# Wood Biomass Storage

## Identifying Gaps & Enabling Scale

Sinéad Crotty

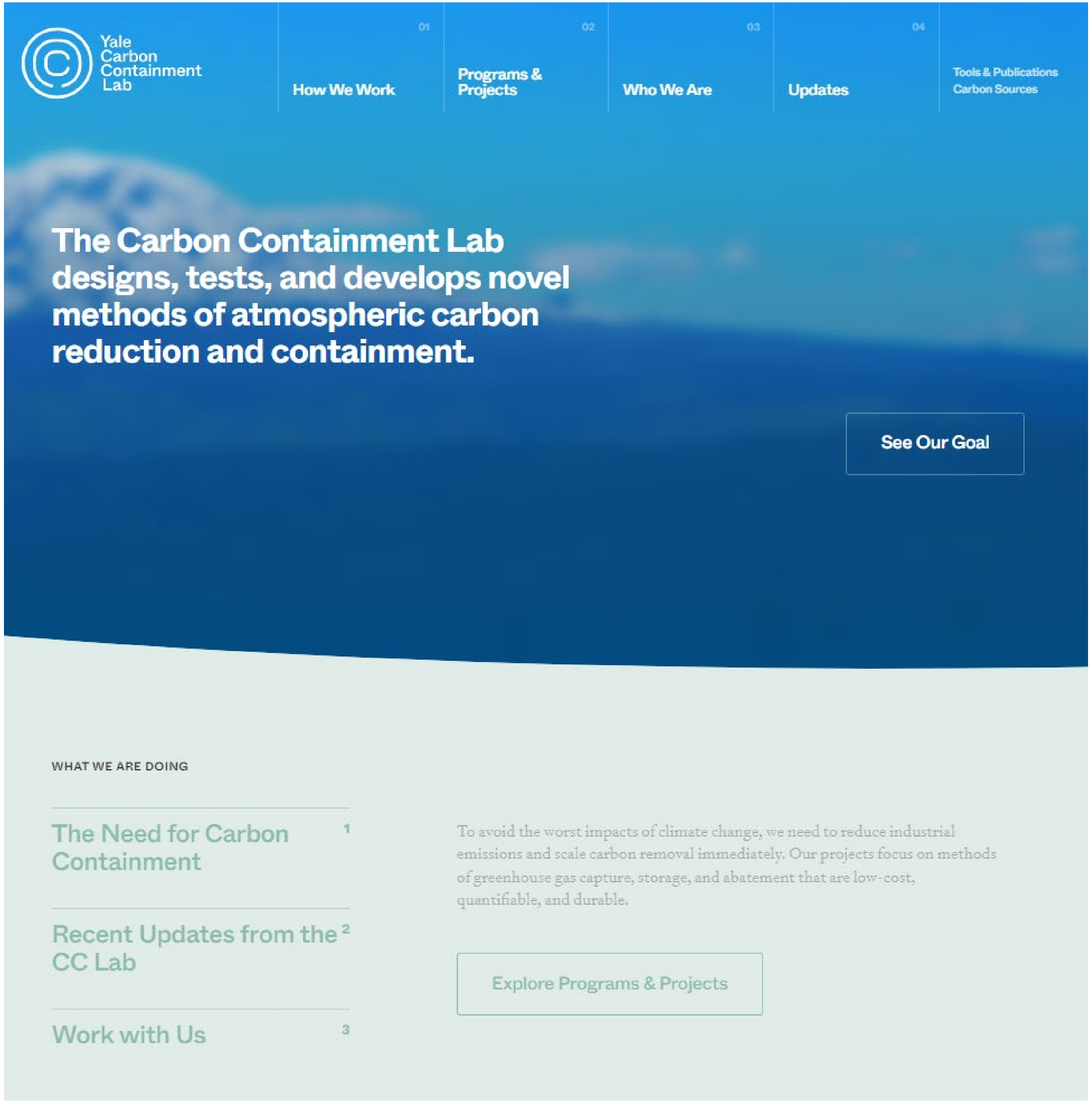
November 16, 2023

Carbon Containment Lab

WHO WE ARE

# Carbon Containment Lab

- Founded in 2020
- Non-profit; gift and grant-funded
- Focused on identifying novel or neglected approaches and addressing gaps or unknowns limiting scalability

# Section 1: Feedstock Availability & Counterfactuals

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CONTEXT

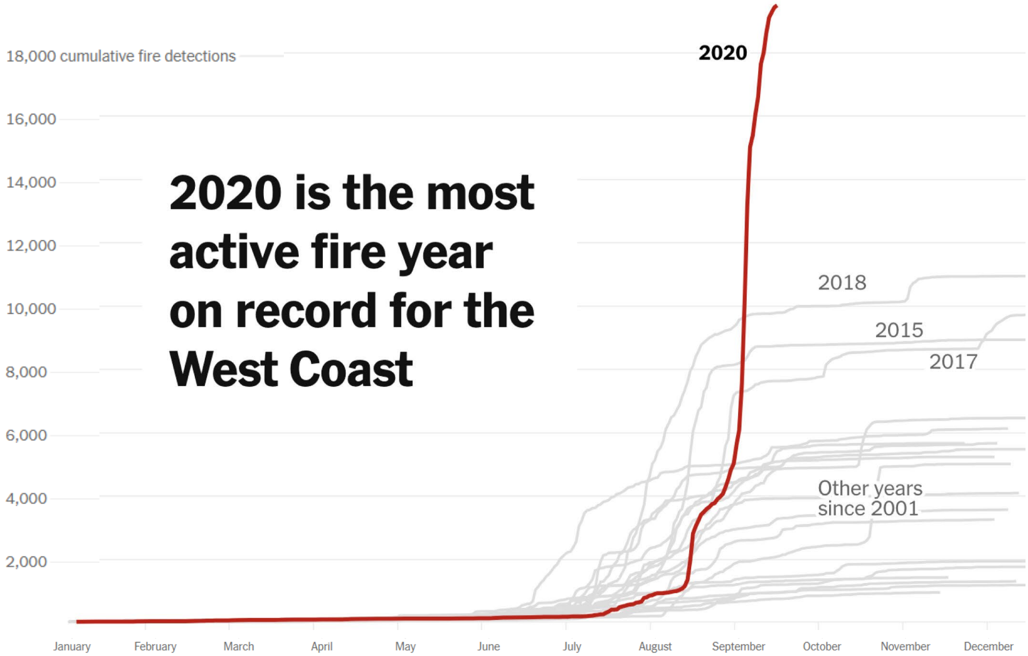
# Western Wildfire

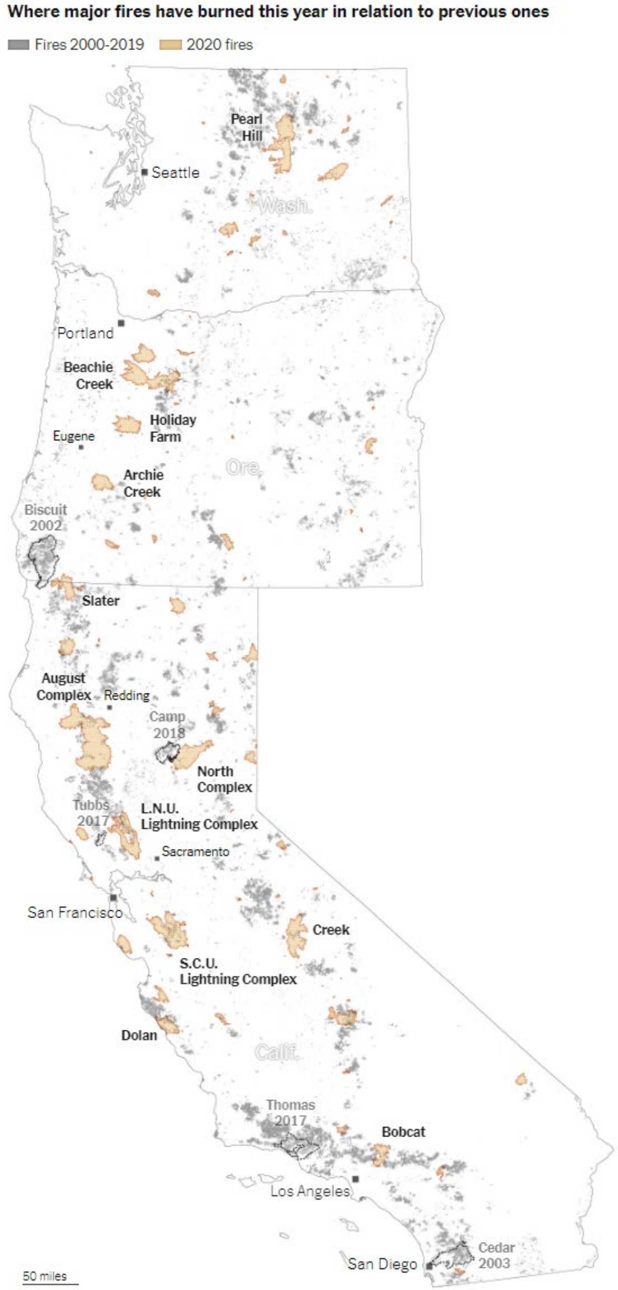
- >10.2 million acres burned in US West
- $19.9 billion in damages
- >127 million $MTCO_2e$ emitted from wildfire in CA alone

## Record Wildfires on the West Coast Are Capping a Disastrous Decade

By Blacki Migliozzi, Scott Reinhard, Nadja Popovich, Tim Wallace and Allison McCann Sept. 24, 2020

With more than a month of fire weather ahead for large parts of the West Coast, the 2020 fire season has already taken a disastrous toll.




