred purchasing options, sustainability certification, Good Neighbor Authority, impact on fire severity/occurrence, offset credit mechanisms, and alternative silvicultural prescriptions within supply areas.

Strategic partnership landscape, gaps, and recommendations

1. 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.
2. Areas of focus for the Institute include
    a. Supply: Identify solutions to achieve predictable, long-term, economical supplies of sustainably harvested forest fiber that promote California's healthy forest initiatives;
    b. Operations**:** Identify regulations and processes that establish a conducive environment for wood processors and increase end-market demand;
    c. Funding and Financing: Identify public and private funds to support mass timber and innovative wood business capital requirements and ongoing operations; and
    d. Economic Development: Incubate mass timber and innovative forest wood product technologies and support rural socio-economic and environmental outcomes.
3. Near-term areas of focus
    a. Conduct applied research and analysis, and
    b. Advance collective action.
    c. Programmatic focus areas
        i. De-risk wood innovation markets through public funding;
        ii. Training and education;
        iii. Steward innovative financing to attract private capital;

        iv. Organize platforms for collective action; and
        v. Educate the public about forest sustainability, mass timber, and forest product innovation

4. Longer-term areas of focus
    a. Encourage entrepreneurship and business development

<u>Recommendations</u>
The following Institute recommendations are based on a review of mass timber and innovative forest products, in-State forest fiber supplies, potential strategic partnerships, and barriers to mass timber and wood innovation in the State.

Structure: Near-term Institute efforts should focus on

1. Funding applied research and analysis
2. Advancing collective action

Priorities: Near-term research and outreach priorities include

1. Project: Joint development of product layup for mass timber panels from California feedstock (True Firs: red, white, and mixed species)
    a. Perform standardized tests for selected feedstock, design a structural engineered wood panel product, prototype and structural load testing, in-state demonstration, attain building product certification
    b. Collaboration with TallWood Design Institute
2. Project: Identify ideal structural wood applications for low-value biomass
3. Funding for outreach and convening projects. Topics include:
    a. Develop a wood supply strategy that engages public and private landowners to prioritize removal areas, and support year-round forest maintenance operations that could produce a sustainable roadside-ready small log and forest wood biomass supply to facilities operating within defined working circles.
    b. Engage with State agencies and entrepreneurs to promote low-carbon and carbon-negative transportation fuels derived from forest biomass.
4. Provide seed grants to in-State entrepreneurs and academics to perform commercialization analysis, such as market research and technology-to-market plans

Table of Contents

List of figures

List of tables

Acknowledgements

Forthcoming

Chapter I. **Innovative wood products and key market indicators**

1. Summary

Information contained in chapter:

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

Methodologies:

1. Literature Review
2. Research Gap Analysis

Conclusions:

1. Laminated timber, including mass timber panels, holds substantial promise as a new California product made from merchantable, in-state lumber. The Institute can undertake market formation activities to promote development of manufacturing capacity.
2. Some California tree species have not been investigated for laminated timber products, presenting a barrier to near-term adoption.
3. Ideal mass timber products derived from California's non-merchantable biomass (e.g. OSB, mass plywood) are unclear. More research is needed in this area.
4. 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.
5. There are relatively few export opportunities for innovative wood products manufactured in California, with the exception of biocoal/torrefied wood.
6. 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 to entrepreneurs and academics could facilitate these technologies.

2. Visual Matrix

Product Classification: mass timber panels	**Cross Laminated Timber (CLT)**	**Nail bonded CLT**	**Dowel bonded CLT**
Representative feedstock required	Small 2.1 MMBF (6.3 MBDT)/y Medium 6.4 MMBF (19 MBDT)/y Large 12.7 MMBF (38 MBDT)/y	Min : 0.3 MMBF (1 MBDT)/y Typical: 1.0 MMBF (3 MBDT)/y	Typical : 0.85 MMBF (2.5 MBDT)/y
Carbon storage	Yes (product)	Yes (product)	Yes (product)
Technology readiness level	9	9	9
Commercial readiness level	8	7	6
Feedstock use	Merchantable logs >Y" 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	small (boutique)	small (boutique)	small (boutique)
Research or analysis need	yes	no	yes
Can JIWPI influence outcomes?	yes	yes	yes

Table 1. Mass timber panels

Product Classification: Pyrolysis- non-energy products	**Wood Vinegar (Pyro-ligneous Acid)**	**Carbon Black**	**Biochar**	**Activated Carbon**
Representative feedstock required	35,000 BDT/year (Corigin LLC)	Unknown	150,000 BDT/year (National Carbon Technologies)	150,000 BDT/year (National Carbon Technologies)
Carbon storage	No	Yes (product)	Yes (char)	Yes (char)
Technology readiness level	5	4-5	9	9
Commercial readiness level	2-3	3	5	9
Feedstock use	Non- merchantable	Non- merchantable	Non- merchantable	Non- merchantable

International markets	Yes	Yes	Yes	Yes
Potential market size	Small	Large	Uncertain	M-L
Research or analysis need	High	High	High	Medium
Can JIWPI influence outcomes?	Low	Medium	Medium	Low

Table 2. Pyrolysis: non-energy products

Product Classification: Pyrolysis – Solid and gaseous fuels	**Torrefied Wood / Biocoal**	**Renewable Natural Gas**	**Renewable Hydrogen**
Representative feedstock required	149,000 BDT/y (Restoration Fuels)	250,000 BDT/yr (GTI Stockton)	45,000 BDT/yr (Clean Energy Systems
Carbon storage	No	Yes (CCS)	Yes (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

Table 3. Pyrolysis-solid and gaseous fuel

Product Classification: Liquid Fuels	**Fischer - Tropsch Fuels**	**Gas Fermentation for Fuels**	**Transportation Fuels via Fast Pyrolysis and Hydroprocessing**	**Lignocellulosic Ethanol (non-pyrolysis based)**
Representative feedstock required	68,000 BDT/yr (Red Rock Biofuels)	133,000 BDT/yr (Aemetis, Inc.)	300,000 BDT/yr feedstock (SPI Camino site)	100,000 BDT/Year (Axens/Anderson Biomass)
Carbon storage	Yes (CCS)	No	Yes (char)	No
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	Medium	Medium	Low

Table 4. Liquid fuels

Product Classification: Nanomaterials	**Ultra-strong Wood**	**Transparent Wood**	**Wood Fiber Insulation Board**
Representative feedstock required	Unknown	Unknown	90,000 BDT/yr (GO Labs)
Carbon storage	Yes	Yes	Yes
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?	No	No	Yes

Table 5. Nanomaterials

Product Classification: Chemically treated wood	**Acetylated Wood**	**Furfurylated Wood**

Representative feedstock required	7,000 BDT/yr (Accsys Technologies PLC)	1,750 BDT/yr (Kebony AS)
Carbon storage	Yes (long-lived wood products)	Yes (long-lived wood products)
Technology readiness level	8	8
Commercial readiness level	4	4
Feedstock use	Merchantable (Accoya) & Nonmerchantable (Tricoya)	Merchantable
International markets	Yes	Yes
Potential market size	Medium	Medium
Research or analysis need	Yes	Yes
Can JIWPI influence outcomes?	Yes	Yes

Table 6. Chemically treated wood

3. Materials and methods

3.1.1. 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

3.1.2. *Indicators for visual matrix*

Representative feedstock required (numerical): This is 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). We using 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 = 6 GT of logs
- 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 emissions 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."

Commercial readiness level (numerical ranking, 1-9):
Our assessment is based on guidance from the Advanced Research Projects Agency-Energy (ARPA-E 2014).

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 unvalidated.
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.

Table 7. Description of commercial readiness level

<u>Technological readiness level (numerical ranking, 1-9)</u>:
Our assessment is based on guidance from the National Academies of Science Engineering and Medicine for emerging bioenergy technologies (National Academies 2018).

	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).
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)

Table 8. Description of technology readiness level

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.

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

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

Table 9. Categories for market size determination

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.

References:
Shelley, John (2007). "Woody Biomass Definitions and Conversion Factors." https://ucanr.edu/sites/WoodyBiomass/newsletters/IG003_-_Woody_Biomass_Definitions_and_Conversions_Factors31510.pdf

ARPA-E (2014). "Technology to Market Plan: Template and Instructions" https://arpa-e.energy.gov/sites/default/files/ARPA-E%20T2M%20Plan%20Template%20rev.%204-30-14.docx

National Academies of Sciences, Engineering, and Medicine (2018). "Negative Emissions Technologies and Reliable Sequestration: A Research Agenda." Washington, DC: National Academies Press.

4. Detailed examination of products

4.1. Mass timber panels

Introduction
The report is concerned with three types of commercially fabricated massive composite panel product comprised of cross-layered pieces of dimension lumber bound together by structural adhesives, nails or hardwood dowels so that the whole panel is acting as a single load bearing element. All three are relatively new engineered composite products enabling new building technologies and revolutionizing the use of timber in construction. 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.

Product overviews

Cross-laminated timber (CLT), the best known, and the most common of these three, is defined as "a prefabricated 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 Alpine region of Europe in 1990s, and then gradually evolved to a viable industry, consequently gaining hold in other regions of the world. Currently, there is 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-day is 18-story Brook Commons on the campus of University of British Colombia in Vancouver Canada, though taller buildings are already being in various stages of development). However, the adhesive bonded CLT is also manufactured for access mats or "temporary timber pavements," which are considered 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].

Success indicators

General comments: in terms of most of the success indicators marked in the summary table above all three types of massive cross-laminated panels measure similarly. Therefore, the comments below apply to all three in the same way, unless specifically differentiated by the panel type.

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 conducted. Dowel-bonded CLT is marketed as 100% wood product. The utilization of the waste stream generated in production is discussed separately in section ***0***. 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 is present for decades. Companies in other region still spend substantial amount 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 project pool. Market readiness in North America is still 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 of 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, 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 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. As for California, 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 an 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, obviously, that 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 in case of the 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 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.
This 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. 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 seems to be in position to support a substantial fraction of the global CLT production. The perspective is even more interesting if one focuses on Austria, 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.

	Area		**Population**	**GDP**	**CLT output (2019)[2]**
	x 1k sq mi	**x 1k km^2**	**x 1M**	**x $1B**	**x 1k m^3**
DACH+I+CZ	333	863	171	$7,815	683
Austria	32.4	83.9	8.8	$461	393
CA	164	424	40	$3,000	0

Table 10. Comparison of California and European markets for CLT

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 had no precedence in timber construction and offered new opportunities in design and construction to professionals intimately familiar with the product. Thus, historically, 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. That way the actual product of the industry is a building, 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, however, 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. The alignment with the principles of Industry 4.0 is, actually, an artefact, not a goal for this industry.

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 (. Press types and sizes vary greatly (there is no size standard for CLT panels). Many companies had their presses and other special equipment designed and fabricated specifically for their needs. However, over the past 3 years 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 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 thousand cubic meters (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 thousand cubic meters (or nearly 13 MMBF).

Research gaps

Essentially no research is needed to commercialize any of the discussed products. However, both, the *adhesive- and dowel-bonded CLT* would definitely benefit from research focused on market development and code recognition, 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 endo-of-life scenarios for structures executed in these technologies.
We are not aware of any specific research needs for panels marketed as access mats.

Substitutions

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).

The supply chain 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).

Waste streams and byproducts: 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.

References

1. ANSI/APA, *ANSI/APA PRG 320-2018 Standard for Performance-Rated Cross-Laminated Timber*. 2018, APA The Engineered Wood Association: Tacoma, WA. p. 46.
2. Jauk, G., *100.000 m3 als standard? Deutlische Kapayitätsyuwächse in hany Europa. .* Holzkurier, 2019. **2019**(BSP Special issue): p. 6-11.
3. Santi, S., et al., *Massive wood material for sustainable building design: the Massiv–Holz–Mauer wall system.* Journal of Wood Science, 2016. **62**(5): p. 416-428.
4. OIB/EOTA, *European Technical Approval ETA-13/0799*, in *ETA-13/0799*, O.I.f.B.E.O.f.T. Approvals, Editor. 2013: Austria. p. pp 21 +6.
5. Thoma, E., et al. *Wood100 is 100% wood*. 2020 [cited 2020 1/2/2010]; Available from: https://www.thoma.at/100-percent-wood/?lang=en.
6. TechnoWood, A. and Web-D-Vision. *TWOODS - THE SOLID WOOD SYSTEM*. 2016 [cited 2019 8/22/2019]; Available from: https://www.technowood.ch/en/solutions/twoods.
7. Nägeli, A. and G. Webstobe. *APPENZELLERHOLZ*. 2019 [cited 2019 8/15/2019]; Available from: https://www.naegeli-holzbau.ch/appenzellerholz.html#technische-daten.
8. Muszyński, L., et al., *Insights into the Global Cross-Laminated Timber Industry.* BioProducts Business, 2017. **22**(8): p. 77-92.

4.2. Other structural wood products

Forthcoming

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.

References

Bridgwater, A.V.; Meier, D.; and Radlein, D. 1999. An overview of fast pyrolysis of biomass. *Organic geochemistry.* 30(12): 1479-1493.

Grewal, A.; Abbey, L.; and Gunupuru, L.R. 2018. Production, prospects and potential application of pyroligneous acid in agriculture. J. Anal. Appl. Pyrolysis. 135: 152–159. https://doi.org/10.1016/j.jaap.2018.09.008

Pollard, A.S.; Rover, M.R.; and Brown, R.C. 2012. Characterization of bio-oil recovered as stage fractions with unique chemical and physical properties. *Journal of Analytical and Applied Pyrolysis.* 93: 129-138.

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.

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
It is estimated that the global market for wood vinegar will reach $6.7 million by 2022 (CAGR, 2016). According to a 2019 survey in Australia and New Zealand, one liter of wood vinegar ranges from $2 to $12, with an average price of $4.63 per liter (Robb and Joseph, 2019). Production is concentrated in Asia, but exists at a small scale in Australia, New Zealand, Chile, France, Finland, and many other countries. Many of the technical and feasibility studies to date were based in Asian countries (Grewal et al., 2018). In the US, wood vinegar is more commonly used for smoke flavoring or as a food additive (Grewal et al., 2018). The "liquid smoke" global market was valued at $56.5 million in 2018 (Grand View Research, 2019).

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).

Barriers to product or process innovation and growth
Multiple barriers exist that hinder the wood vinegar market. In California, the largest barrier to producing wood vinegar from forest biomass is feedstock inaccessibility; the cost to access slash and other non-merchantable wood is too high (Truesdall, 2019). Consequently, small-scale wood vinegar production across the country appears to utilize agricultural biomass. In California, almond shells and other fruit orchard debris are the most common feedstock (Truesdall, 2019).

Market growth may also be limited because wood vinegar is not the highest value pyrolysis product. 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. Temperature consistency in slow pyrolysis operations remains a challenge and impacts product efficacy.
- **Commercial readiness level** *2-3.* 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. Market research is sparse and derived from secondary sources like CAGR, and competitive analysis and value-chain studies are not yet completed. Permitting, especially in regards to air quality, is challenging for pyrolysis operations, but does not appear specific to PLA production.
- **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 (CAGR, 2016).
- **Potential market size** *Small.* It is estimated that the global market for wood vinegar will reach $6.7 million by 2022 (CAGR, 2016). Markets will likely attract organic farmers initially, although this growing niche is significantly smaller than conventional agriculture. Interestingly, market size has the potential to increase if the cost to access forest biomass is reduced in California and no longer impedes production.
- **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; Corigin LLC, has obtained a "Certificate for Registration of Organic Materials" in California for its PLA product, but federal regulations remain unclear.
- **Can the Institute influence outcomes?** *Low*. The Institute may support research into using conifer feedstock for PLA production, but the most significant market barrier remaining is product efficacy and marketing. However, the Institute may facilitate some market growth for PLA by lowering the

cost of accessing forest woody biomass. Until then, orchard residues and other agriculture waste will dominate as the more economical feedstock.

References

Bauer, L., 2017. Biomass Pyrolysis Comes of Age : Biofuels Digest [WWW Document]. BioFuels Dig. URL https://www.biofuelsdigest.com/bdigest/2017/06/08/biomass-pyrolysis-comes-of-age/ (accessed 11.9.19).

BioGreen Energy, E.T. for I. (ETIA), 2019. Wood Vinegar (Pure Smoke Water) Bio-Stimulant [WWW Document]. URL https://greenmanchar.com.au/products/wood-vinegar-puresmokewater (accessed 10.18.19).

