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
Record Wildfires on the West Coast Are Capping a Disastrous Decade

By Racket Mjelozzi, Scott Reinhard, Nadia Popovich, Tim Wallace and Allison McCain  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.

2020 is the most active fire year on record for the West Coast

Western Wildfire

- >10.2 million acres burned in US West
- $19.9 billion in damages
- >127 million MTCO₂e emitted from wildfire in CA alone
Fuel reduction treatments can help forests adapt

Without ecological thinning - High intensity, Destructive Fire

With ecological thinning - Low intensity Fire

Images Copyright TNC/Erika Simnek Sloniker
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 firesheds for prioritization
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.
RESULTS

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)
Biomass Availability

- >1.3 billion bone dry tonnes of low value biomass
- Equivalent to >2Gt CO2e in non-utilized residues over 10 years
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.
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
**Western Biomass Residue Emissions Characterization (West-BREC) model**

1. Expand feedstock and fire modeling to entire US West

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
Variable Approaches to Wood Storage

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

Output
- Carbon Product
  - Gaseous CO₂
  - Biochar
- 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
EARLY RESEARCH

Field Experiments

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

**BIOTIC DECAY**

- Microbes
  - Fungi
  - Bacteria
- Invertebrates
  - Termites
  - Shipworms
  - Indirect pathways

**ABiotic Decay**

- Fire
- Photodegradation

**Controls**

- Water
- Oxygen
- Temperature
- Nutrients
- Secondary pathways
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
DRAFT:

Mechanisms of Wood Preservation Diagram

Next Phase:

Suggested measurement types and spatiotemporal sampling design

Early warning signs of failure
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**Mechanisms of Wood Preservation Diagram**

**Next Steps**

1. **Mechanisms of Wood Preservation**
   - **Mechanisms:**
     - Fire
     - Photodegradation
     - Intermittent increases in WA
     - Land Use

2. **Solutions for Decay Prevention**
   - **Solutions:**
     - Compaction & encasement
     - Cover to prevent direct sunlight
     - Use in engineering, encasement + burial

3. **Early Warning Signs**
   - **Early Warning Signs:**
     - 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.

4. **Environmental Conditions**
   - **Environmental Conditions:**
     - OXYGEN present?

5. **Decay Pathways**
   - **Decay Pathways:**
     - With sufficient water and oxygen, aerobic decay pathways occur.

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**Additional Information:**

- **Lignocellulosic Carbon Storage:** Pathways & Mechanisms
- **Yale Carbon Containment Lab**
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Lignocellulosic Carbon Storage: Pathways & Mechanisms

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 = 0.77 - Lower limit of observed microbial growth

Is Water Activity < 0.60?
Yes. If maintained, no biotic decay can occur.
No. Agents of decay require different threshold WAs

Is OXYGEN present?

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 | Active Monitoring
Land Use | Aboveground storage will require surface land use. | Use in engineering, encasement + burial

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

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ANAEROBIC DECAY
Methanogens are microorganisms 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.

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

**Mechanisms of Wood Preservation Diagram**

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

### Table 1
Summary of literature assessed, DOC recorded and methodological approach.

<table>
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<tr>
<th>Author</th>
<th>Year</th>
<th>Location</th>
<th>Samples</th>
<th>Avg. DOC (Std. Dev)</th>
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<tr>
<td>Wang and Barlaz</td>
<td>2016</td>
<td>North America</td>
<td>HW (n = 2), SW (n = 2)</td>
<td>0.232 (0.047) (HW), 0.0475 (0.019) (SW)</td>
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<tr>
<td>Ximenes et al.</td>
<td>2015</td>
<td>Cairns, Australia, Sydney, Australia</td>
<td>SW (n = 14), HW (n = 18), SW (n = 53), HW (n = 50)</td>
<td>0.018 (0.03) (Sydney), 0.022 (0.03) (Cairns), 0.19 (0.11) (Cairns)</td>
</tr>
<tr>
<td>Wang et al.</td>
<td>2011a,b</td>
<td>North America</td>
<td>SW (n = 2), HW (n = 2), EW (n = 5)</td>
<td>0.009 (0.012) (SW), 0.039 (0.055) (HW), 0.0474 (0.084) (EW)</td>
</tr>
<tr>
<td>Ximenes et al.</td>
<td>2008</td>
<td>Sydney Park (SP), Landfill and Lucas Heights (LH) Landfill, Australia</td>
<td>HW (n = 25), SW (n = 16), HW (n = 16), SW (n = 21)</td>
<td>0.17 (SP), 0.08 (SP), NA (SW &amp;HW, LH)</td>
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HW, Hardwood; SW, Softwood; EW, Engineered Wood.

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

O’Dwyer et al 2017
DRAFT:

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

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

HW vs. SW
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.
NEXT STEPS

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 CH₄ oxidation, mainly belonging to Proteobacteria.
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.
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