CONFIDENTIAL

# Fuel reduction treatments can help forests adapt

Without ecological thinning – High intensity, Destructive Fire

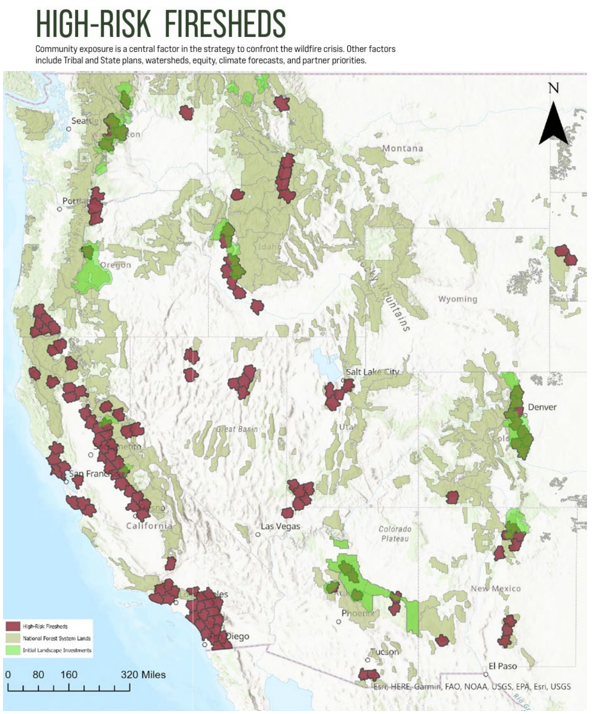

With ecological thinning – Low intensity Fire

## CONTEXT

# Wildfire Crisis Implementation Plan

- Committed to treatment of up to an additional 50 million acres of forestland (in addition to 20 million acres already planned)
- Identified high-risk fire-sheds for prioritization





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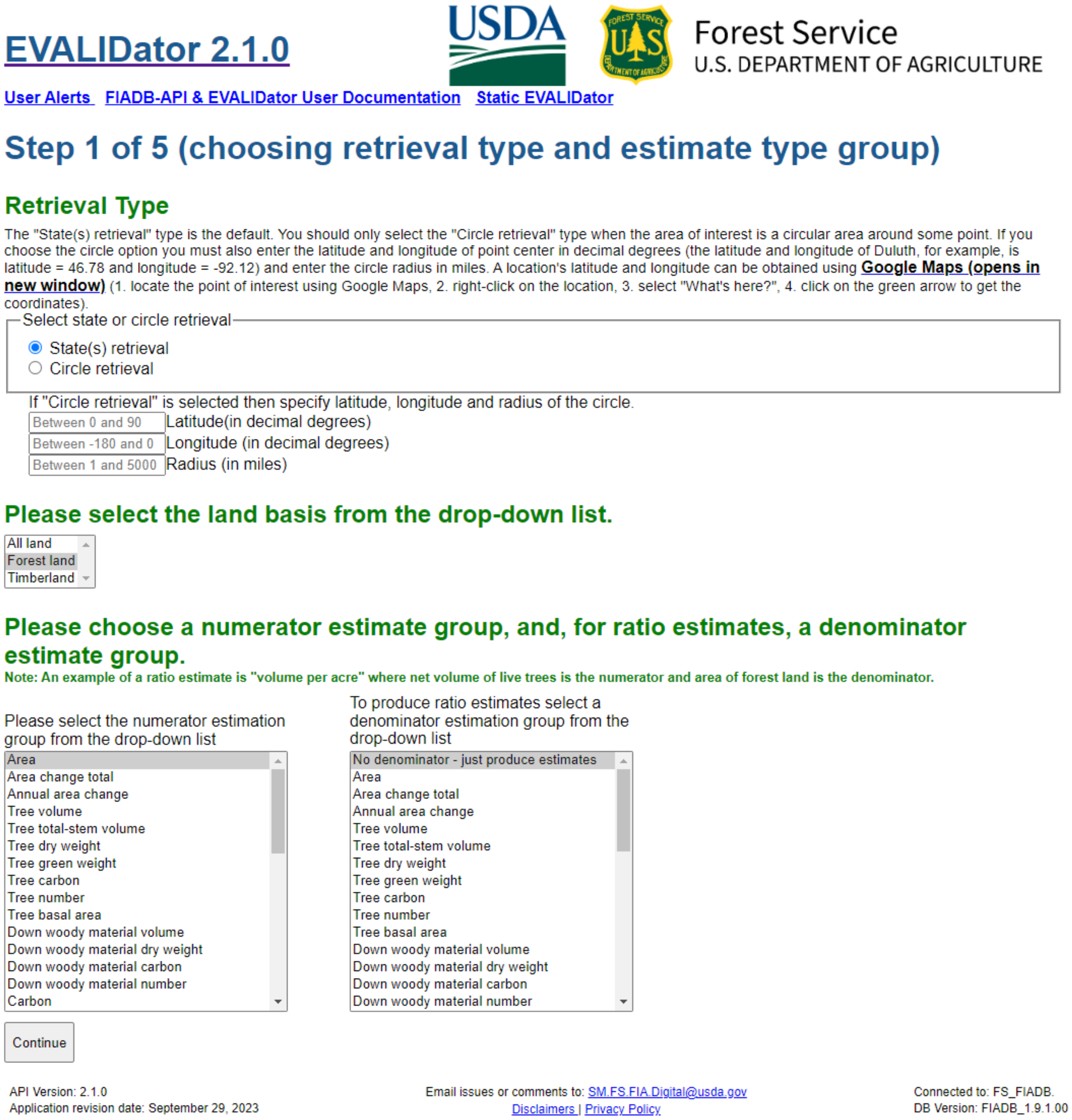
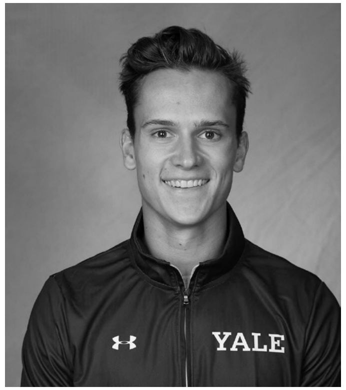
# Biomass Availability

Used Forest Inventory and Analysis (FIA) data to assess amount of low value woody biomass in need of removal in highest risk locations




Nicholas Dahl



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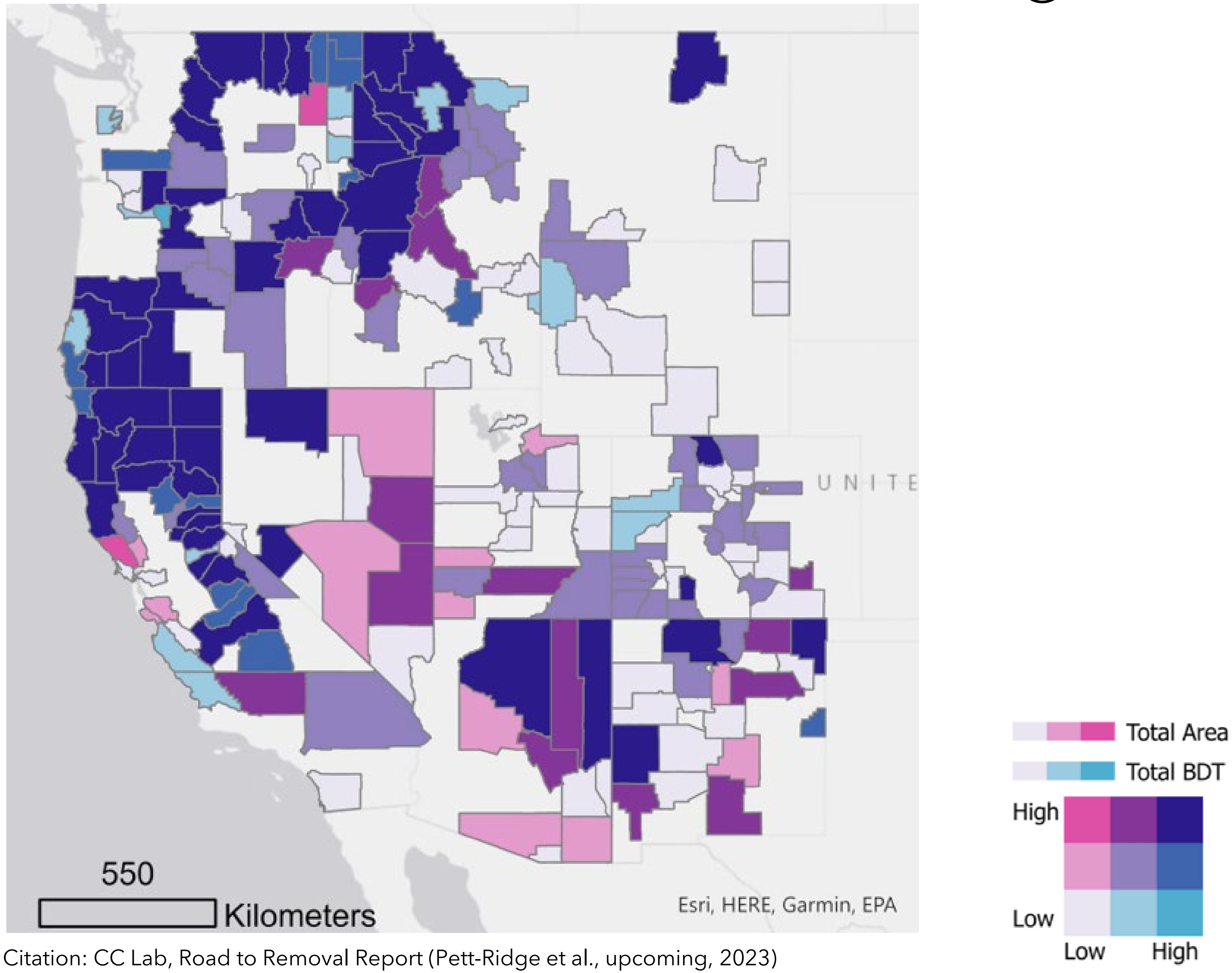
# Biomass Availability