CAGR, R. and M., 2016. Wood Vinegar Market by Pyrolysis Method (Slow Pyrolysis, Fast Pyrolysis, and Intermediate Pyrolysis), Application (Agriculture, Animal Feed, Food, Medicinal, and Consumer Products), and Region - Global Forecast to 2022 [WWW Document]. Res. Mark. URL https://www.researchandmarkets.com/reports/3989538/wood-vinegar-market-by-pyrolysis-method-slow (accessed 10.18.19).

Corigin Solutions, LLC, 2019. Products: Coriphol [WWW Document]. Corigin Solut. LLC. URL https://www.corigin.co/products/coriphol.html (accessed 11.10.19).

Fagernäs, L., Kuoppala, E., Arpiainen, V., 2015. Composition, Utilization and Economic Assessment of Torrefaction Condensates. Energy Fuels 29, 3134–3142. https://doi.org/10.1021/acs.energyfuels.5b00004

Grand View Research., 2019. Liquid Smoke Market Size, Share Trends | Industry Report, 2019-2025. Retrieved November 30, 2019, from https://www.grandviewresearch.com/industry-analysis/liquid-smoke-market

Grewal, A., Abbey, Lord, Gunupuru, L.R., 2018. Production, prospects and potential application of pyroligneous acid in agriculture. J. Anal. Appl. Pyrolysis 135, 152–159. https://doi.org/10.1016/j.jaap.2018.09.008

Luo, X., Wang, Z., Meki, K., Wang, X., Liu, B., Zheng, H., You, X., Li, F., 2019. Effect of co-application of wood vinegar and biochar on seed germination and seedling growth. J. Soils Sediments 1–11. https://doi.org/10.1007/s11368-019-02365-9

Mohan, D., Pittman, C.U., Steele, P.H., 2006. Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. Energy Fuels 20, 848–889. https://doi.org/10.1021/ef0502397

Robb, S., Joseph, S., 2019. A Report on the Value of Biochar and Wood Vinegar: Practical Experience of Users in Australia and New Zealand. Australia-New Zealand Biochar Initiative.

Theapparat, Y., Chandumpai, A., Faroongsarng, D., 2018. Physicochemistry and Utilization of Wood Vinegar from Carbonization of Tropical Biomass Waste | IntechOpen, in: Tropical Forests: New Edition. InTech Open, p. Chapter 8.

Truesdall, K., 2019. Interview with Corigin.

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.

References

Alsaleh, A., & Sattler, M. L. (2014). Waste Tire Pyrolysis: Influential Parameters and Product Properties. Current Sustainable/Renewable Energy Reports, 1(4), 129–135. https://doi.org/10.1007/s40518-014-0019-0

Fan, Y., & Fowler, G. D. (2018). The Potential of Pyrolytic Biomass as a Sustainable Biofiller for Styrene-Butadiene Rubber. In M. A. Chowdhury (Ed.), Advanced Surface Engineering Research. https://doi.org/10.5772/intechopen.79994

Grand View Research. (2019). Carbon Black Market Size, Share & Trends Analysis Report By Application (Tires, High-performance Coatings, Plastics), By Region (North America, Middle East & Africa, Asia Pacific, Europe), And Segment Forecasts, 2019—2025 (p. 113) [Industry Report].

McCaffrey, Z. (2019, October 28). *Carbon black research questions interview with Zach McCaffrey at USDA - bioproducts*.

Toth, P., Vikström, T., Molinder, R., & Wiinikka, H. (2018). Structure of carbon black continuously produced from biomass pyrolysis oil. Green Chemistry, 20(17), 3981–3992. https://doi.org/10.1039/C8GC01539B

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, including as an animal feed, as a soil amendment, and in water filtration. When biochar is added to agricultural soils, it can increase crop yield by enhancing soil hydrological and nutrient properties (Pourhashem et al., 2019).

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

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.

References

Campbell, R. M., Anderson, N. M., Daugaard, D. E., & Naughton, H. T. (2018). Financial viability of biofuel and biochar production from forest biomass in the face of market price volatility and uncertainty. Applied energy, 230, 330-343.

Grand View Research (2019). Biochar Market Size, Share & Trends Analysis Report By Technology (Gasification, Pyrolysis), By Application (Agriculture (Farming, Livestock)), By Region, And Segment Forecasts, 2019 - 2025. Retrieved from https://www.grandviewresearch.com/industry-analysis/biochar-market.

Polaris Market Research. (2019).Biochar Market Share, Size, Trends, & Industry Analysis Report, [By Technology (Gasification, Pyrolysis, Others), By Application (Agriculture {Livestock Farming, General Farming (Organic Farming, Inorganic Farming, Others)} Others), By Regions Segment Forecast, 2019 - 2026. Retrieved from https://www.kennethresearch.com/report-details/biochar-market/10082391.

Pourhashem, G., Hung, S. Y., Medlock, K. B., & Masiello, C. A. (2019). Policy support for biochar: Review and recommendations. GCB Bioenergy, 11(2), 364–380. https://doi.org/10.1111/gcbb.12582

Steiner, C., & Harttung, T. (2014). Biochar as a growing media additive and peat substitute. Solid Earth, 5(2), 995-999.

US Biochar Initiative (USBI). (2018). Survey and Analysis of the U.S. Biochar Industry. Retrieved from http://biochar-us.org/sites/default/files/news-files/Preliminary%20Biochar%20Industry%20Report%2008162018_0.pdf.

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.

References

Adeleke, V. (2018). IBIS World Industry Report OD4484 Activated Carbon Manufacturing in the US. IBISWorld.

Beroe (2018). Category Intelligence on Activated Carbon. Retrieved from https://www.beroeinc.com/category-intelligence/activated-carbon-market/.

Grand View Research. (2019). Activated Carbon Market Size, Share & Trends Analysis Report By Product (Powdered, Granular), By Application (Liquid, Gas), By End Use (Water Treatment, Air Purification), By Region, And Segment Forecasts, 2019 - 2025. Retrieved from https://www.grandviewresearch.com/industry-analysis/activated-carbon-market.

Market Reports World (2019). Activated Carbon Market - Growth, Trends, and Forecast (2019 - 2024). Retrieved from https://www.marketreportsworld.com/activated-carbon-market-growth-trends-and-forecast-2019-2024--13347362.

Shukla, S. (2016). Activated Carbon Market by Product Type (Powdered, Granular, and Others), End-Use (Water Treatment, Food & Beverage Processing, Pharmaceutical & Medical, Automotive, Air purification, and Other End-Uses), and Application (Liquid, and Gaseous) and - Global Opportunity Analysis and Industry Forecast, 2014-2022. Allied Market Research. Retrieved from https://www.globenewswire.com/news-release/2019/07/15/1882739/0/en/Global-Activated-Carbon-Market-Size-to-Reach-5-12-Billion-At-9-3-CAGR.html.

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 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.

References

Banja, M., Sikkema, R., Jégard, M., Motola, V., & Dallemand, J.-F. (2019). Biomass for energy in the EU – The support framework. Energy Policy, 131, 215–228. https://doi.org/10.1016/j.enpol.2019.04.038

Cremers, Marcel, Jaap Koppenjan, Jan middlekamp, Joop Witkamp, Shahab Sokhensanj, Staffan Melin, Sebnem Madrali. (2014) Status overview of torrefaction technologies: a review of the commercialsation status of biomass torrefaction. IEA Bioenergy

Fengler, W. A., & Ward, D. A. (2017). Preserving Solid Fuel Firing in a Post-Coal World. 22.

Mody, J., Saveliev, R., Bar-ziv, E., & Perelman, M. (2014.). Production and characterization of biocoal for coal-fired boilers. Proceedings of the National Academy of Sciences. ASME Power Conference (2014).

Ribeiro, J., Godina, R., Matias, J., & Nunes, L. (2018). Future Perspectives of Biomass Torrefaction: Review of the Current State-Of-The-Art and Research Development. Sustainability, 10(7), 2323. https://doi.org/10.3390/su10072323

Thrän, D., Peetz, D., Schaubach, K., Mai-Moulin, T., Junginger, H. M., Lamers, P., & Visser, L. (2017). Global Wood Pellet Industry and Trade Study 2017. IEA Bioenergy Task 40.

Wild et al. 2016. Possible effects of torrefaction on biomass trade. IEA Bioenergy Task 40. April 2016.

Wilén, Carl, Kai Sipilä, Sanna Tuomi, Ilkka Hiltunen, Christian Lindfors, Esa Sipilä, Terttu-Leea Saarenpää & Markku Raiko. 2014. Wood torrefaction – market prospects and integration with the forest and energy industry. VTT Technology 163. 55 p.

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 CO_2/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.

References
Gas Technology Institute (GTI). (2019). *Low-Carbon Renewable Natural Gas (RNG) from Wood Wastes*. Retrieved from https://www.gti.energy/wp-content/uploads/2019/02/Low-Carbon-Renewable-Natural-Gas-RNG-from-Wood-Wastes-Final-Report-Feb2019.pdf

Penev, M., Melaina, M., Bush, B., Muratori, M., Warner, E., & Chen, Y. (2016). *Low-carbon natural gas for transportation: well-to-wheels emissions and potential market assessment in California* (No. NREL/TP-6A50-66538). National Renewable Energy Lab.(NREL), Golden, CO (United States).

San Joaquin Renewables. (2019, August 23). About San Joaquin Renewables. Retrieved from https://sjrgas.com/about-san-joaquin-renewables/.

SoCalGas. (n.d.). Biogas and Renewable Natural Gas: SoCalGas. Retrieved December 4, 2019, from https://www.socalgas.com/smart-energy/renewable-gas/biogas-and-renewable-natural-gas.

S.B. 1440, Energy: biomethane: biomethane procurement.(Ca. 2018). https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1440

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.

References

Burlington Electric Department (2019). “More about McNeil.” https://burlingtonelectric.com/more-mcneil

California Fuel Cell Partnership (2019). “List of Hydrogen Fueling Stations” https://cafcp.org/sites/default/files/h2_station_list.pdf

Clean Energy Systems (2019). “Carbon-Negative Energy: An Opportunity for California” https://static1.squarespace.com/static/5390f017e4b036cdc56eed84/t/5d3901ba2b531500013b9527/1564017089160/CES_Carbon+Negative+Energy_An+Opportunity+for+California_july2019.pdf

West, Aaron (2015). “Blue Lake Rancheria’s innovative power program in spotlight” *Times Standard*. https://www.times-standard.com/2015/01/08/blue-lake-rancherias-innovative-power-program-in-spotlight/

4.5. Liquid Fuels

Product: Fischer - Tropsch Fuels

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
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, 2018). This facility has not yet been placed in service.
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.

References
Sanchez, D. L., & Kammen, D. M. (2016). A commercialization strategy for carbon-negative energy. Nature Energy, 1, 15002.

Kreutz, T. G., Larson, E. D., Liu, G., & Williams, R. H. (2008, September). Fischer-Tropsch fuels from coal and biomass. In *25th annual international Pittsburgh coal conference* (Vol. 29, p. e2). Princeton University Pittsburg.

Red Rock Biofuels. (n.d.). Lakeview Site. Retrieved December 4, 2019, from https://www.redrockbio.com/lakeview-site.html.

Stratmann, P. (n.d.). From waste woody biomass to carbon negative transportation fuels via CCUS. Retrieved December 4, 2019, from http://www.biofuelsdigest.com/bdigest/2019/12/02/from-waste-woody-biomass-to-carbon-negative-transportation-fuels-via-ccus/.

California, S. of. (n.d.). Board of Equalization Home Page. Retrieved December 4, 2019, from http://www.boe.ca.gov/.

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
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. 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?** *Medium*. Should the Aemetis Riverbank facility be successful, JIWPI could commercialize this process using forest biomass.

References

Shaver, K. (2018, March 6). Aemetis Completes Operation of Cellulosic Ethanol Integrated Demonstration Unit, Produced Record Yields. Retrieved from http://www.aemetis.com/aemetis-completes-operation-of-cellulosic-ethanol-integrated-demonstration-unit-produced-record-yields/.

Aemetis. (2019). *Commercializing Below Zero Carbon Advanced Biofuels Production.* Retrieved from http://www.aemetis.com/wp-content/uploads/2019/01/Aemetis-Corporate-Presentation-2019-01-18.pdf

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
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:** *6.* Pilot-scale prototype system is being demonstrated in a relevant environment.
- **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.

References

Brown, T. R., Thilakaratne, R., Brown, R. C., & Hu, G. (2013). Techno-economic analysis of biomass to transportation fuels and electricity via fast pyrolysis and hydroprocessing. *Fuel*, *106*, 463-469.

Anex, R. P., Aden, A., Kazi, F.K., Fortman, J., Swanson, R.M., Wright, M.M., Satrio, J.A., Brown, R.C., Daugaard, D.E., Platon, A., Kothandaraman, G., Hsu, D.D., and Dutta, A. (2010). "Techno-economic comparison of biomass-to-transportation fuels via pyrolysis, gasification, and biochemical pathways." Fuel Techno-economic Comparison of Biomass-to-Biofuels Pathways 89(Supplement 1), S29-S35.

McCoy, S. (2018). Wood-to-fuel for California's Transportation Sector using Autothermal Pyrolysis [Powerpoint Slides]. Retrieved from http://sofarcohesivestrategy.org/wp-content/uploads/2017/06/McCoy-Wood-to-Fuel-pilot.pdf

Product: Lignocellulosic Ethanol
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.

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
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). 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.

References
Spyridon, A., Euverink, W., & Jan, G. (2016). Consolidated briefing of biochemical ethanol production from lignocellulosic biomass. *Electronic Journal of Biotechnology*, *19*(5), 44-53.

Zhu, J. Y., & Pan, X. J. (2010). Woody biomass pretreatment for cellulosic ethanol production: technology and energy consumption evaluation. *Bioresource technology*, *101*(13), 4992-5002.

Lynd, L. R., Liang, X., Biddy, M. J., Allee, A., Cai, H., Foust, T., ... & Wyman, C. E. (2017). Cellulosic ethanol: status and innovation. *Current opinion in biotechnology*, *45*, 202-211.

Carroll, A., & Somerville, C. (2009). Cellulosic biofuels. *Annual review of plant biology*, *60*, 165-182.

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.

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

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

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).

References

Agenda 2020 Technology Alliance (2016). "Cellulose Nanomaterials Research Roadmap." https://www.researchgate.net/publication/305720842_Agenda_2020_Cellulose_Nanomaterials_Research_Roadmap

Andrews, C (2012). "Wood in Warfare." Engineering & Technology Magazine 7(9).

Shatkin, J. A., et al. (2014). "Market Projections of Cellulose Nanomaterial-Enabled Products– Part 1: Applications." TAPPI Journal 13(5): 9–16.

Stora Enso (2019). "Stora Enso invests in producing bio-based carbon materials for energy storage" https://www.storaenso.com/en/newsroom/regulatory-and-investor-releases/2019/7/stora-enso-invests-in-producing-bio-based-carbon-materials-for-energy-storage

Demuner, I. F., Colodette, J. L., Demuner, A. J., and Jardim, C. M. (2019). "Biorefinery review: Wide-reaching products through kraft lignin," *BioRes.* 14(3), 7543-7581. https://bioresources.cnr.ncsu.edu/resources/biorefinery-review-wide-reaching-products-through-kraft-lignin/

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?** *No*. This product is likely too technologically and commercially immature to be the focus of JIWPI efforts at present.

References

Song et al. (2018). "Processing bulk natural wood into a high-performance structural material" *Nature*, volume 554, pgs 224–228. https://www.nature.com/articles/nature25476

InventWood. "MettleWood." https://www.inventwood.com/mettlewood

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?** *No*. This product is likely too technologically and commercially immature to be the focus of JIWPI efforts at present.

References

US Patent US10480126B2. "Super clear cellulose paper." https://patents.google.com/patent/US10480126B2/en

InventWood. "Transparent Wood." https://www.inventwood.com/transparent-wood

Ye et al (2019). Ultrahigh Tough, Super Clear, and Highly Anisotropic Nanofiber-Structured Regenerated Cellulose Films. *ACS Nano* 2019, 13, 4, 4843-4853. https://doi.org/10.1021/acsnano.9b02081

Zhu, Mingwei et al (2016). "Highly Anisotropic, Highly Transparent Wood Composites". *Advanced Materials*. **28** (26): 5181–5187. doi:10.1002/adma.201600427

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?** *High*. 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.