- >1.3 billion bone dry tonnes of low value biomass
- Equivalent to >2Gt CO2e in non-utilized residues over 10 years




Citation: CC Lab, Road to Removal Report (Pett-Ridge et al., upcoming, 2023)

RESULTS

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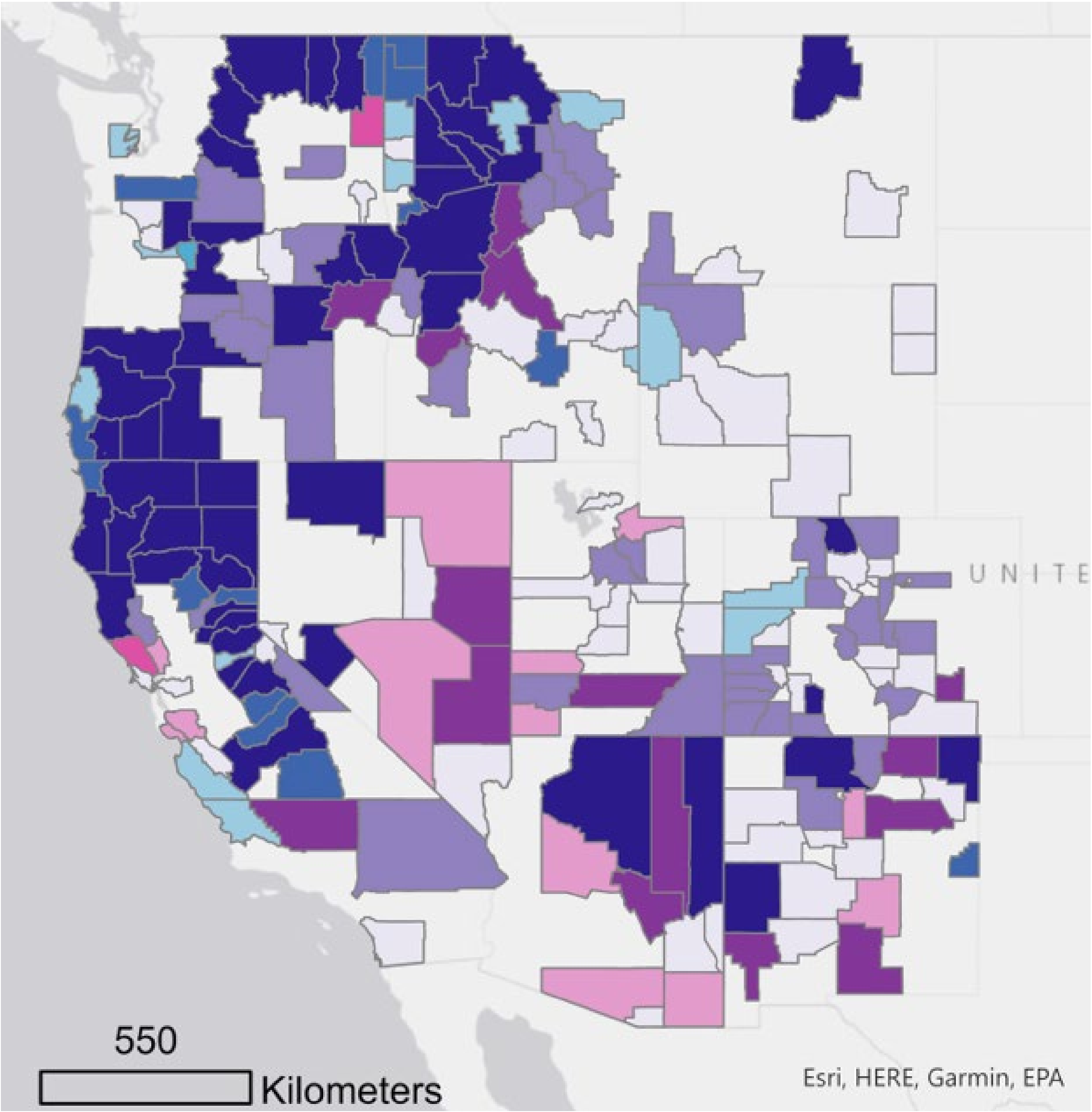


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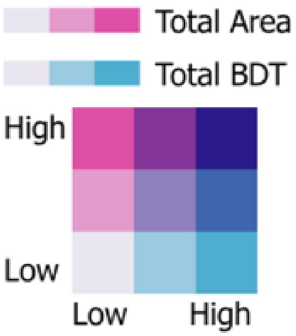
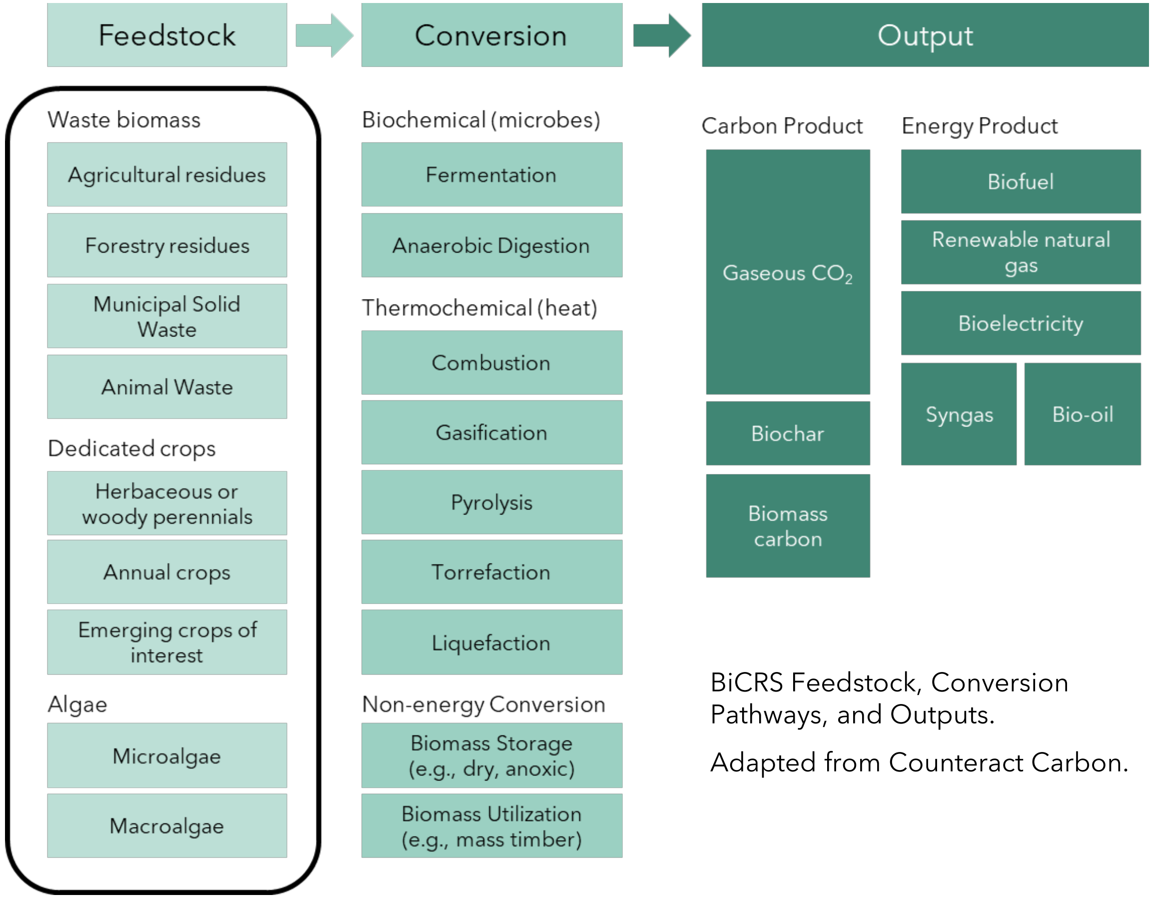


GAP #1

# Current feedstock counterfactuals are inaccurate…

- Under GHG Protocol guidelines, biogenic emissions are considered carbon neutral
- Near-term emissions lead to increased climate forcing over policy-relevant time frames even if emitted later by decay or wildfire
- Decay pathways of BiCRS feedstocks will vary widely and will be context-dependent
- Carbon Intensity (CI) of biofuel production will inform decision-making and, therefore, requires more complete counterfactual accounting




BiCRS Feedstock, Conversion Pathways, and Outputs.