References

Turkel, Tux (2017) "Maine company seeks to produce innovative wood-fiber insulating boards" *Press Herald*. https://www.pressherald.com/2017/08/17/company-works-multiple-angles-to-produce-innovative-insulating-boards-in-maine/

InventWood. "Insulating Wood." https://www.inventwood.com/insulating-wood

Li et al (2018). "Anisotropic, lightweight, strong, and super thermally insulating nanowood with naturally aligned nanocellulose" *Science Advances*, vol. 4, no. 3, doi: 10.1126/sciadv.aar3724

McCarthy, James (2019). "GO Lab lands $250K grant to test and market its 'disruptive' fiberboard insulation" MaineBiz. https://www.mainebiz.biz/article/go-lab-lands-250k-grant-to-test-and-market-its-disruptive-fiberboard-insulation

Wicklein et al. (2015). "Thermally insulating and fire-retardant lightweight anisotropic foams based on nanocellulose and graphene oxide" *Nature Nanotechnology*, 10, 277–283

4.7. Chemically treated wood

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 attempt, 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. Nowadays, acetylated wood is scaled-up in the Netherlands, under the commercial name Accoya, which utilizes radiate 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)

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

Accsys Technologies PLC (2016). "Annual Report and Financial Statements 2016" http://www.annualreports.com/HostedData/AnnualReportArchive/a/LSE_ACCS_2016.pdf

Papadoupolous et al. "Nanomaterials and Chemical Modifications for Enhanced Key Wood Properties: A Review" *Nanomaterials* **2019**, *9*, 607; doi:10.3390/nano9040607

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

Kebony AS. "New facility set to double Kebony's production capacity" October 10, 2018. https://kebony.com/en/blog/new-facility-set-double-kebonys-production-capacity

Papadoupolous et al. "Nanomaterials and Chemical Modifications for Enhanced Key Wood Properties: A Review" *Nanomaterials* **2019**, *9*, 607; doi:10.3390/nano9040607.

4.8. Chemicals and extractives

Forthcoming

Chapter II. **Trends and projections of timber and biomass supply for wood product innovation**

1. Summary

Information contained in chapter:

1. Summary of supply-based barriers to innovative wood products
2. Analysis of wood supply data for 25 primarily-forested Tier 1 High Hazard Zone counties
3. Exploration of the key elements of a proposed "bufferwood" initiative to ensure reliable wood supply from public and private lands

Methodologies:

1. Literature review
2. 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 supplies;
    b. Dramatic supply variability from year to year;
    c. High cost to access low-grade wood supplies;
    d. Lack of adaptability of both under-utilized and young growth species for use in innovative value-added wood products;
    e. Lack of primary processing infrastructure for non-energy wood products (especially small log processing and dry kiln infrastructure); and
    f. Lack of environmentally appropriate options to harvest fuelwood in 25 primarily forested High Hazard Zone (HHZ) counties.
2. California should convene public and private landowners in a strategy to prioritize removal areas, and support year-round forest maintenance operations that could produce sustainable roadside-ready small log and wood biomass supplies to facilities operating within defined working circles.
3. Over the last 10 years (2009 - 2018) there was an increase in cumulative sawlog volume sold, but not harvested from national forests in analyzed counties. Over that same period, there was an increase in cumulative fuelwood harvested, but not sold off of the same forests.
4. US Forest Service annual harvest volumes have declined over the last five years compared to private land forest restoration in the majority of analyzed counties.
5. Based on an approximate 50-mile-radius from the center of a bufferwood working circle, eight bufferwood 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.
6. Tree mortality in the Sierra Nevada range has most recently been highest in red and white fir stands. Analysis of new innovative forest products for California should address how these species can be used as product supply.
7. Further recommendations for continued intrastate supply analysis include:
    a. Determine the type, size, and volume of forest vegetation that would be harvested and processed within roadside working circles;
    b. Investigate additional options for small diameter log processing, including the applicability of HewSaw technologies; and
    c. Evaluate preferred purchasing options, sustainability certification, Good Neighbor Authority, impact on fire severity/occurrence, offset credit mechanisms, and alternative silvicultural prescriptions within supply areas.

---

2. Introduction

This chapter focuses on the trends and projections of the state of timber and biomass supply in CA that could service new wood product innovation development in the state. Numerous recent publications have targeted analysis on supply options assuming altered regulatory and legal restrictions limiting access to supply. Yet without failing, all publications (and business interviews undertaken for each publication) ultimately underscore six reoccurring supply log jams to moving innovative wood product development forward:

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
6. Lack of primary processing infrastructure for <u>non-energy</u> wood products (especially small log processing and dry kiln infrastructure).
7. Lack of environmentally appropriate options to harvest fuelwood in 25 primarily forested High Hazard Zone (HHZ) counties.

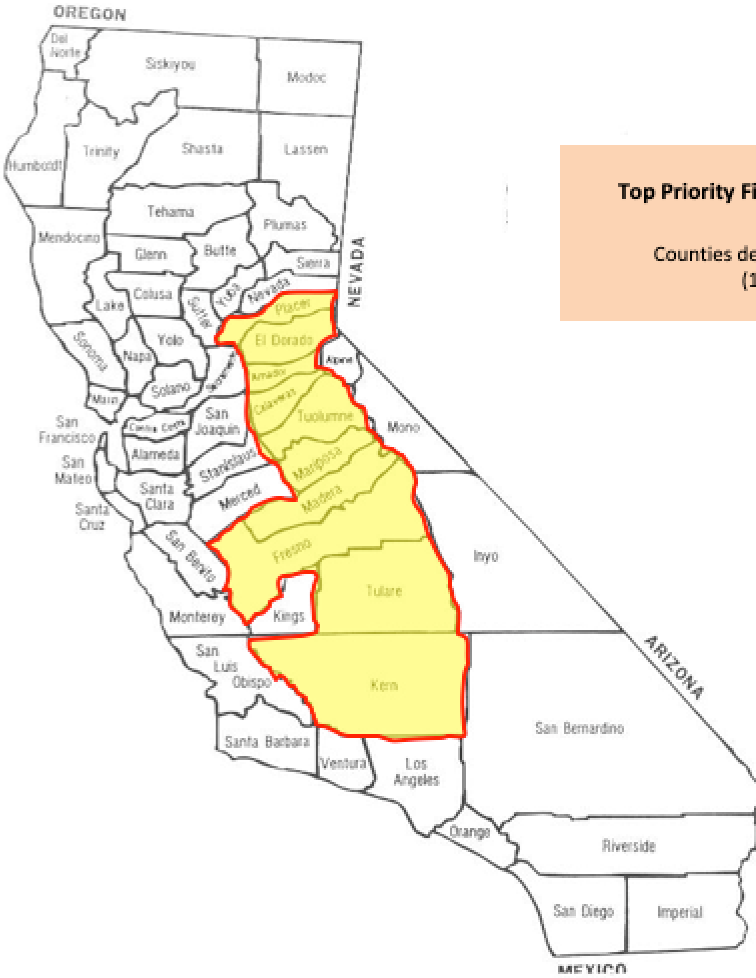
Not withstanding the generally challenging and costly factors associated with establishing new manufacturing operations in California, the research conducted in preparation for this chapter underscores unique opportunities to open access to currently underutilized and added new sources of wood supply. Based on the above, prioritized areas of follow-on research are also delineated in this chapter.

It should be noted that for purposes of this project phase, much of the completed supply analysis is centered around the 25 primarily-forested Tier 1 HHZ counties to support consideration of a "Bufferwood" Initiative in the State.

3. What is a Bufferwood Initiative and why consider implementing it within forested HHZ counties?

Separate from general timber and fuelwood harvest and sales considerations for wood products innovation, CalFire has determined 10 counties in central and southern California to be top priority counties for fire treatment activities (see **Figure A**). Selection of these counties likely followed general patterns of past fire incidents matched to location of larger urban areas and population densities. Dramatic reductions in deadwood trees and deadwood acres on National forestlands throughout California occurred in 2018 *without normal cut and sold documentation* (see cut and sold discussion below) showing who purchased the extracted salvage or fuelwood volume or how much was paid for the supply. This suggests "emergency" extractions may have been allowed presumably at heavily discounted prices or with paid fuelwood removal contracts (see more detailed discussion below on this issue). According to 2019 USFS deadwood data, 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. Questions regarding what the supply was, where the supply went, at what price, and what if any added general timber sales and harvests were triggered by these "emergency" fuelwood removals remain unanswered.

Figure A



Top Priority Fire Treatment Counties

Counties determined by CALFIRE
(10 counties)

Figure 1. Top priority fire treatment counties.

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. See **Figure B** for 2018 statewide overview. These most recent fluctuations in location of deadwood acres and trees matched to likely heavily discounted ‘emergency removal’ prices underscores the necessity of engaging in a larger-scale coordinated strategy that not only targets reduced litigation-risk removal areas, but is designed to provide year-round operations that could produce sustainable roadside-ready small log and wood biomass supply to mills operating within defined bufferwood working circles.

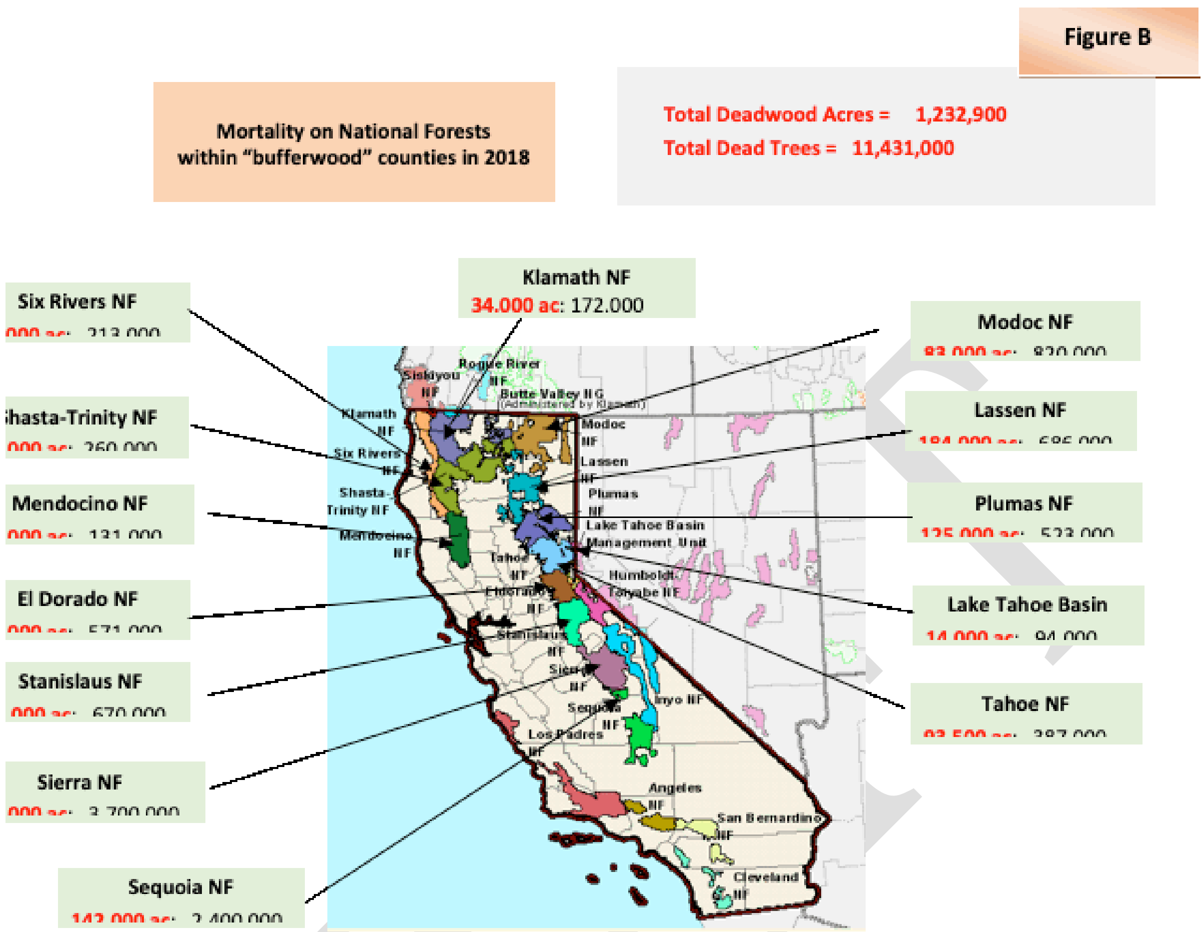


Figure 2. Mortality on national forests within bufferwood counties in 2018.

Key elements of a proposed bufferwood initiative are as follows:

1. “Bufferwood” acres are those acres of land located within a confined strip of <u>forest designated land</u> that measures 300’ from centerline on both sides of a currently open, improved road in forested Tier 1 High Hazard Zone counties. For this project phase we used a 300’ setback from centerline, but that number can be adjusted to better match sustainability requirements to economic viability factors. As an example, in 2015 in Alaska on the Tongass NF, an 800’ bufferwood set-back was used for analysis purposes and coordination with environmental organizations.

2. The limited setback is a crucial bufferwood design element in helping to substantially reduce environmental litigation involving fuel-load reduction strategies. Roadside buffers rarely include environmentally-sensitive conditions or important habitats, yet can house extensive wood biomass and other vegetation that create conditions for extreme wildfires. Much of the wildfire size and origin data analyzed for this project show a notable percentage of the large (>1,000 acres burned per occurrence) wildfires in California since 2013 have been started in roadside areas.

3. There are 25 counties in California with forested Tier 1 HHZ bufferwood acres (see **Figure C**). Almost 60% of those counties are in the northern region of the state; another 30% are located in central California, and the remaining three counties are in the southern part of the state including Kern County

Figure C

Proposed "Bufferwood" Counties

HHZ Tier 1 acres
"Bufferwood" Initiative Counties

- 435,039 forested acres in buffer
- 25 counties
- 35% federal acres
- 64% private acres
- 1% state acres

- Focus is on forest-designated acres
- Buffer = 300' setback each side from centerline of currently open, improved roads.

GIS mapping data for proposed "Bufferwood" Initiative accessible at *www.databasin.org*. (search "Bufferwood") then click on "Bufferwood: High Hazard Forests, Road Adjacent, CA Raster)".

Figure 3. Proposed bufferwood counties.

4. Based on an approximate 50 radial mile distance from a bufferwood working circle (WC) centerpoint, eight (8) bufferwood working circles could become operational (see **Figure D**).