Adapted from Counteract Carbon.

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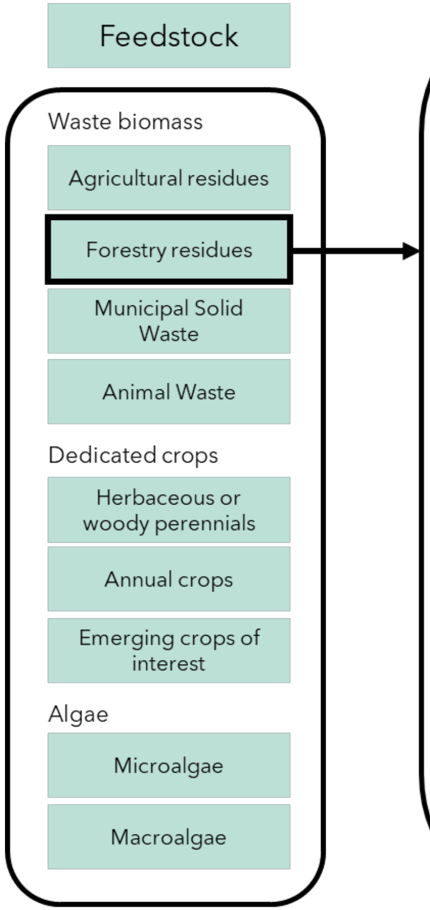
# ...But pathways to improve counterfactuals are available

- California Biomass Residue Emissions Characterization (C-BREC) model
- LCA tool that accounts for the GHG and criteria air pollutant emissions associated with 'reference case' of decay or pile burning versus 'use case' of biopower generation from forest residues in California
- Captures spatial variability in residue characteristics and climatic conditions which significantly influence decay processes and fire behavior

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## Climate and air pollution impacts of generating biopower from forest management residues in California

Kevin R Fingerman[1,2,*], Jerome Qiriazi[2], Cassidy L Barrientos[2], Max Blasdel[2], Jeffrey M Comnick[3], Andrew R Harris[2], Carisse Geronimo[1,2], Chih-Wei Hsu[1,2], Jeffrey M Kane[1], Elaine Oneil[4], Sabrinna Rios-Romero[1,2], Luke W Rogers[3], Mark Severy[5] and Micah C Wright[2]

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Keywords: biopower, climate, forest residue, LCA, life cycle analysis, biomass, bioenergy

### Abstract

California faces crisis conditions on its forested landscapes. A century of aggressive logging and fire suppression in combination with conditions exacerbated by climate change have created an ongoing ecological, economic, and public health emergency. Between commercial harvests on California's working forestlands and the increasing number of acres the state treats each year for fire risk reduction and carbon sequestration, California forests generate millions of tons of woody residues annually—residues that are typically left or burned in the field. State policymakers have turned to biomass electricity generation as a key market for woody biomass in the hope that it can support sustainable forest management activities while also providing low-carbon renewable electricity. However, open questions surrounding the climate and air pollution performance of electricity generation from woody biomass have made it difficult to determine how best to manage the risks and opportunities posed by forest residues. The California Biomass Residue Emissions Characterization (C-BREC) model offers a spatially-explicit life cycle assessment framework to rigorously and transparently establish the climate and air pollution impacts of biopower from forest residues in California under current conditions. The C-BREC model characterizes the variable emissions from different biomass supply chains as well as the counterfactual emissions from prescribed burn, wildfire, and decay avoided by residue mobilization. We find that the life cycle 'carbon footprint' of biopower from woody residues generated by recent forest treatments in California ranges widely—from comparable with solar photovoltaic on the low end to compara with natural gas on the high end. This variation stems largely from the heterogeneity in the fire decay conditions these residues would encounter if left in the field, with utilization of residue th would otherwise have been burned in place offering the best climate and air quality performanc California's energy and forest management policies should account for this variation to ensure desired climate benefits are achieved.

Schatz Energy Research Center

HUMBOLDT STATE UNIVERSITY

NEXT PHASE OF WORK

# Western Biomass Residue Emissions Characterization (West-BREC) model

1. Expand feedstock and fire modeling to entire US West

SCIENTIFIC DATA

OPEN | DATA DESCRIPTOR

## TreeMap, a tree-level model of conterminous US forests circa 2014 produced by imputation of FIA plot data

Karin L. Riley[1], Isaac C. Grenfell[1], Mark A. Finney[1] & Jason M. Wiener[2]

A 30 × 30m-resolution gridded dataset of forest plot identifiers was developed for the conterminous United States (CONUS) using a random forests machine-learning imputation approach. Forest plots from the US Forest Service Forest Inventory and Analysis program (FIA) were imputed to gridded c2014 landscape data provided by the LANDFIRE project using topographic, biophysical, and disturbance variables. The output consisted of a raster map of plot identifiers. From the plot identifiers, users of the dataset can link to a number of tree- and plot-level attributes stored in the accompanying tables and in the publicly available FIA DataMart, and then produce maps of any of these attributes, including number of trees per acre, tree species, and forest type. Of 67,141 FIA plots available, 62,758 of these (93.5%) were utilized at least once in imputation to 2,841,601,981 forested pixels in CONUS. Continuous high-resolution forest structure data at a national scale will be invaluable for analyzing carbon dynamics, habitat distributions, and fire effects.

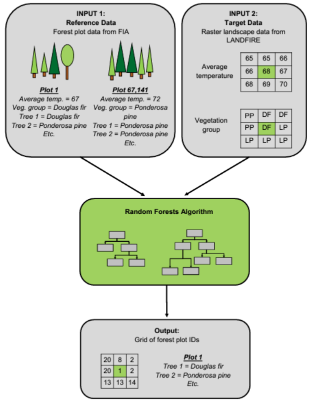
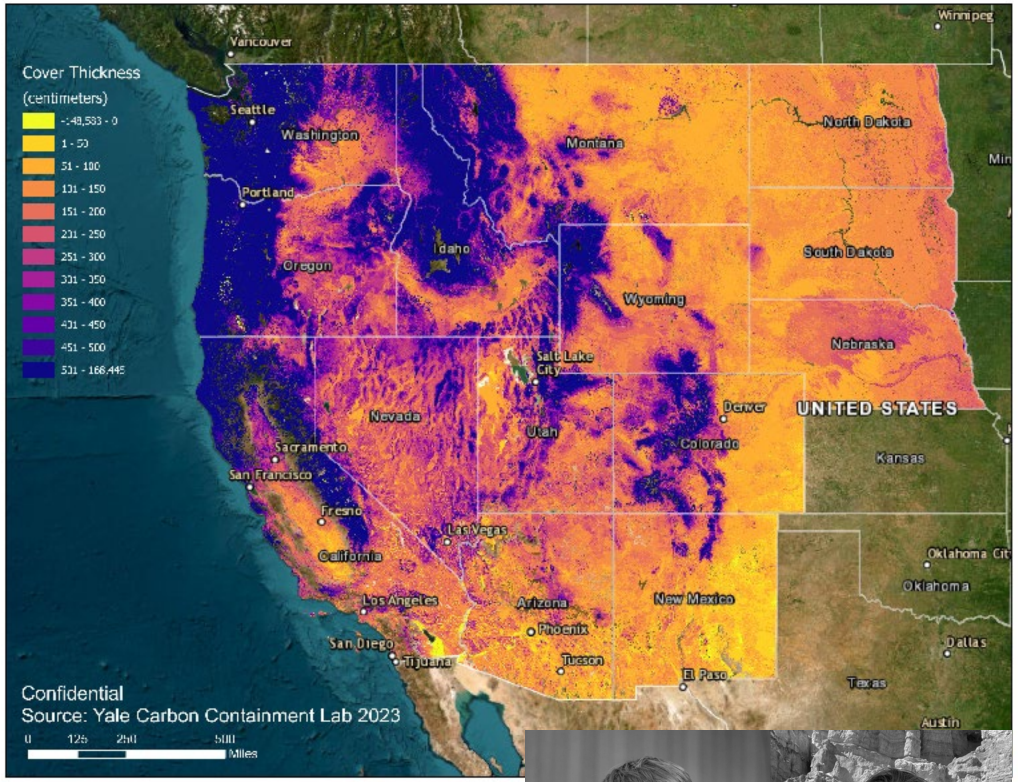



Fig. 1 The project workflow. FIA forest plots (reference data) and raster landscape data from LANDFIRE (target data) were employed in a random forests algorithm that imputed the plot data to all forested pixels on the CONUS-wide landscape.

2. Expand the suite of in-field decay constants and climate multipliers dataset to include additional species of interest and climates of relevance across entire region.

3. Build new 'use' cases for biomass storage.




# Section 2: Wood Storage

## Mechanisms & Implications

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# Variable Approaches to Wood Storage

## Feedstock → Conversion → Output

### Feedstock

Waste biomass

- Agricultural residues
- Forestry residues
- Municipal Solid Waste
- Animal Waste

Dedicated crops

- Herbaceous or woody perennials
- Annual crops
- Emerging crops of interest

Algae

- Microalgae
- Macroalgae

### Conversion

Biochemical (microbes)

- Fermentation
- Anaerobic Digestion

Thermochemical (heat)

- Combustion
- Gasification
- Pyrolysis
- Torrefaction
- Liquefaction

Non-energy Conversion

- Biomass Storage (e.g., dry, anoxic)
- Biomass Utilization (e.g., mass timber)

### Output

Carbon Product

- Gaseous $CO_2$
- Biochar
- Biomass carbon

Energy Product

- Biofuel
- Renewable natural gas
- Bioelectricity
- Syngas
- Bio-oil

- *Short-term (decades) or long-term (centuries+)*
- *Approaches utilize different mechanisms*
- *Proposed approaches include:*
  - *Aboveground dry storage*
  - *Biomass burial (clay versus evapotranspirative covers) or subterranean injection*
  - *Biochar storage/ burial*
  - *Submergence/sinking*
  - *Encasement*

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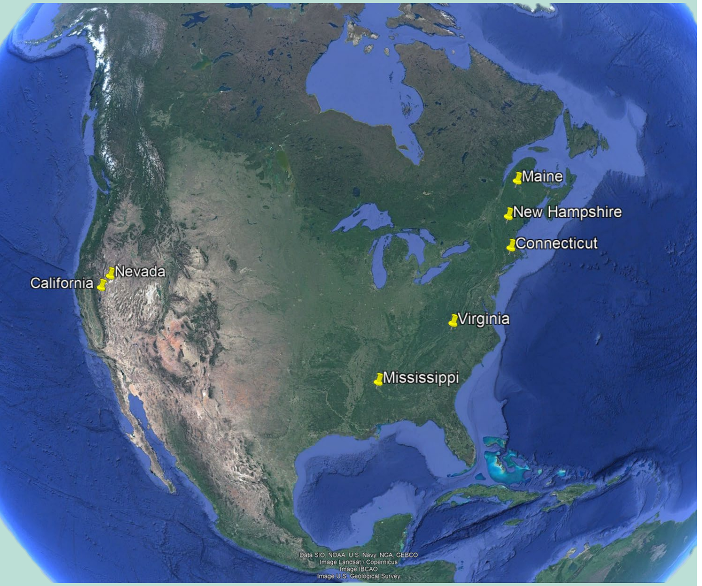
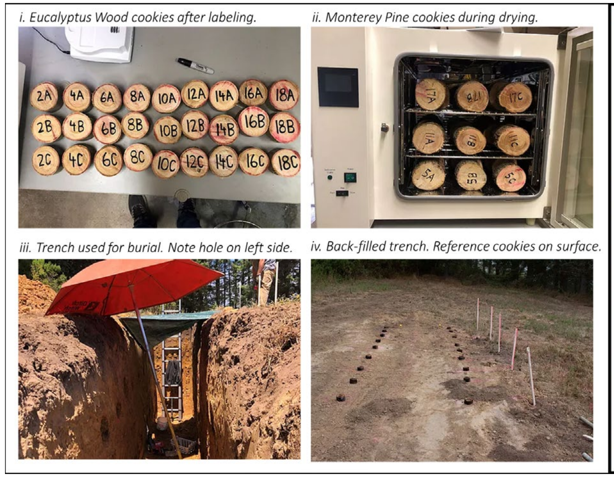
# Field Experiments





Proto Credits: Alex Wyckoff, Jana VanderGoot, Juliet Tang, & Robert Hayes



i. Eucalyptus Wood cookies after labeling.

ii. Monterey Pine cookies during drying.

iii. Trench used for burial. Note hole on left side.

iv. Back-filled trench. Reference cookies on surface.

i. Monterey pine logs before burial.

ii. First layer of buried logs.

iii. Second layer of buried logs.

iv. Back-filled trench. Outline marked by stakes.


# Agents of Decay

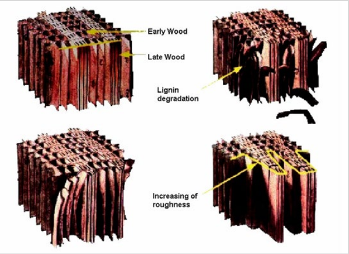
**BIOTIC DECAY**

- Microbes
  - Fungi
  - Bacteria

- Invertebrates
  - Termites
  - Shipworms
  - Indirect pathways

**ABIOTIC DECAY**

- Fire
- Photodegradation




## CONTROLS

- Water
- Oxygen
- Temperature
- Nutrients
- Secondary pathways

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# We need to clarify mechanisms, risks, and MRV needs

## The Reykjavik Protocol

The Reykjavik Protocol is a set of principles that governs how carbon credit suppliers can bring their solutions to market ethically and sustainably.

"One of the biggest challenges facing the carbon credit industry is a **lack of standardization and a clear set of principles**. This ambiguity is a barrier to market growth, as potential buyers may question the legitimacy of suppliers or the effectiveness of their methods."

Uncertainty in this approach is, in part, driven by a lack of understanding. We can address this.

- How do different wood storage approaches work? How do they vary across contexts?
- What are the risks inherent to each approach? The uncertainties?
- Based on the approach, what measurements are needed to demonstrate success and/or measure early warning signs of failure?
- Propose collaboration to publish "The Mechanism Paper" & industry/scientific coalition to address unknowns

NEXT STEPS

# *DRAFT:*

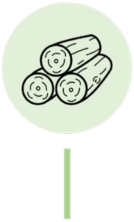
# Mechanisms of Wood Preservation Diagram

*Next Phase:*

*Suggested measurement types and spatiotemporal sampling design*

*Early warning signs of failure*

**Lignocellulosic Carbon Storage: Pathways & Mechanisms**



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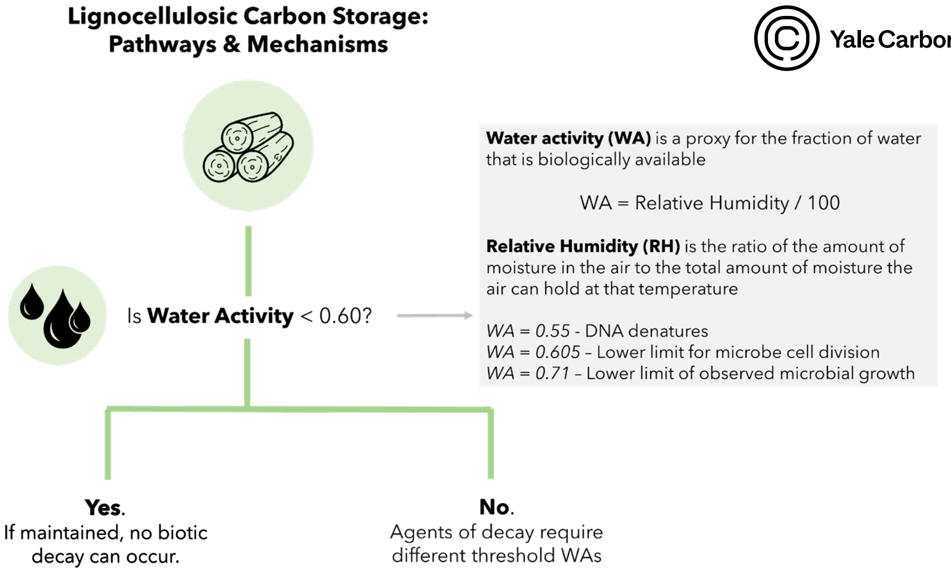


| Risks | Context | Solutions |
|---|---|---|
| Fire | Aboveground storage will be subject to local conditions | Compaction & encasement |
| Photodegradation | UV light can penetrate into wood and degrade outer 5-15mm over 100 years | Cover to prevent direct sunlight |
| Intermittent increases in WA | Intermittent increases in humidity will allow for aerobic decay to occur | Encasement or Active Monitoring |
| Land Use | Aboveground storage will require surface land use. | Use in engineering, encasement + burial |