Figure D

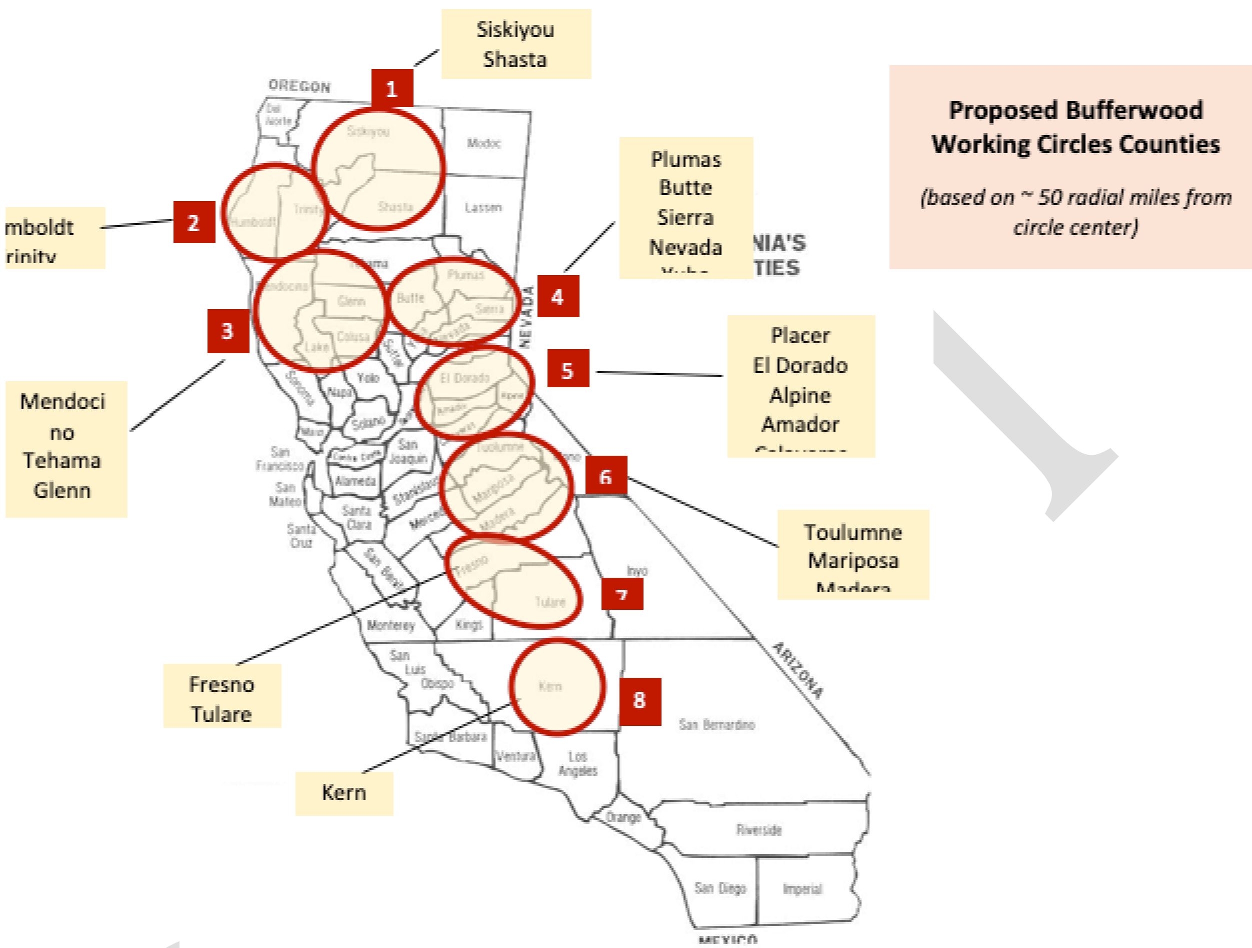


Figure 4. Proposed bufferwood working circles counties

5. Using GIS mapping for this project effort, we were able to determine total bufferwood acres in all 25 bufferwood counties (see **Figure E**). Each working circle has bufferwood acres defined by general landowner types federal forestlands; private forestlands; other public forestlands; and tribal forestlands). In all eight working circles, over 435,000 acres in a 300' bufferwood setback could be made available for bufferwood harvesting to help reduce fire bridging and reshape fire routes and contours. Approximately 46% of those bufferwood acres are located in Northern California bufferwood counties; another 43% are located in central California bufferwood counties; the remainder 12% are located in southern California. For the Northern California working circles between 30% and 50% of bufferwood acres are owned by the Federal government. Between 47% and 70% of acres are owned by private forestland owners. Between 23% and 42% of bufferwood acres in Central California are owned by the feds, with the remainder privately owned. And between 46% to 66% of bufferwood acres in Southern California are federally owned. Altogether, the USFS owns 35% of bufferwood acres; private landowners own 64%; and the State owns 1%.

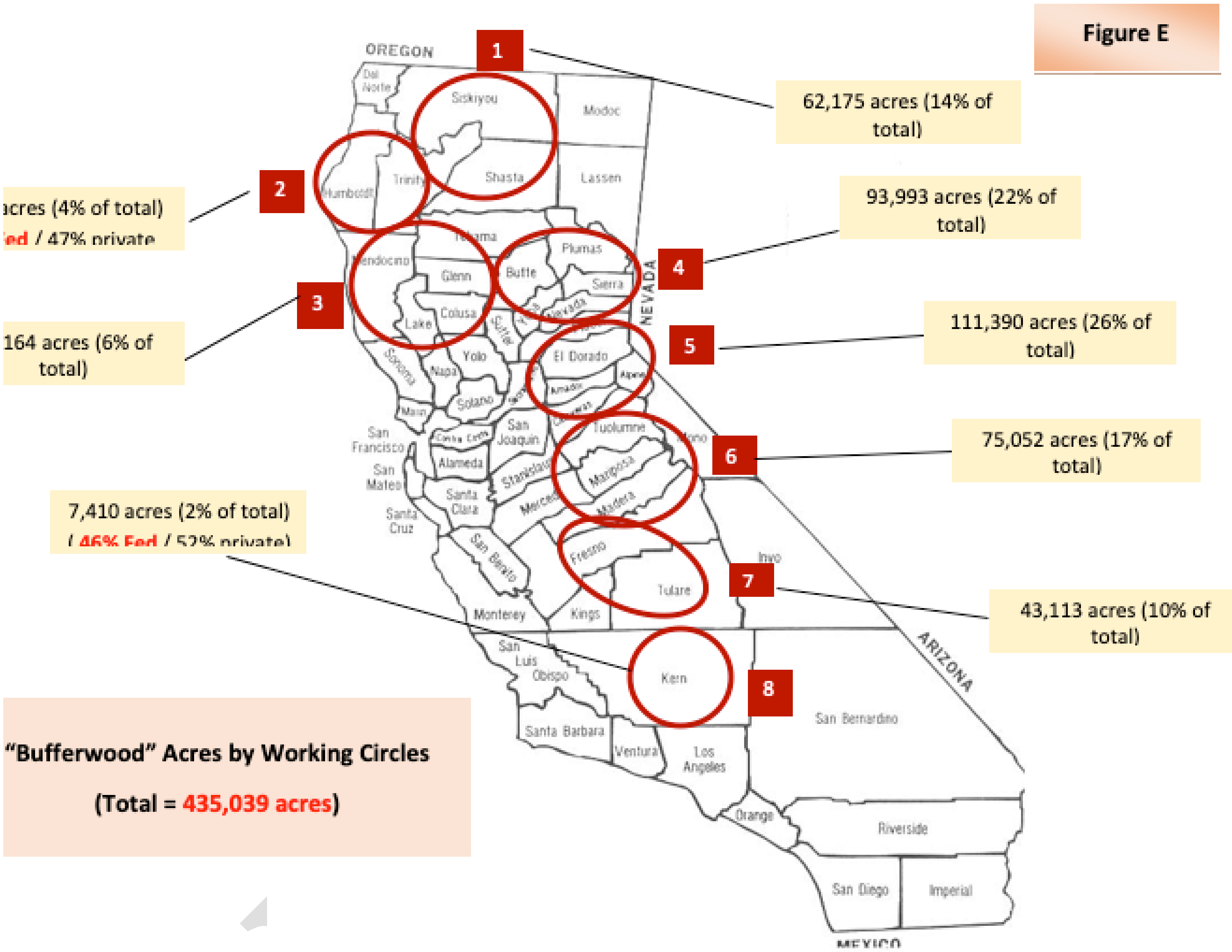


Figure 5. Bufferwood acres by working circles.

6. While over 50% of dead *trees* are located in bufferwood working circles 6,7 and 8 (**Figure F**), the location of deadwood *acres* is more evenly distributed throughout bufferwood working circles (**Figure G**). The abundance of dead trees might suggest a continued focus on bufferwood working circles in the central and southern parts of the state, but an analysis of wildfires over the last six years presents perhaps an added picture for consideration. For this project phase we analyzed all fires recorded in CalFire's published data bank from 2013 through October 2019. We first analyzed for how many burned acres occurred in bufferwood vs non-bufferwood counties, and how the statewide picture looked if you distinguished between fires that burned less than 1,000 acres per each fire occurrence vs those fires that burned over 1,000 acres per fire occurrence. For fires less than 1,000 acres per occurrence, 166,590 acres were burned over the six-year period in the state (**Figure H**). Fifty-two percent (86,973 acres) of all acres burned in this size category in the State were in bufferwood counties. Six out of eight bufferwood working circles each had between 10,000 to 15,000 acres burned in this size category over the six-year period. By contrast, over 5.6 million acres were burned in California where each fire event generated over 1,000 acres burned (**Figure I**). Sixty-seven percent (67%) of total acres burned in this size category in the State were in bufferwood counties but almost 40% of total acres burned in the State were in bufferwood counties housed in working circles 1,2 and 3 (all northern California). Only 13% and 17%, respectively, of all

acres burned in this size category were in central and southern bufferwood counties. When analyzing for number of fires (vs total acres burned) that occurred during the six year timeframe, regardless of fire size per occurrence category, over 50% of all fires per category occurred in bufferwood working circles 1, 2, 3 and 4 (Northern region) (**Figure J**). For fires less than 1,000 acres per occurrence, out of 25 bufferwood counties, Butte, Shasta, Lake, Siskiyou, and Tehama Counties in northern California housed almost 40% of all fires in this size category. In contrast, Fresno, Toulumne, and Kern Counties in central and southern California housed 18% of all fires in this size category. For fires more than 1,000 acres per occurrence, out of 25 bufferwood counties, Siskiyou, Shasta, and Trinity Counties in northern California housed 26% of all fires in this category matching another 26% of fires housed in Fresno, Tulare, and Kern Counties in central and southern California.

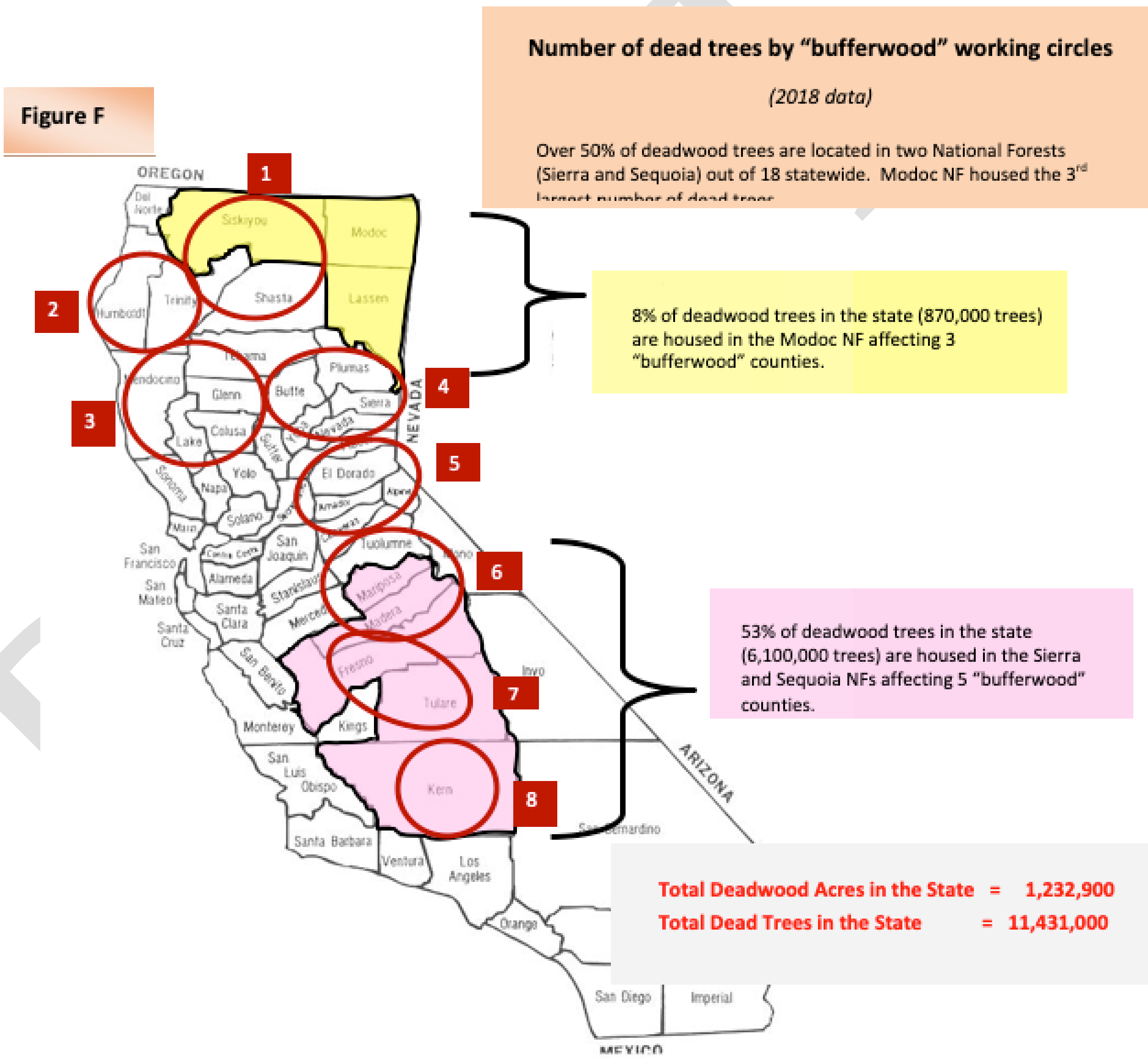


Figure 6. Number of dead trees by bufferwood working circles.

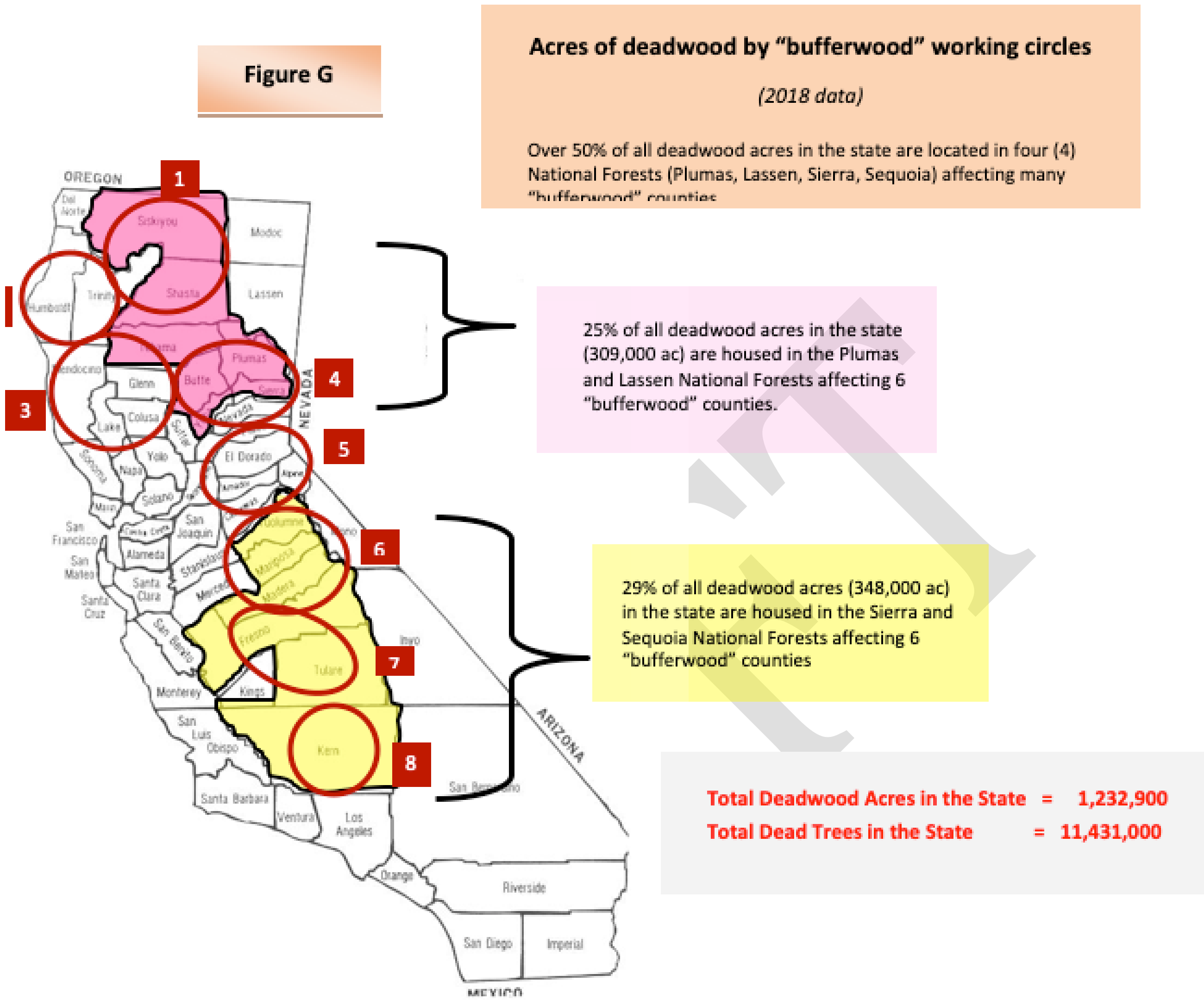


Figure 7. Acres of deadwood by bufferwood working circles.