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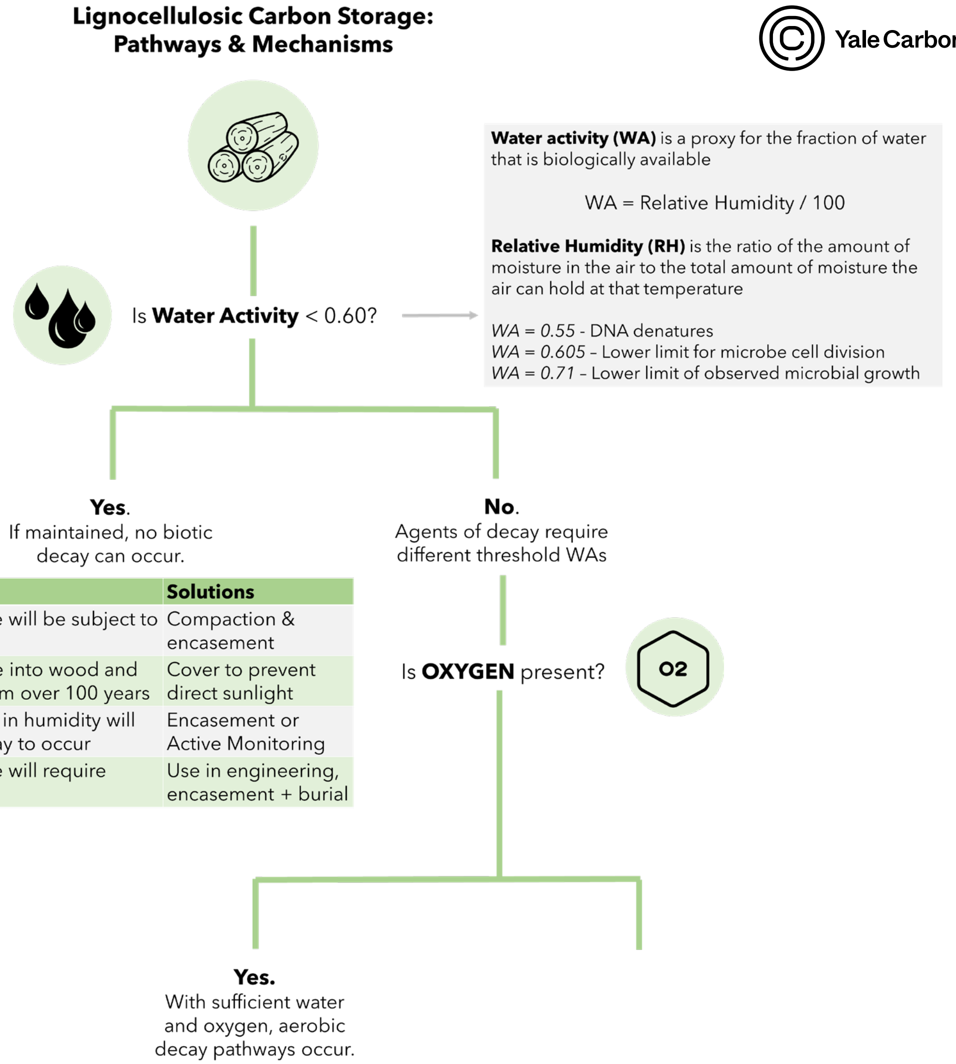


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Is **Water Activity** < 0.60?

**Water activity (WA)** is a proxy for the fraction of water that is biologically available

WA = Relative Humidity / 100

**Relative Humidity (RH)** is the ratio of the amount of moisture in the air to the total amount of moisture the air can hold at that temperature

*WA = 0.55* - DNA denatures
*WA = 0.605* – Lower limit for microbe cell division
*WA = 0.71* – Lower limit of observed microbial growth

**Yes**. If maintained, no biotic decay can occur.

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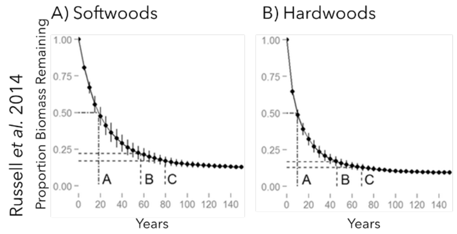
**No**. Agents of decay require different threshold WAs

Is **OXYGEN** present?

O2

**Yes.** With sufficient water and oxygen, aerobic decay pathways occur.




***Feedstock composition, temperature, and pH/nutrient availability will control rate of decay***

| Raw Material | Cellulose (%) | Hemicellulose (%) | Lignin (%) |
|---|---|---|---|
| Grasses | 25-40 | 25-50 | 10-30 |
| Softwoods | 45-50 | 25-35 | 25-35 |
| Hardwoods | 45-55 | 24-40 | 18-25 |

NEXT STEPS

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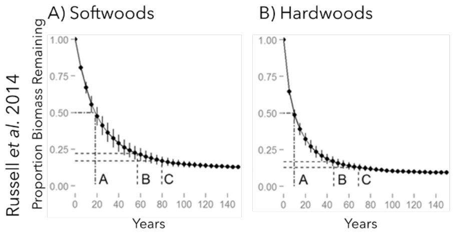


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**No.** Agents of decay require different threshold WAs

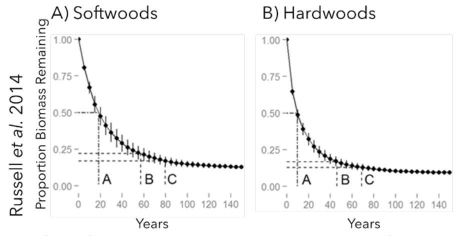
Is **OXYGEN** present?

O2

**Yes.** With sufficient water and oxygen, aerobic decay pathways occur.

**No.** Aerobic decay will be halted, but anaerobic decay may occur.

**ANAEROBIC DECAY**

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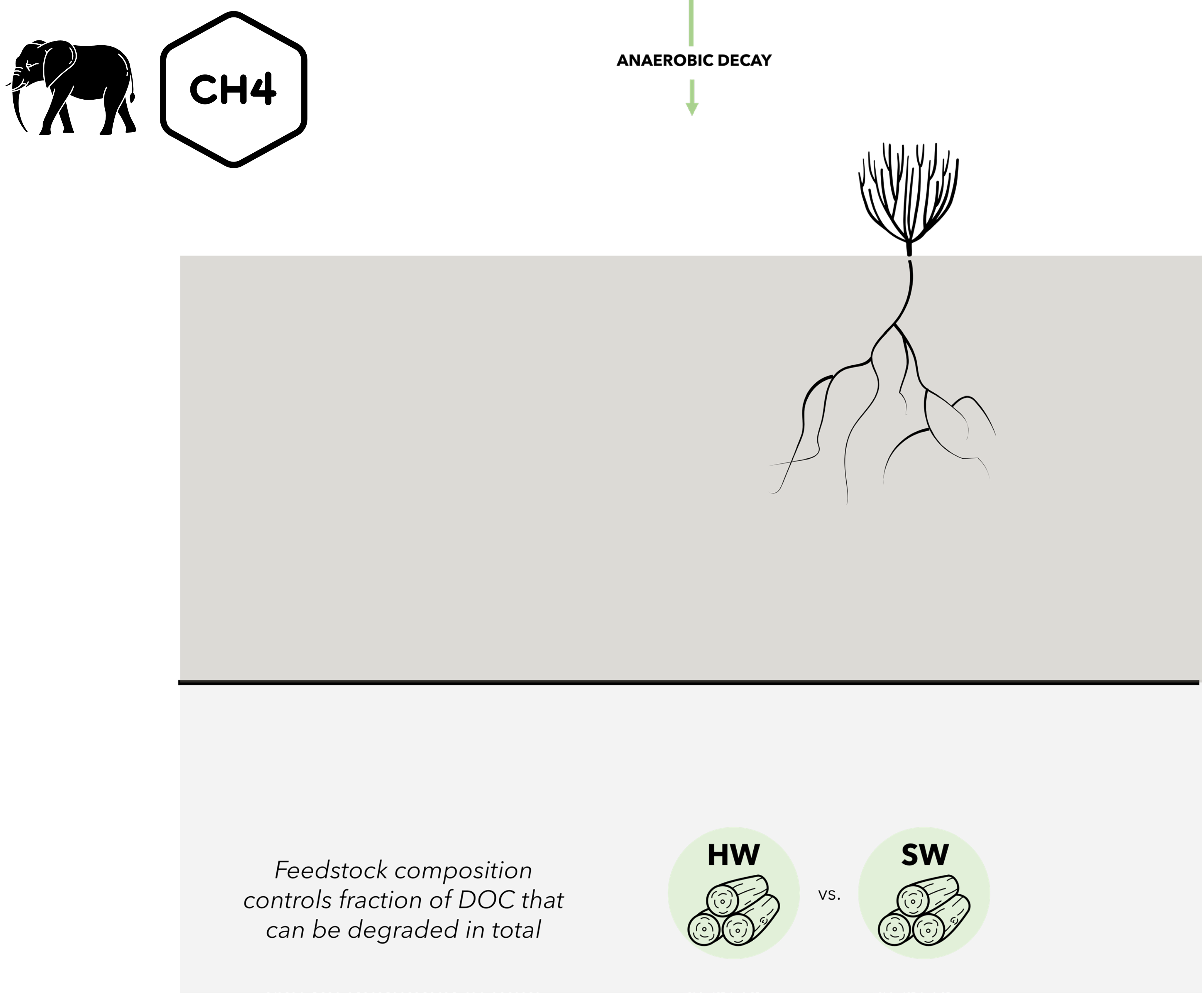
*Methanogens* are micro-organisms that produce methane as a metabolic byproduct, and they can thrive in environments with very low to zero levels of oxygen.

Water facilitates biochemical reactions within the cells of methanogens



NEXT STEPS

# *DRAFT:*

# Mechanisms of Wood Preservation Diagram

**$DOC_f$** represents the portion of an organic material that can be biologically degraded under anaerobic conditions.

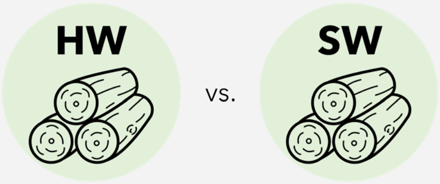
ANAEROBIC DECAY

**Table 1**
Summary of literature assessed, $DOC_f$ recorded and methodological approach.

| Author | Year | Location | Samples | Avg. $DOC_f$ (Std. Dev) |
|---|---|---|---|---|
| Wang and Barlaz | 2016 | North America | HW (n = 2) | 0.232 (0.047) (HW) |
| | | | SW (n = 2) | 0.0475 (0.019) (SW) |
| Ximenes et al. | 2015 | Cairns, Australia | SW (n = 14) | 0.018 (0.03)(Sydney) |
| | | Sydney, Australia | HW (n = 18) | N/A (Sydney) |
| | | | SW (n = 53) | 0.022 (0.03)(Cairns) |
| | | | HW (n = 50) | 0.19 (0.11) (Cairns) |
| Wang et al. | 2011a,b | North America | SW (n = 2) | 0.009 (0.012) (SW) |
| | | | HW (n = 2) | 0.039 (0.055) (HW) |
| | | | EW (n = 5) | 0.0474 (0.084) (EW) |
| Ximenes et al. | 2008 | Sydney Park (SP) Landfill and Lucas Heights (LH) Landfill, Australia | HW (n = 25) | 0.17 (SP) |
| | | | SW (n = 16) | 0.08 (SP) |
| | | | HW (n = 16) | NA (SW &HW, LH) |
| | | | SW (n = 21) | |

HW, Hardwood; SW, Softwood; EW, Engineered Wood.

*Feedstock composition controls fraction of DOC that can be degraded in total*




O'Dwyer et al 2017

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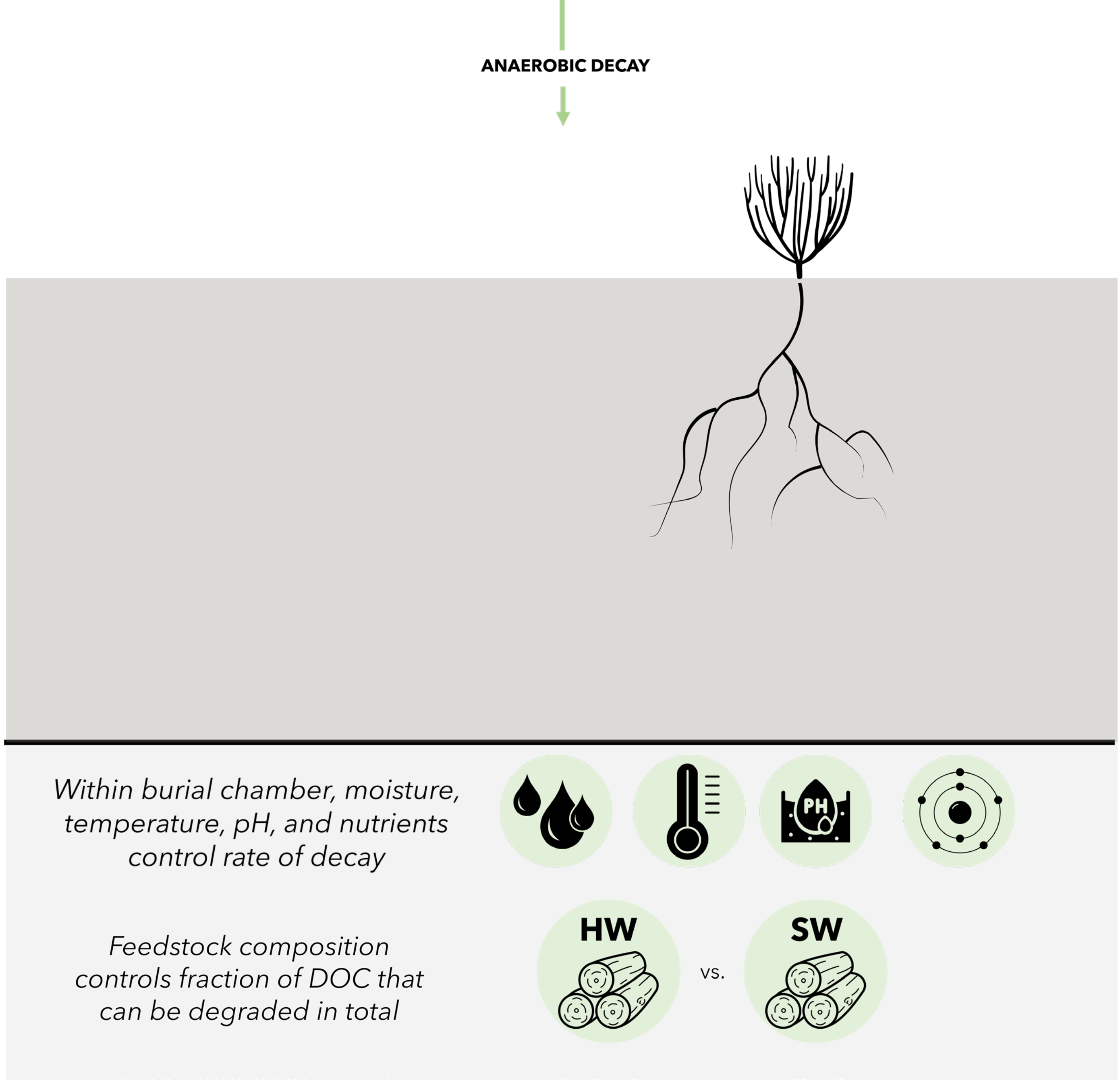
# Mechanisms of Wood Preservation Diagram



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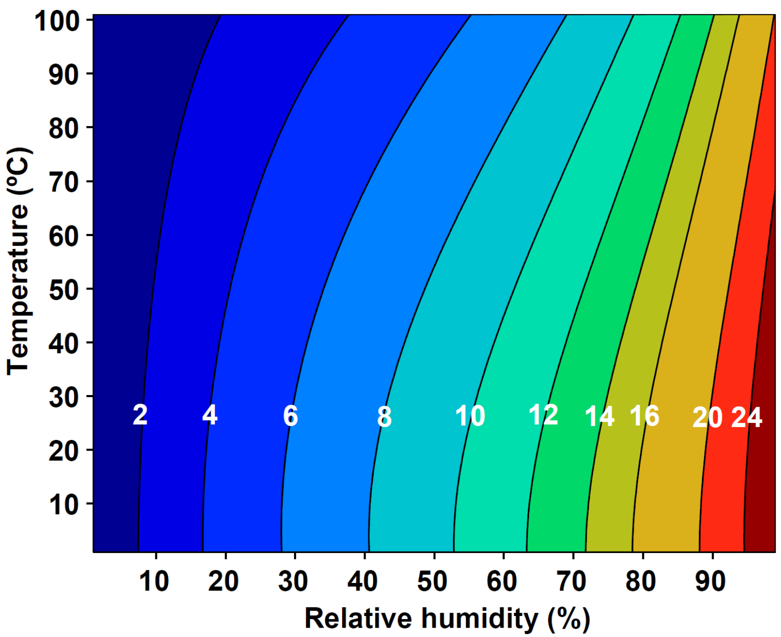
# Mechanisms of Wood Preservation Diagram

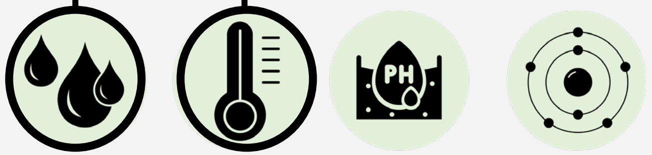
ANAEROBIC DECAY



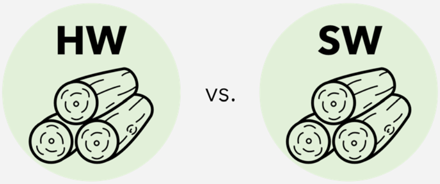

Relative humidity of soils is influenced by a complex set of factors, and it is not always directly correlated with the humidity of the air above the soil.