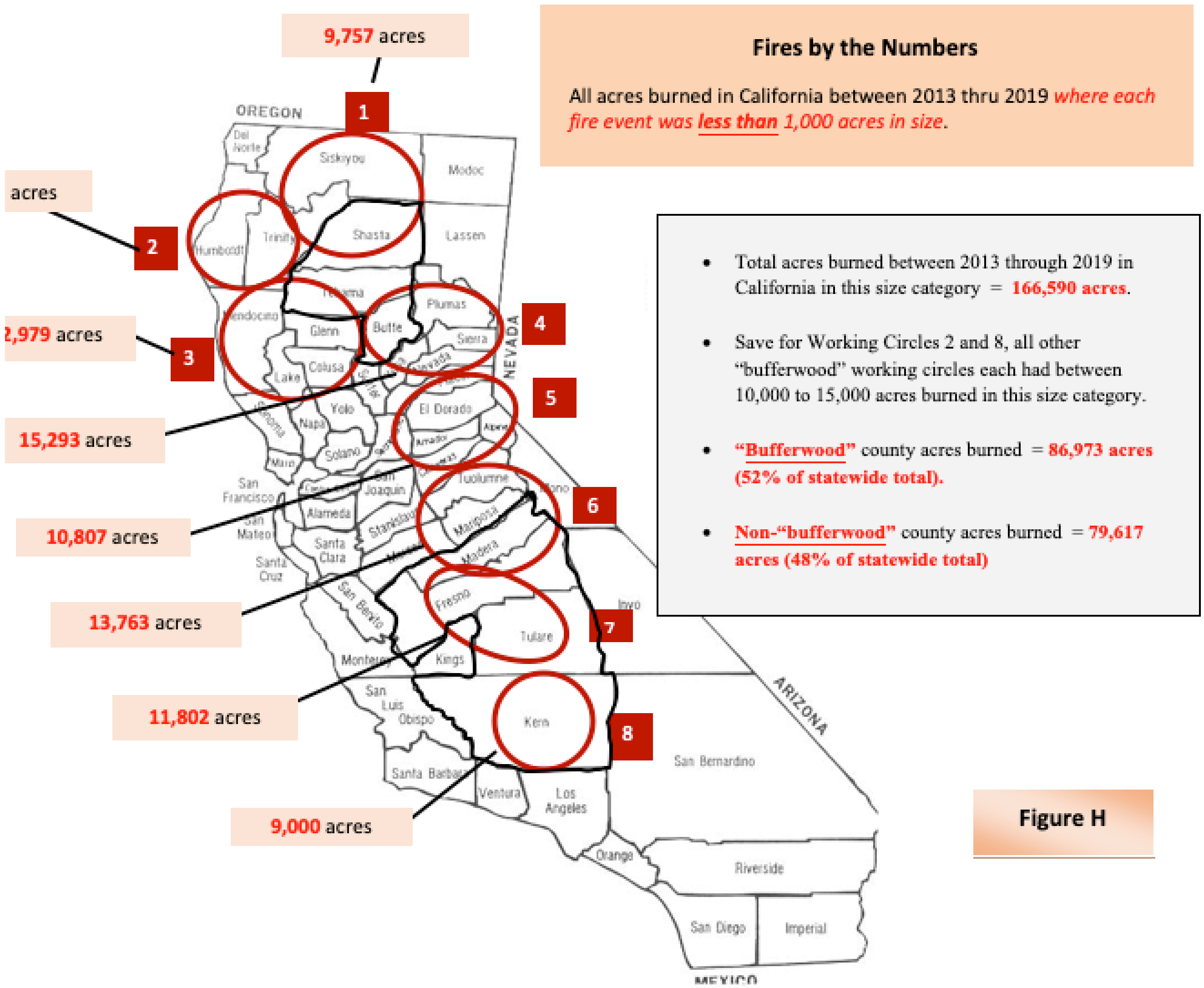


Figure 8. Small fires (<1,000 acres) by working circle, 2013-2019.

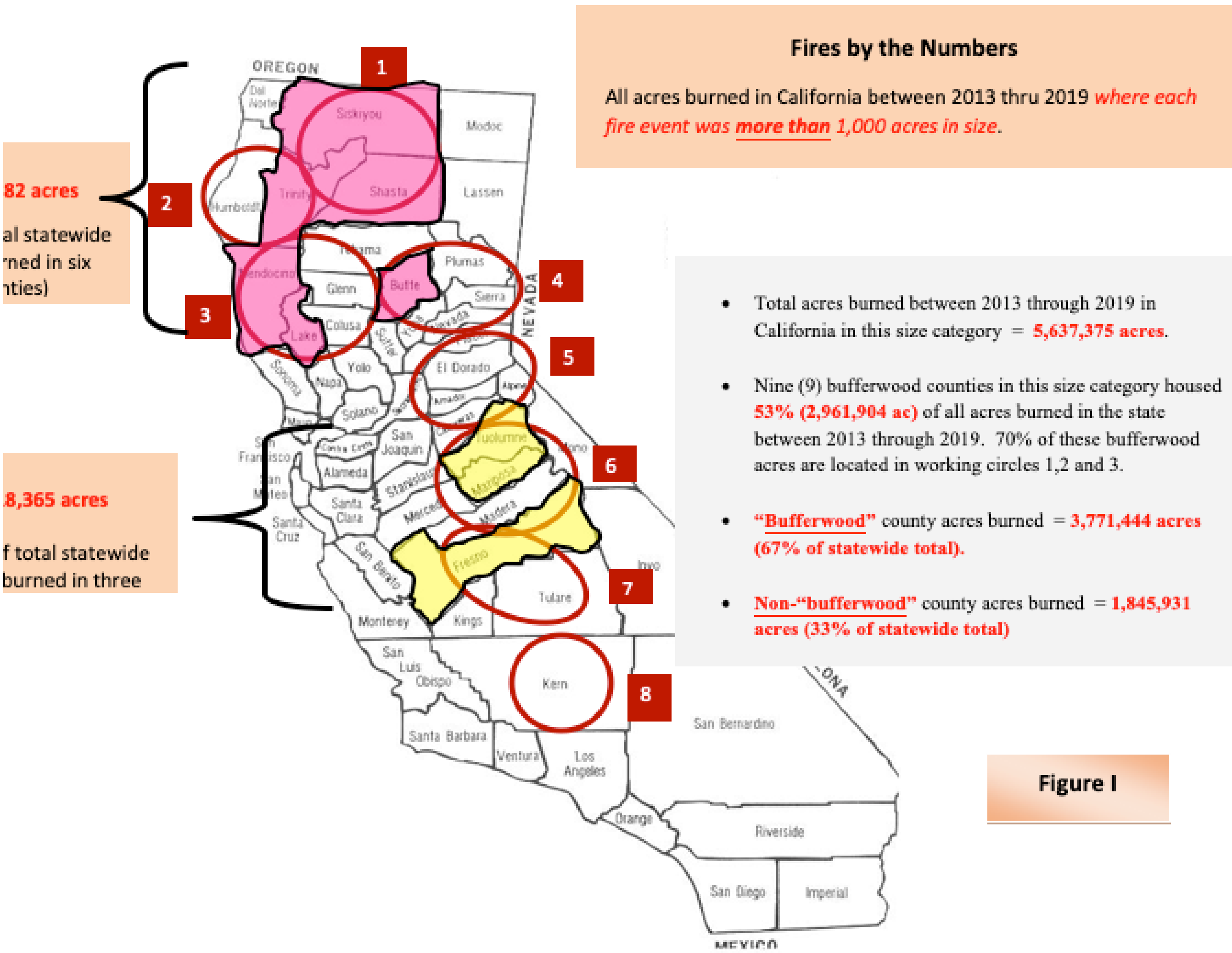
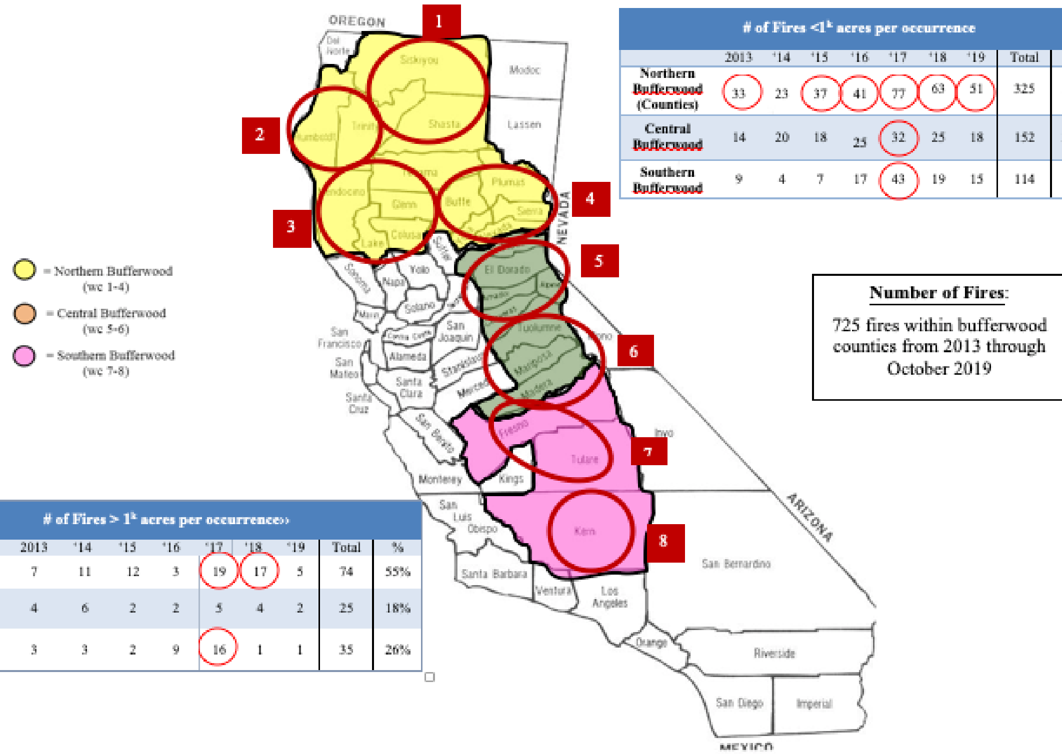


Figure 9. Large fires (>1,000 ac) by working circle.

Figure J



# of Fires <1k acres per occurrence	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%

# of Fires > 1k acres per occurrence»	2013	'14	'15	'16	'17	'18	'19	Total	%
Northern Bufferwood	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%

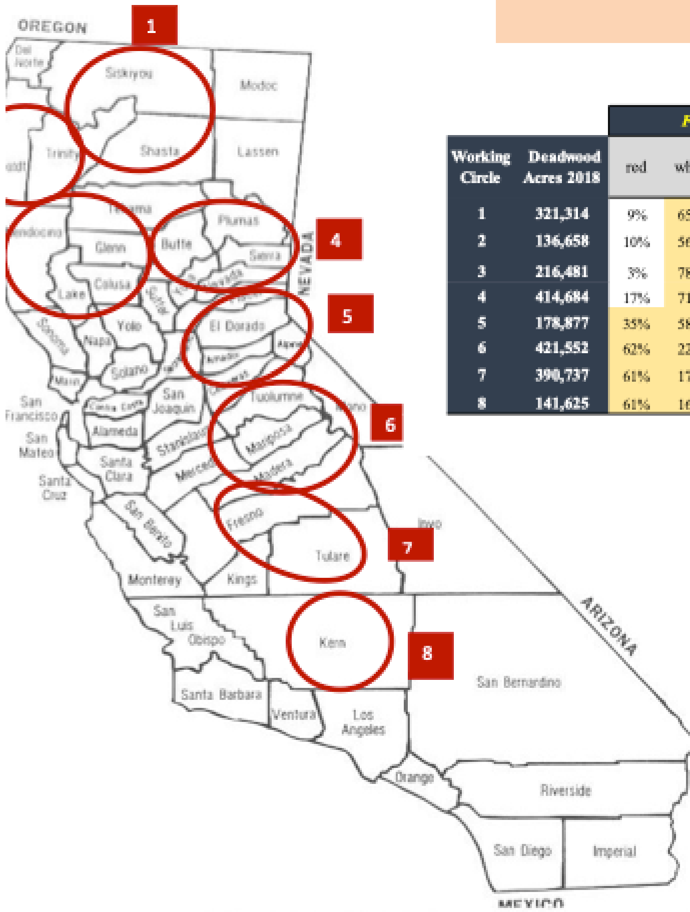
Figure 10. Number of fires, 2013-2019.

7. When viewing the latest 2018 mortality data for federal forestlands, the highest percentages of deadwood acres for all bufferwood working circle occurs in red fir and white fir stands. So analysis of new innovative wood products for California will need to clearly address how these two targeted species can be used as product supply. Between 66% to 93% of all deadwood acres identified within <u>all</u> bufferwood working circles are in these specie classes (**Figure K**).

Figure K

Mortality by species in “bufferwood” working circles

(2018 data)



		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*

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

Figure 11. Mortality by tree species in working circles, 2018.

8. The GIS mapping results for this initial phase of a Bufferwood Initiative have been downloaded into a DataBasin public portal to allow for fast access to current bufferwood data. The bufferwood data layers provide “platforms” that can be data-layered for future bufferwood analysis (see future research areas discussion below). (See www.databasin.org; search “bufferwood”; then click on “Bufferwood: High Hazard Forests, Road Adjacent, CA Raster)”.

4. Recommended Phase 2 research areas for establishing a Bufferwood Initiative in California

- Using DataBasin mapping, determine the type, size, and volume of vegetation that would be harvested and processed within roadside working circles. Of particular importance is the culling out of small logs (down to 5” tops) that are currently left in slash piles. Roadside processing of bufferwood supply should include small log delimbing and bucking to accommodate new recommended small log processing in the State (see HewSaw technology discussion below); and chipping and grinding of residual woody biomass.

Currently, no primary processing mills in California can accommodate small logs (down to 5” tops) on a steady diet, and standard timber cruise protocol for both public and private forestlands only classify down to 6” tops as merchantable supply. Although referenced in prior published data as an important research area, no work has been conducted to date that documents the added sawlog volume that would be generated with a merchantable cruise protocol down to 5” tops. This should be a top priority for the State in order to evaluate future volumes for new innovative wood product development. As example, establishing a CLT operation in California would require a minimum of 22 mmbf log scale for annual supply. Many CLT manufacturers in Oregon and Washington have already invested in installing HewSaw systems to allow for efficient small log processing for CLT and mass plywood production. Much of the supply for these operations come from forest thinning projects where small log supply prior to HewSaw installations had little value.

- UC Berkeley manufacturer’s research data verifies that no mills in California process down to 6” tops on a steady basis. The data further shows manufacturers prefer logs to be at 8” small end for a steady mill diet. Prior research conducted in California shows likely overrun to be at 130% using existing technology to process logs smaller than 7”. This overrun is not financially viable for any milling operation. HewSaw technology can increase overrun on small logs to over 200% but requires a baseline supply volume of 30 mmbf log scale per year to operate cost-efficiently. This appears possible in several working circles based on historic general timber sales and volumes harvest from both FS and private lands. A separate chapter on HewSaw technology will be submitted for this project phase.

- Could bufferwood be harvested year around within each working circle or as a combined set of working circles? How much volume could be sustainably generated?

- Could first-purchase options be set in place for bufferwood working circles allowing manufacturing facilities within those working circles first option for supply purchase (similar to the old USFS sustained yield units)? Requirements to secure the sale would include a requirement for value-added manufacturing within the supply working circle. Precedent has already been established within the USFS for this “sustained yield” protocol, so approval for implementation would be through administrative ruling.

- The initiative presumes clearcutting of bufferwood acres with no replanting required. As a roadside clearance operation, all roadside-ready supply will be considered eligible for use in alternative energy production in the State. Given the interest of some offshore markets (like Japan) for ‘certified’ wood biomass supply for energy production, could a “bufferwood” certification chain of custody protocol be developed to provide market advantage for supply generated from a statewide bufferwood initiative? Could existing forest certification programs (FSC, SFI, etc.) be expanded to include a “bufferwood” certification based on independent third-party verification which may likely be required to capture market advantage? The bufferwood certification could only be applied in states with a history of catastrophic wildfires and a trending of catastrophic wildfires in the future, securing an immediate branding advantage for California.

- Could the Good Neighbor Authority (GNA) protocol be modified to also apply to only bufferwood acres on private lands? How might financing be secured to undertake a bufferwood GNA program on both public and private lands?

- From a wildfire perspective, if a bufferwood initiative were implemented as proposed, how might the occurrence and sizes of wildfires be affected? In particular could implementing the initiative reduce the number of large-scale fires (over 1,000 acres burned per occurrence)?

- Could a bufferwood initiative help increase much-needed forest thinning projects by using selective harvesting and reduced clearcutting on forested acres already targeted for thinning that are immediately adjacent to bufferwood zones? These possible 'thinning bridges' could be an added data layer to the DataBasin platform for analysis purposes and could be an important new tool to increasing fuel load reductions while operating within sustainability parameters watched closely by environmental communities in the State.

- 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. 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, allowing the State to serve as the lead agent for a bufferwood initiative. This would be a new type of carbon offset project for CARB, but not necessarily impossible to design and implement.

5. General sawtimber and fuelwood supply constraints that should be addressed to compliment a bufferwood initiative undertaking

There are two key areas of focus with regard to sawlog and fuelwood volume cut and sold from both federal and private forestlands that warrant added examination:

1. Over the last ten years (2009 through 2018) there was an <u>increase</u> in cumulative sawlog volume <u>sold but not harvested</u> off national forests in bufferwood counties. Over that same period of time there was an <u>increase</u> in cumulative fuelwood <u>harvested but not sold</u> off of those national forests.

   For this project phase we analyzed all FS Cut and Sold reports going back to 2009 to gain a better understanding of volume location and offerings likely to come from FS lands throughout the state in the future. While some carryover between volumes sold and volumes cut, particularly in sawlog volumes, is to be expected, the net cumulative volumes for sawlog volume sold but not harvested in many of the NF systems over the last decade through 2018 was alarming. During the last ten years, over 355 million board feet of sawlog volume sold off of national forests in bufferwood counties appears to have not been harvested. An average cumulative annual carryover of ~ 20 mmbf log scale may be considered reasonable for future harvest planning purposes, but over half of the NFs in bufferwood counties show net cumulative sawlog volumes not harvested that exceed this annual carry-over range (**Figure L**). The Klamath NF had a net cumulative carryover of 73 mmbf at end of 2018; the Ed Dorado NF had 54 mmbf; the Sierra NF had 47 mmbf; the Stanislaus NF had 45 mmbf; and the Modoc NF had 32 mmbf. In contrast, the Shasta-Trinity NF appears to have harvested ~22 mmbf more of sawlog volume than was sold over the last decade. **Appendix 1** shows the progression of net carryover in sawlog sale volumes per year by NF over the last decade. The trended increases in net carryover sawlog sold but not harvested volumes beginning around 2015 in the 5 national forests detailed above needs further examination. Also noteworthy are the key purchasers of sawlog sales during the last decade on these national forests.

Based on USFS Volume Distribution Reports we obtained for the past 10 years, the top sawlog sales purchasers for the five national forests were: SPI for El Dorado, Stanislaus, and Sierra National Forests; Siskiyou Cascades Resources for the Klamath Nation Forest; and Franklin Logging for the Modoc National Forest.

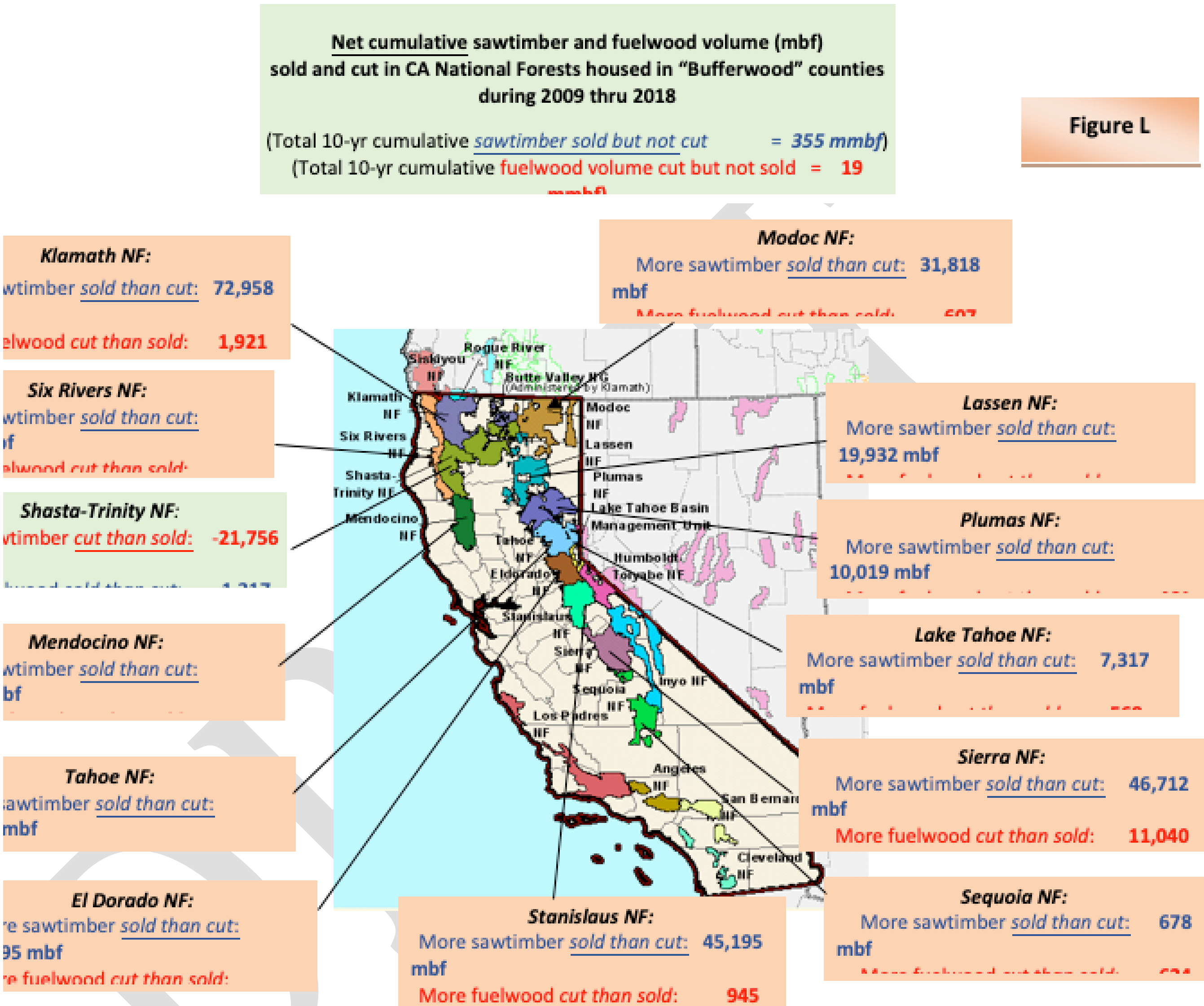


Figure 12. Sawtimber and fuelwood cut and sold in each National Forest housed in bufferwood counties, 2009-2018.

With regard to net fuelwood data obtained from Forest Service Cut and Sold reports (and perhaps reflecting back on the prior discussion of "emergency removal" practices) all NFs save the Shasta-Trinity NF forest appear to have harvested more fuelwood than they sold over the last decade. Total net cumulative fuelwood volume harvested but not sold by 2018 was ~19 mmbf for the 13 national forests in bufferwood counties. Out of the 13 national forests, a net cumulative average of ~650,000 board feet more of fuelwood was cut than sold by 2018 in all but the Shasta-Trinity and Sierra national forests. The Forest Service data shows the Shasta-Trinity National Forest appears to have sold more fuelwood than they cut over the last decade, and shows that the Sierra National Forest cut over 11 million board feet more fuelwood volume than it sold through 2018. **Appendix 2** shows the progression of net cumulative carryover in fuelwood sales per year by NF over the last decade and spotlights the dramatic change in cumulative fuelwood volume harvested over sold that occurred on the Sierra National Forest beginning 2016.

2. There has been notable reduction in average annual harvested volumes from Forest Service lands compared to private lands in the majority of bufferwood counties over the last half decade. For this project phase we obtained annual harvest data published by the Bureau of Business and Economic Research (BBER). The data records separate annual harvest volumes experienced in each bufferwood county by private/tribal forestland harvest volume compared to harvest volume from federal lands in each county. To look at supply trending and projections, we analyzed the average annual harvested volumes from 2009 through 2013 (first half decade) and then compared that to average annual harvested volumes from 2010 through 2018 (second half decade).

   Harvest volume from private lands:

   Eighty percent (80%) of bufferwood counties experienced average annual increases in harvested volumes from private lands in the second half decade compare to the first half decade (**Figure M**). Net average annual harvest volume increases from private lands for the second half decade in all bufferwood counties equaled 152 mmbf. Almost 70% of gross average annual harvest volume gains over the first half decade (which equaled 202 mmbf) occurred in four bufferwood counties: Siskiyou County (bufferwood working circle #1); Humboldt County (bufferwood working circle #2); Mendocino County (bufferwood working circle #3); and El Dorado County (bufferwood working circle #5). Almost 75% of that gross average annual harvest volume gain occurred in bufferwood counties in northern California (working circles 1,2 and 3). Five bufferwood counties (20%) experienced a decrease in average annual harvest volume from private lands in the second half decade. The total average annual volume decrease in bufferwood counties equaled 50 mmbf, with almost 80% of that volume loss coming from Shasta County (working circle #1) and Tehama County (working circle #3).

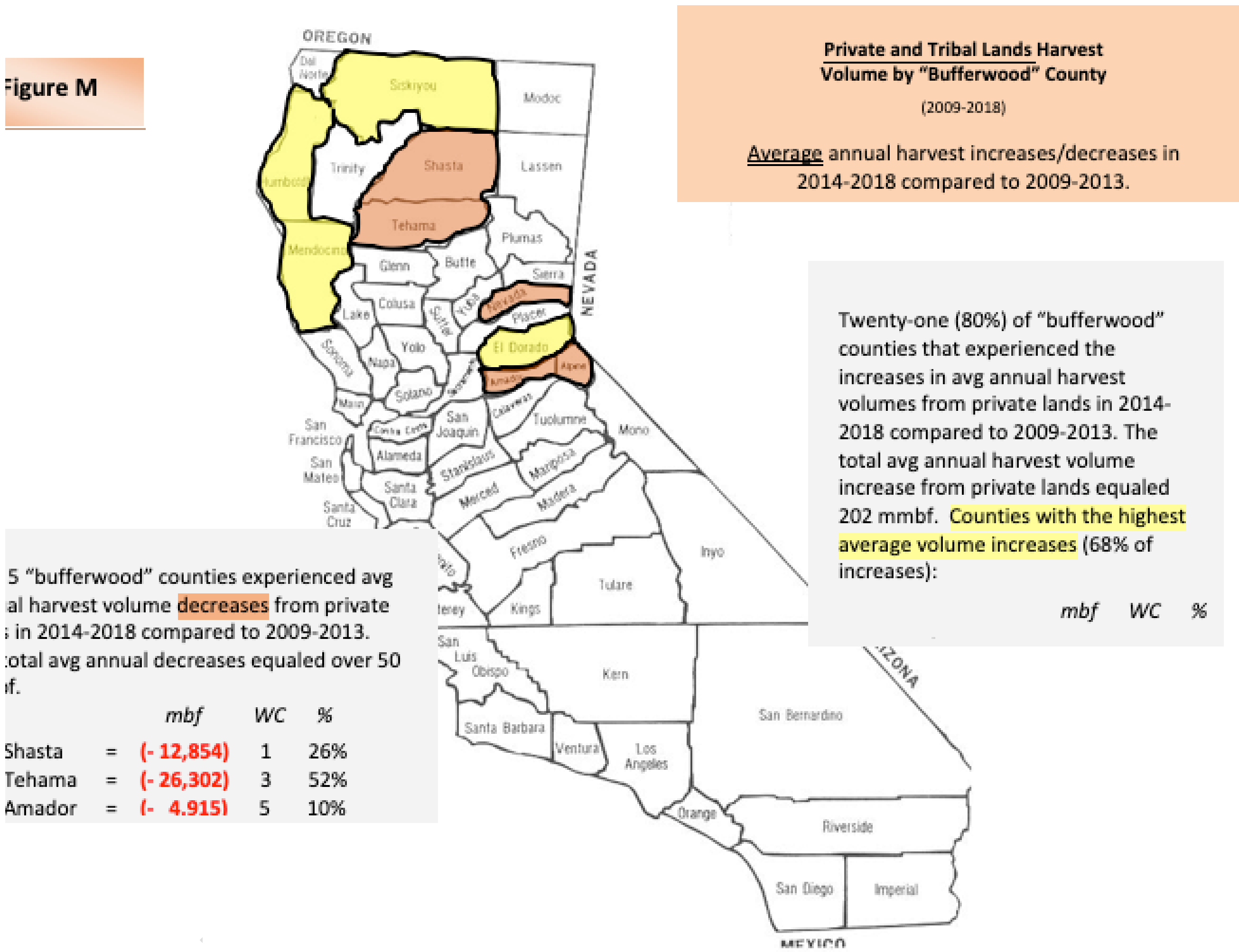


Figure 13. Private and tribal lands harvest for each bufferwood county, 2009-2018.

<u>Harvest volume from federal lands:</u>

Over half (56%) of bufferwood counties experienced average annual decreases in harvested volumes from federal lands in the second half decade compared to the first half decade (**Figure N**). Sixty percent (60%) of gross average annual harvest volume losses from federal lands in the second half decade (which totaled ~19 mmbf) occurred in bufferwood counties in working circles 2,3 and 4. Interestingly, Sierra County experienced the highest average annual harvest volume loss of all bufferwood counties (~3.5 mmbf) followed by Plumas County (~2.7 mmbf). Both counties are in bufferwood working circle #4. It is unclear why there was a notable drop in average annual harvest volume from federal lands in the same counties that experienced notable harvest increases from private lands during the second half decade. And, as noted earlier, the harvest volumes from federal lands do not necessarily track with volume sold from federal lands through 2018.

While the majority of bufferwood counties experienced average annual harvest volume losses from federal lands in the second half decade, the overall gross average annual harvest volume gains, at 102 mmbf, dwarfed overall losses, producing a net average annual harvest gain of 83 mmbf for all bufferwood counties. However, as a tempering comment, it should be noted that almost 60% of that total harvest gain from federal lands occurred only in two counties: Placer County (working circle #5) and Toulumne County (working circle #6).

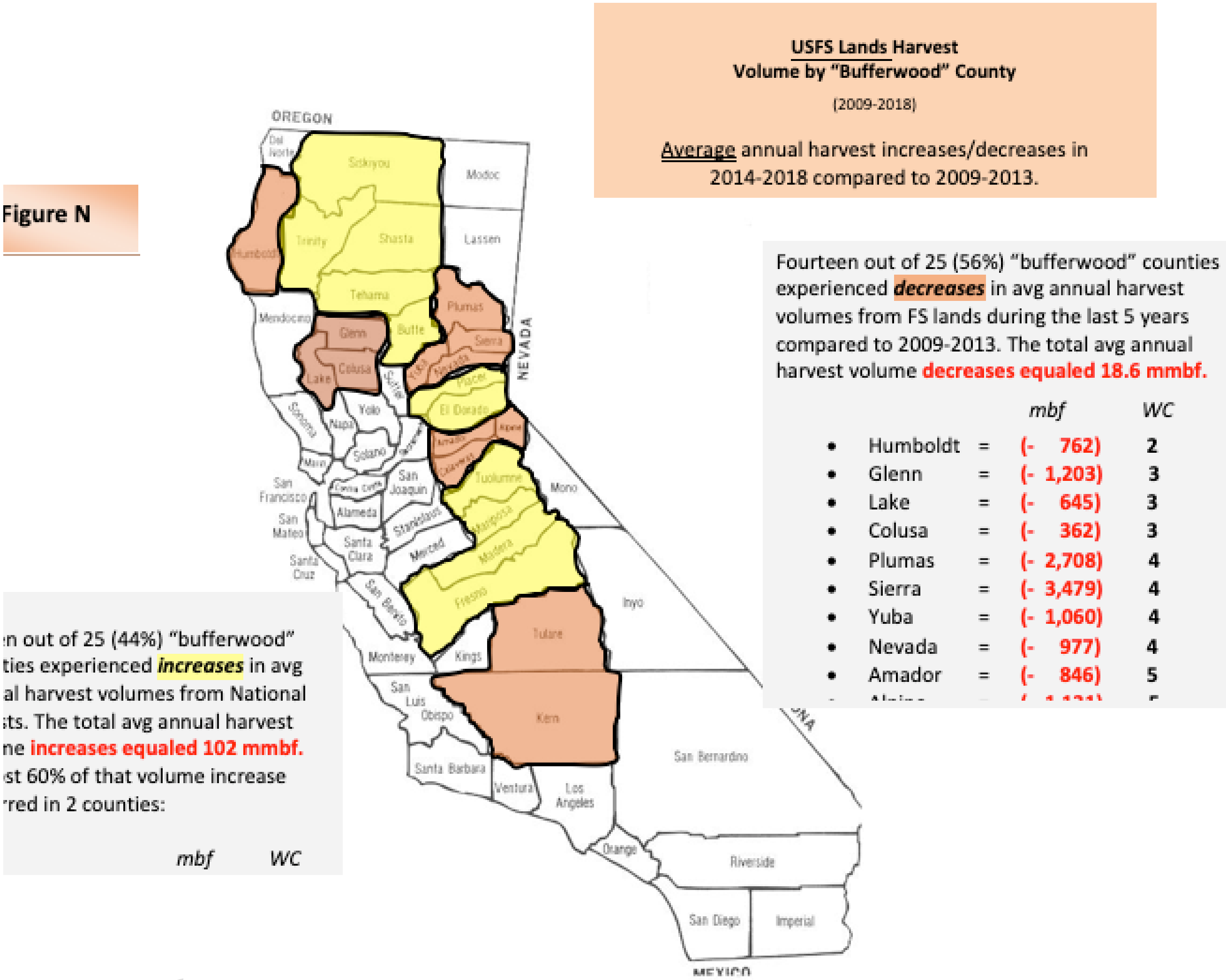


Figure 14. USFS harvest volumes in bufferwood counties, 2009-2018.