*White numbers (inset) are the equilibrium moisture content (EMC) of wood*

*Within burial chamber, moisture, temperature, pH, and nutrients control rate of decay*




*Feedstock composition controls fraction of DOC that can be degraded in total*




Glass & Zelinka 2010

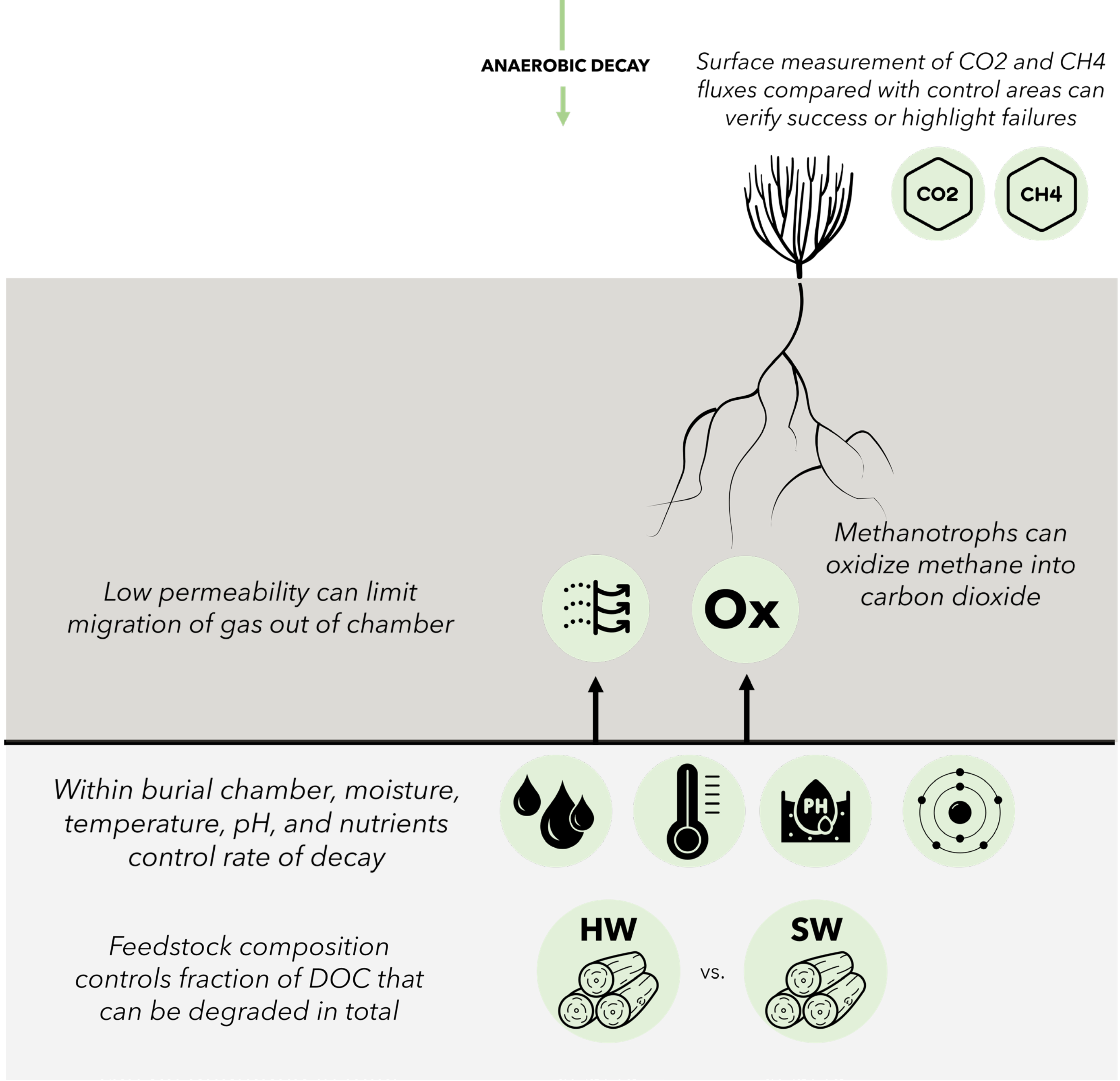
NEXT STEPS

# *DRAFT:*

# Mechanisms of Wood Preservation Diagram

When methane is generated in landfills, it can be oxidized to carbon dioxide in landfill cover soils.

*Aerobic methanotrophs* are the main participants in $CH_4$ oxidation, mainly belonging to *Proteobacteria*



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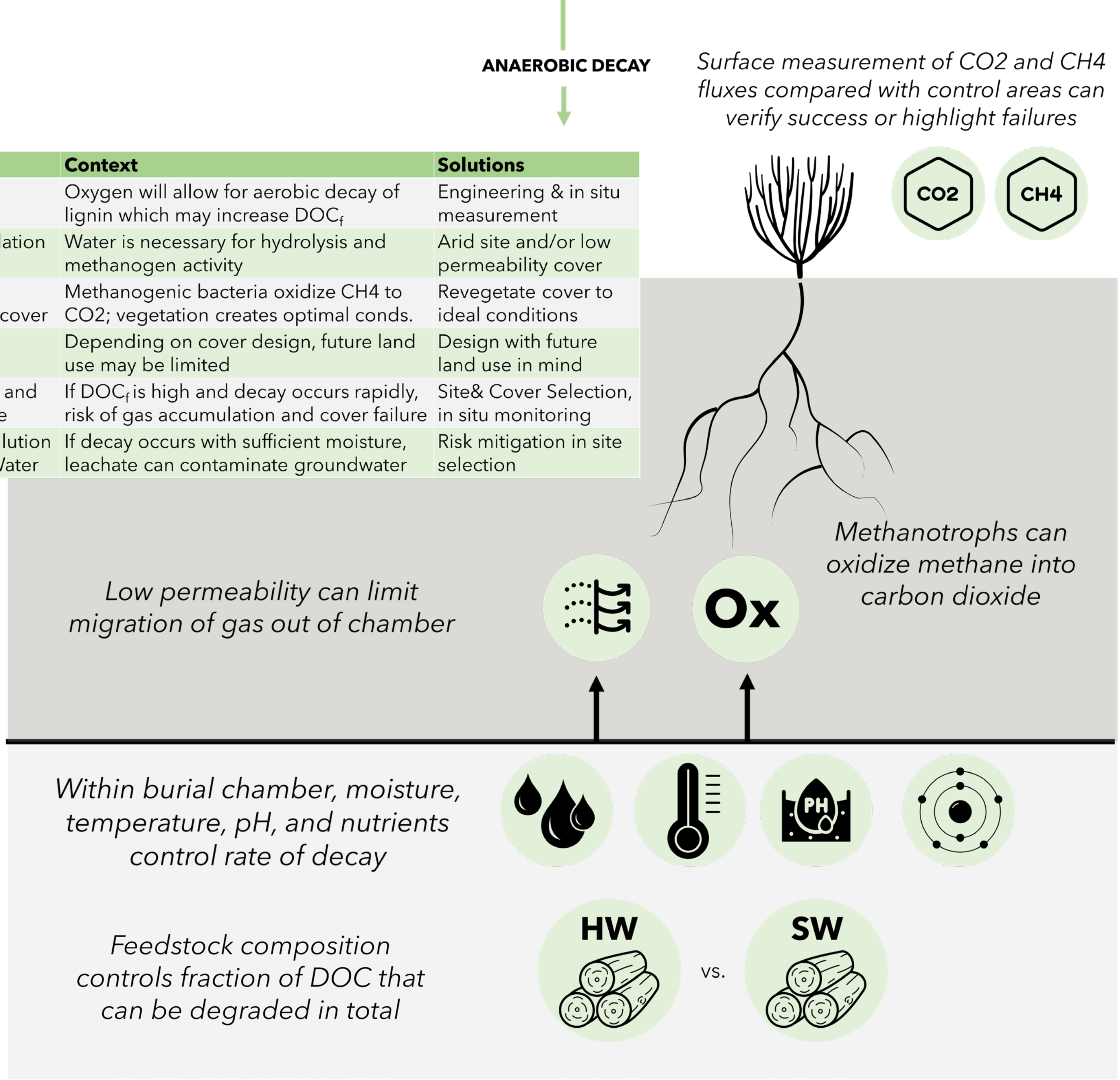
| Risks | Context | Solutions |
|---|---|---|
| Oxygen Penetration | Oxygen will allow for aerobic decay of lignin which may increase $DOC_f$ | Engineering & in situ measurement |
| Water Percolation | Water is necessary for hydrolysis and methanogen activity | Arid site and/or low permeability cover |
| Insufficient oxidation in cover | Methanogenic bacteria oxidize CH4 to CO2; vegetation creates optimal conds. | Revegetate cover to ideal conditions |
| Land Use | Depending on cover design, future land use may be limited | Design with future land use in mind |
| Gas Buildup and Cover Failure | If $DOC_f$ is high and decay occurs rapidly, risk of gas accumulation and cover failure | Site& Cover Selection, in situ monitoring |
| Leachate Pollution of Ground Water | If decay occurs with sufficient moisture, leachate can contaminate groundwater | Risk mitigation in site selection |



# Next Steps in Addressing Uncertainty & Enabling Scale

- Improved counterfactuals and new geospatially-informed ‘use cases’ can allow for more informed decision making and site selection
- Community agreement on knowns and unknowns improves transparency and paves the way for new data to address unknowns
- Movement toward industry standards ensuring environmental safety
- Field experiments and pilot testing are crucial next steps
- Need to involve regulatory agencies (local, state, and federal) early and often

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