Best bets for future feedstock supply for innovative wood product development based on historic bufferwood county harvest trends:

Research shows that a medium-sized CLT or mass plywood operation would require between 20 mmbf to 30 mmbf log scale per year to operate. A medium-sized engineered wood flooring operation would require about the same log scale volume to operate a facility in northern California and generate green power to both run the facility (at ~ 2 MW requirement) and sell an excess of 3 MW to the regional power grid[1]. It remains unclear how much log scale volume would be required to operate typically lower-yield (more log volume required to produce end product volume) operations such as might be required for pyrolysis, wood-based fuels, or biochar operations. What seems clear is that projected overall traditional wood supply within only four of the eight bufferwood working circles would be sufficient to accommodate an additional wood product innovation plant assuming the following:

[1] CMM; personal conversations with Jim Litherland.

- Existing demand for current volumes harvested in each county would continue, requiring additional volume to come on board during the next half decade (2020-2024) to accommodate wood innovation product development.

- Projected increases in wood volume for 2020-2024 are conservatively based on 50% of the actual average annual harvest volume increases experienced in each bufferwood working circle in the second half decade (2014-2018).

Appendix 3 provides the breakout of average annual harvest increases/(decreases) for the second half decade compared to the first half decade for all eight bufferwood working circles. **Figure O** summarizes the results for projected future supply meeting the minimum 20 mmbf/yr requirement within bufferwood working circles 1,2,5 and 6. All other working circles fall below the 20 mmbf/yr added harvest volume requirement. This scenario obviously does not address the requirement for desired long-term supply (typically 10 years), but does show the potential to meet future demand under a business-as-usual scenario without factoring in added long-term supply that could potentially be generated by engaging a bufferwood initiative and altering timber cruise protocol to adjust merchantable volume calculations based on a 5" top (vs the 6" now used). These projected results also bode well for utilizing existing and idled infrastructure already in place that could be modified, expanded, or re-engaged to accommodate new innovative wood product development. **Figures P and Q**, respectively, show 17 out of 29 (~60%) of currently operating sawmilling facilities and 10 out of 16 (63%) of currently idled sawmilling facilities in California reside in the 'best bet' working circles identified above.

Figure O

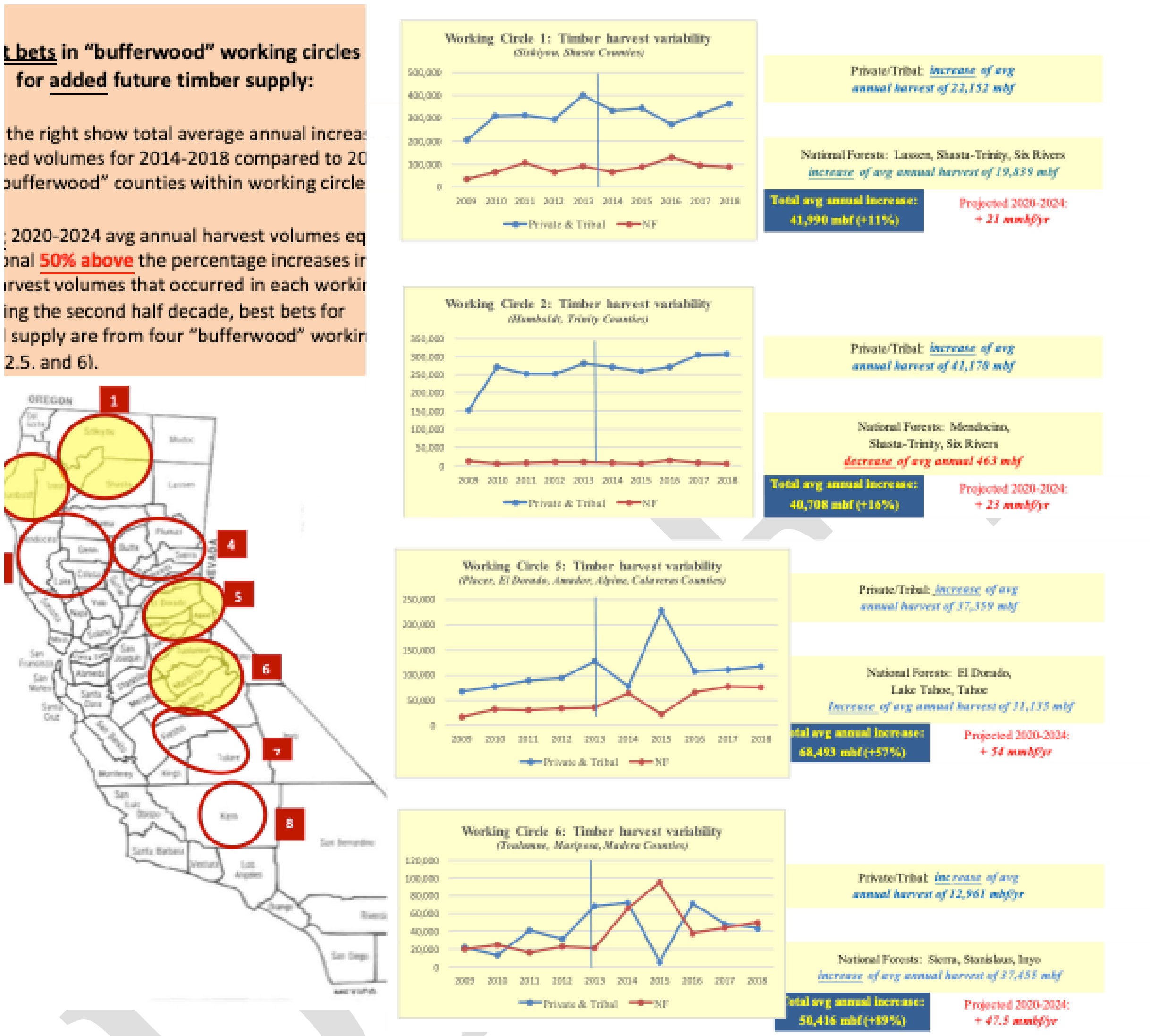
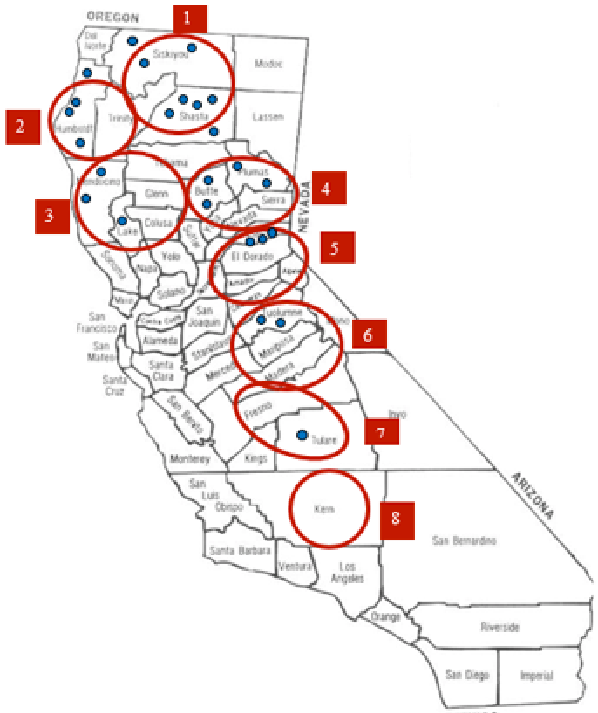


Figure 15. Best bets in bufferwood working circles for added timber supply.

Sawmills in operation in 2019

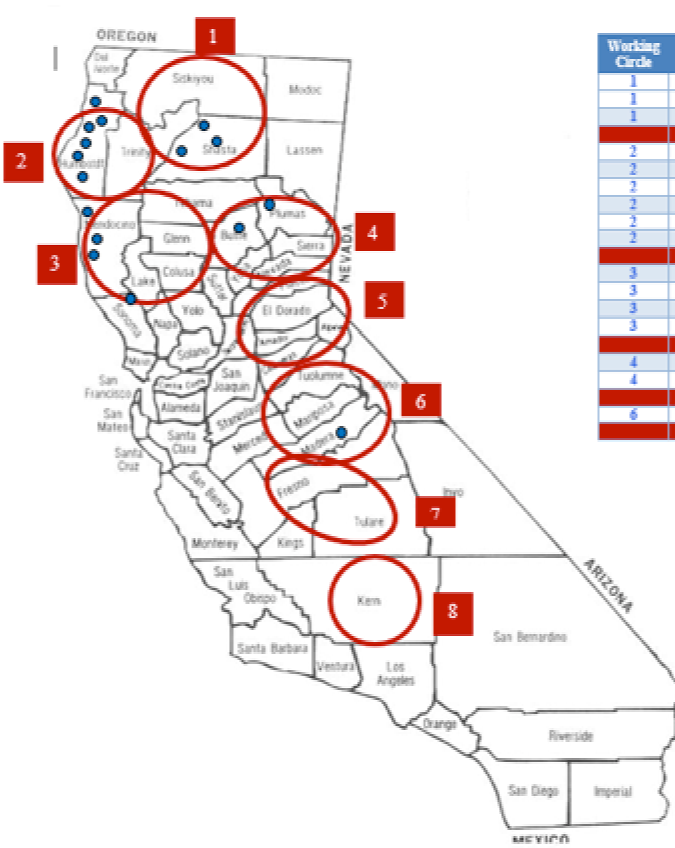


Working Circle	Company	City
1	Sierra Pacific	Anderson
1	Shasta Green Sawmill	Burney
1	Sierra Pacific	Burney
1	Sierra Pacific	Redding
1	Alta California Roundwood	Anderson
1	Roseburg Forest Products Veneer Mill	Weed
1	Fruit Growers Supply Co	Yreka
1	Timber Products Co	Yreka
2	Schmidbauer Lumber	Eureka
2	Arcata Forest Products	Arcata
2	North Fork Lumber Co	Korbel
2	Arcata Forest Products	Arcada
3	Collins Pine	Lakeview
3	Agwood Mill & Lumber Co	Ukiah
3	Mendocino Forest Products	Ukiah
4	Sierra Pacific	Oroville
4	Apex Lumber	Oroville
4	Collins Pine	Chester
4	Sierra Pacific	Quincy
5	Sierra Pacific	Lincoln
5	Bohemia	Lincoln
5	California Hardwood Producers	Auburn
6	Sierra Pacific	Chinese Camp
6	Sierra Pacific	Sonora
7	Sierra Forest Products	Terra Bella

Figure 16. Sawmills in operation in 2019.

Figure Q

Sawmills idle in 2019



Working Circle	Company	City
1	Elkins Sawmill	Anderson
1	Publishers	Burney
1	US Plywood Champion Papers	Anderson
2	Britt Lumber/Arcata Forest Products	Arcata
2	California Redwood Co	Korbel
2	Britt Lumber/Arcata Forest Products	Arcata
2	Louisiana Pacific	Carlotta
2	Englewood Lumber	Redcrest
2	Pacific Lumber Co. Mill B	Scotia
3	Georgia Pacific	Potter Valley
3	Harwood Products	Willits
3	Coombs Lumber	Piercy
3	Molalla Forest Products	Cloverdale
4	Butte Lumber Co	Chico
4	Erickson Lumber, Plumas Lumber	Crescent Mills
6	Yancey Lumber Co	Madera

Figure 17. Sawmills idle in 2019.

Chapter III. **Strategic partnership landscape, gaps, and recommendations**

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 roadblocks and barriers in 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. 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.
2. Areas of focus for the Institute 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>Operations</u>**:** Identify regulations 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.
3. Near-term areas of focus
    a. Conduct applied research and analysis, and
    b. Advance collective action.
    c. Programmatic focus areas
        i. De-risk wood innovation markets through public funding;
        ii. Training and education;
        iii. Steward innovative financing to attract private capital;
        iv. Organize platforms for collective action; and
        v. Educate the public about forest sustainability, mass timber, and forest product innovation
4. Longer-term areas of focus
    a. Encourage entrepreneurship and business development

Related Appendices: (5A) Organizations interviewed (5B) Domestic and international academic centers of excellence in wood product innovation (5C) Forest Futures gathering back-casting worksheet and workshop results and report-outs (5D) Bibliography

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[2] 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]

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."*

Table 12. Activities as mandated by the Joint Institute for Wood Products Innovation Charter.

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 industrial operations, 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 forest fiber that promote California's healthy forest initiative.
- **Operations:** Identify regulations 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.

[2] The SB859 Working Group first recommended the establishment of a Joint Institute to "align California academic centers to perform product research, development, and testing; promote business innovation; and connect diverse disciplines to accelerate research, development, and adoption, including forestry, wood engineering and nanotechnology, business administration, marketing, architectural design, and forestry workforce development."

	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 collective action: 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 5.2: Recommended Institute programs – a logic model and methodology for prioritizing individual projects and scopes.

3. 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. De-risking the underlying economics of wood innovation markets through public funding

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 annual billion-dollar need. Market-based demand for forest-thinned material could defray costs and increase the pace of restoration. However, this is an infrastructure-heavy, capital-intense, and high-risk market at present. The primary challenge is not a lack of private capital, but rather the underlying economics. Policy changes that can help correct wood market challenges include: assigning a monetary value to forest restoration public benefits, placing a cost on the externalities of catastrophic wildfire, and providing financial security to address the untenable risk-to-upfront-cost ratio for critical infrastructure development.

Ensure State bond measures enable forest restoration investment and wood product infrastructure. There are bond measures in the next legislative cycle directing capital either directly allocated for forest restoration or, at a minimum, accessible to forest restoration projects. Communicating the importance of wood product infrastructure, including biomass power and biofuels, in this funding with the appropriate agencies and legislators is key. To reach current forest resilience goals, it is critical that we utilize all available funding tools, improving existing funding structures[3] and simultaneously developing new 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.[4] 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 transportation including roads, rails, and diesel is a significant barrier to forest wood innovation market growth. Californians paid an average of $.30 more per gallon of gasoline than Americans in other states in 2018.[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,[5] taxes, BioRAM reforms,[6] and more. Findings could help inform the following:

---

[3] 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.

[4] 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

[5] 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.

[6] 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

- 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 (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 outcomes. Institute research and convening work focused on developing the methods and metrics for shifting land management rewards from the "value of a tree" (which, for small diameter trees, is often a net cost) to the "value of an acre restored" could be a significant contribution to the sector.

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 Polytechnical Institute (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

like the BioRAM sealed bid auction process to bring more biomass power plants that are currently idle back into an operating capacity.

innovation markets. Additionally, continual budget cuts to California's academic systems result in (or exacerbate) competition for resources and/or de-facto privatization, 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, annual basis.[7] 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.[8] **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.**[9]

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 and Oregon State University,[10] expressed interest in developing a platform to share curricula and expertise in service of kick-starting West-wide wood innovation markets.[11] 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).

3.3. Stewarding innovative financing to attract private capital

Monetizing the public benefit of forest restoration to stimulate wood innovation markets is essential. In 2018, California spent $947 million on fire suppression and emergency response, far exceeding the budgeted $450 million[x] 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. Internalization of these externalities is key to understanding the full value of forests and forest resiliency.

---

[7] For example, the Energy Biosciences Institute partnership between Shell and UC Berkeley.

[8] 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.

[9] 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.

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

[11] 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.

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 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 section is in the form of venture capital investments in individual businesses[12] 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.[13] In short, private finance currently has little ability to affect restoration at a scale proportionate to the challenge.

Blended finance 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. There are two private entities in California focused on establishing innovative finance to increase the pace of forest restoration.

- Climate Trust Capital makes early-stage investments in (approved by the California Air Resources Board and other federal/State bodies) qualified carbon reduction projects and generates revenue through the sale of carbon offsets on both the California and voluntary offset markets.[14]
- Blue Forest Conservation operates a pre-development loan fund for approved restoration projects, financed via private and foundation investment in a conservation bond. They have played an ad hoc role in furthering additional innovative financial models throughout the State and are aiming to pioneer additional models over time.[15]

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 require 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

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

[13] 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.

[14] This model has some associated risk given the volatility of offset supply and demand (particularly in voluntary markets) and the risk of attaching any investment to regulation and a government-mandated program which could shift over time.

[15] Offset invalidation is not a material risk (less than 1% of all compliance offsets have been invalidated).

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.[xiv] Further, the vast majority of federal wildfire expenses (85%) are related to short-term expenses such as emergency response, and not long-term resilience.[xv] 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) network 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 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. The annualized economic burden from wildfire is estimated to be between $71.1 billion and $347.8 billion (2016 data). Meeting the 1 million-treated acres/year goal[16] will cost approximately $2,500-$3,000/acre for sustainable thinning, or close to $3 billion/year for about 10 years,[xviii]

[16] Newsom's executive order, January 2019.

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.[17] 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,[18] 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.

Housing: There are numerous opportunities to link housing to forest restoration range, 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

[17] Interestingly, one entrepreneur is attempting to create a new wildfire insurance company, focused on wildfire. It is extremely challenging to do because of State and federal regulations, ultimately requiring that the entrepreneur initially partner with existing insurers.

[18] 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.).

the University of Arkansas.[xxv] [19] 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),[20] 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 mean 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. Collective action platforms

Collective action platforms from neutral bodies are critical to break down siloes and democratize knowledge and networks. 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.

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

[19] The wood used was spruce, pine, and fir sourced from Europe.
[20] 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.

boundaries.[21] [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.

Ignite 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 for efficient use of all forest material: There is opportunity to build collaboration within industry and investment as it relates to waste streams and feedstock use. For example, cross laminated timber (CLT) uses approximately XX of its input by mass. The rest is unusable due to quality constraints (cite). Therefore, a viable CLT business is 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.[22]

Publicly articulate the need for a California timber industry forum: Unlike other industries in California, there is no forum for connection and knowledge-sharing within the timber industry. There is a need for a roundtable to foster common language, build relationships and establish narrowly defined working groups of mutual interest across stakeholders to address forest restoration, specifically sustainable thinning, across land management boundaries. Interviews with some timber industry representatives suggest an appetite for a broad collaborative platform[23] where they can express their perspectives in terms of the market value of their assets, and pursue discussions of both risk mitigation and carbon sequestration in a productive, non-adversarial, and action-oriented environment. Some noted the need for this to be very closely defined so any collaborative is addressing a very specific challenge and includes the necessary stakeholders for action rather than broad consensus building.[24] This collaborative would need to be led by a neutral entity with some industry or commercial experience. The Institute, as a public agency without the flexibility to pivot outside of scopes and with time-intensive public notification requirements, is not the right entity to take this on – it is nonetheless a critical gap to identify for catalyzing these markets. The Buy National Softwood Lumber Council is a good example to follow, enabling industry to convene and the legislature to ultimately hear from a variety of stakeholders directly.

3.5. Public Education

Sustainable wood innovation markets offer a critical 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

[21] 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.

[22] Brian Brashaw.

[23] Neal Ewald of Green Diamond notes that while they do not prioritize the use of small diameter trees, 'every tree has a top' and there is "a lot of inherent interest in adding value to the byproducts of dimensional lumber and traditional timber harvest" However, there are currently no collaboratives that effectively provide opportunity for regulators, policy makers, and timber industry leadership to discuss opportunities in a neutral space. This was reflected in discussion with several private landowners and timber companies.

[24] The Sierra Pacific Industry's cross-boundary prescribed fire collaborative is a good example.

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.[25] 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:

- Compelling education and outreach highlighting the benefits of forest resilience and sustainable forestry;
- 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.

[25] 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.

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.[26] 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.

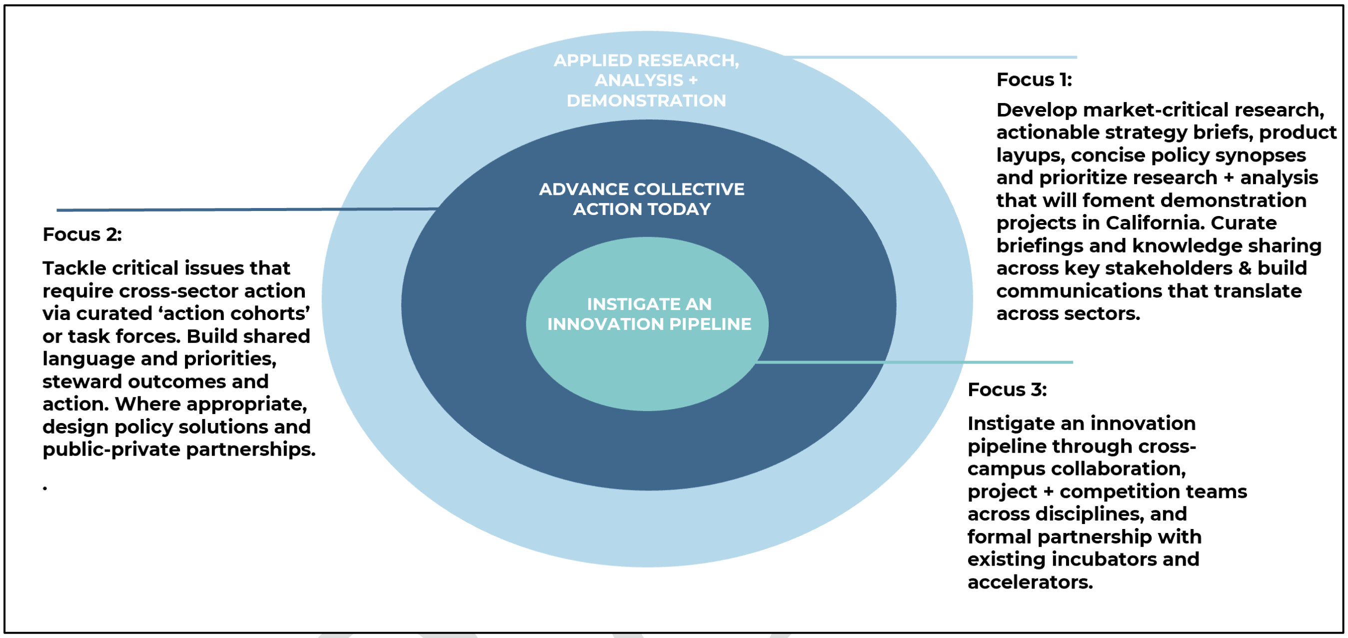


Figure 18. Foci suggested for Institute.

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 addition to funding applied research and analysis on critical market gaps, the Institute should proactively develop avenues to inform key audiences and encourage strategic action where possible.

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.

[26] 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 activities might include:

- **Academic partnerships to streamline and clarify opportunities:**
    a. Develop and maintain 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.
- **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[27]
    b. Financing opportunities to kick-start innovative public funding mechanisms[28]

Future research topic areas for the Institute might include:

- **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.
- **Convene key data organizations to foment the creation of a publicly accessible model for economics modeling of wood innovation businesses and investments:**
    a. Convene, for example, The Spatial Informatics Group, Humboldt State University, and National Renewable Energy Laboratory (NREL) to build a technology portal to replicate the System Advisor Model (SAM) model at the NREL, providing financial modeling to the public to understand what transport, harvesting, equipment, labor, and other costs would have to be for any particular wood innovation model or concept to function. Conduct an annual survey to update the data and keep a running track on how, where, and why finance is moving in to, and out of, wood innovation markets in California.

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. Advance Collective Action

[27] 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.

[28] 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.

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.

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.

Specific initial cohorts the Institute might convene in order to foment shared action and to provide briefs on relevant findings and solutions include:[29]

- **Harvesting and transportation technologies:** Curate a small group to focus on improving harvesting technologies and piloting harvesting equipment funding and financing opportunities. Bring in large trucking companies who operate in the Sierra Nevada, existing wood transportation and harvesting companies, an energy entrepreneur (like Tesla), Sierra Pacific Industries or smaller processing facilities, and design and technology thought leaders to explore possibilities. Examples may include return-load transportation partnerships,[30] closed-loop energy systems which utilize on-site biomass to fuel harvesting technologies, developing a web of biomass superchargers, or a focus on wood polymers in lieu of plastics in the materials like those Tesla uses to produce its vehicles.
- **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.
- **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. 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, 1-2 systems thinkers like Sierra Business Council and/or BAIN project leads from recent TNC scope, and Woodworks.

---

[29] 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.

[30] When trucks deliver products to rural regions, many return to ports and urban centers empty. Connecting trucking companies with transportation needs from processing facilities to those same ports and urban centers is an opportunity for efficiency improvements and cost reduction.

- **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[31] 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.
- **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] [32] 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.

4.3. Workforce and entrepreneurship

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:

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	3. Kick-start 1-2 physical locations for wood innovation technology testing & demonstration and business model innovations. These will not be

[31] 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.

[32] The roadmap is still in development in partnership with the UN Environment Program (UNEP), UN Environment's Principles for Sustainable Insurance (UNEPSI), UCLA, UC Berkeley, and the California Department of Insurance (CDI).

Advisory Council, to provide insight and feedback to select project teams.	'Institute' locations but the Institute will build the partnerships, make the case, provoke and guide the relationships and provide the human capital and financial capital to project manage and steward these into existence.

Table 13. Recommended near-term and long-term actions for workforce and entrepreneurship

Specific opportunities and approaches:

- **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. The UCANR *Elevate Rural California* program 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.
    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.
- **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.

REFERENCES

[i] State of California Executive Department (Edmund Brown). Executive Order B-52-18 – Forest Management Task Force. 10 May, 2018.

[ii] North, Malcolm et al., "Constraints on Mechanized Treatment Significantly Limit Mechanical Fuels Reduction Extent in the Sierra Nevada." academic.oup.com. *Journal of Forestry,* January 18, 2015. Web, January 2, 2020.

[iii] Kollars, Deb, "California's Wildfire Crisis: New Call to Action Report Urges Swift, Massive Response." Caeconomy.org. California Economic Summit, October 21, 2019. Web. October 24, 2019.

[iv] Dodd, Bill, "Senate Bill No. 901 Wildfires, Chapter 626." 901. 2018. Web. December 16, 2019.

[v] California Energy Commission, "Additional Analysis on Gasoline Prices in California." Energy.ca.gov. California Energy Commission, October 21, 2019. Web. January 2, 2020.

[vi] United States Forest Service, "Conservation Toolkit." Nationalforests.org. National Forest Foundation. Web. January 2, 2020.

[vii] Lupien, Sandra, "White Paper: Identifying Market Interests and Opportunities for Sierra Nevada Sustainable Forestry Materials." Livingforests.org. Living Forests, July 13, 2019. Web. December 2, 2019.

[viii] Public Policy Institute of California, "Higher Education in California." Ppic.org. April, 2016. Web, January 2, 2020.

[ix] Patringenaru , Ioana, "UC San Diego Shake Table, Robot Win Best of What's New Award from Popular Science." Ucsdnews.ucsd.edu. UC San Diego News Center, November 14, 2013. Web. December 2, 2019.

[x] "Should California Buy Disaster Insurance?" calmatters.org. CalMatters, February 14, 2019. Web. December 16, 2019.

[xi] Gudel, Jonathan, "Governor Newsom Proclaims State of Emergency on Wildfires to Protect State's Most Vulnerable Communities." oesnews.com. Cal OES News, March 22, 2019. Web. December 2, 2019.

[xii] Kollars, Deb, "California's Wildfire Crisis: New Call to Action Report Urges Swift, Massive Response." Caeconomy.org. California Economic Summit, October 21, 2019. Web. October 24, 2019.

[xiii] Bass, Rachel, et al. *Scaling Impact Investment in Forestry*. Global Impact Investing Network. 2019.

[xiv] Headwaters Economics, *The Full Community Cost of Wildfire. May, 2018.*

[xv] Headwaters Economics, *The Full Community Cost of Wildfire. May, 2018.*

[xvi] Bass, Rachel, et al. *Scaling Impact Investment in Forestry*. Global Impact Investing Network. 2019.

[xvii] Bass, Rachel, et al. *Scaling Impact Investment in Forestry*. Global Impact Investing Network. 2019.

[xviii] Kollars, Deb, "California's Wildfire Crisis: New Call to Action Report Urges Swift, Massive Response." Caeconomy.org. California Economic Summit, October 21, 2019. Web. October 24, 2019.

[xix] Radeloff , Volker C. et al. “Rapid Growth of the US Wildland-Urban Interface Raises Wildfire Risk." pnas.org. Proceedings of the National Academy of Sciences of the United States of America, March 27, 2018. Web, December 2, 2019.

[xx] Rennie Short, John, “The West Is on Fire – and the US Taxpayer Is Subsidizing It.” theconversation.com. The Conversation, September 23, 2015. Web. December 3, 2019.

[xxi] Kousky, Carolyn et al. *Wildfire Costs in California: The Role of Electric Utilities.* Wharton University of Pennsylvania. August, 2018.

[xxii] Stevens, Pippa, “PG&E Power Outage Could Cost the California Economy More than $2 Billion.” cnbc.com. CNBC, October 10, 2019. Web, December 16, 2019.

[xxiii] Williams, Sam, “When the PG&E Line Goes down, Honey Lake Power Keeps Lights On.” lassennews.com. Lassen News, December 19, 2018. Web, December 2, 2019.

[xxiv] Cordery-Cotter, et al. *Biomass in the Sierra Nevada.* Sierra Business Council. November, 2019.

[xxv] Franklin, Sydney, “America’s Largest Mass Timber Building Opens at the University of Arkansas.” Archpaper.com. The Architect's Newspaper, November 25, 2019. Web, December 16, 2019.

[xxvi] reThink Wood, “Mass Timber in North America.” Awc.org. American Wood Council, Octoer 31, 2016. Web, January 3, 2020.

[xxvii] Southern California Gas Company, “SoCalGas Announces Vision to Be Cleanest Natural Gas Utility in North America.” prnewsire.com. Cision PRNewswire, March 6, 2019. Web, December 16, 2019.

[xxviii] Cordery-Cotter, et al. *Biomass in the Sierra Nevada.* Sierra Business Council. November, 2019.

[xxix] California Tahoe Conservancy and Sierra Business Council, “Background Papers for the California Land Conservation Summit.” Tahoe.ca.gov. California Tahoe Conservancy, October 9, 2019. Web, January 2, 2020.

[xxx] British Columbia Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, Washington State Department of Natural Resources, and California Natural Resources Agency. “*Memorandum of Understanding: Pacific Coast Temperate Forests.”* December 18, 2018. PDF.

[xxxi] *Lupien, Sandra, “White Paper: Identifying Market Interests and Opportunities for Sierra Nevada Sustainable Forestry Materials.” Livingforests.org. Living Forests, December 2, 2019. Web. July 13, 2019.*

[xxxii] California Department of Insurance. *Commissioner Lara and United Nations Announce Nation’s First Sustainable Insurance Roadmap to Reduce California’s Climate Risks*. July 24, 2019. Web, December 3, 2019.