Developing an Integrated Logistics Model for Beetle-killed Biomass

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Background

- The ongoing outbreak of the mountain pine beetle has affected over 19 million hectares in the United States
- Beetle-killed wood represents a vast, high-density biomass feedstock resource for bioenergy and bio-based products
- BANR was launched as a USDA NIFA project to explore the use of beetle-killed and other forest biomass as a bioenergy feedstock
Background

Utilization of Beetle-Kill and Other Forest Management Feedstocks to Sustainably and Economically Diversify our Nations Transportation Fuels Markets

**BANR Basics**
- Announced Fall of 2013
- 2014 Project Begins
- 5 Years
- 5 States
- $10 million
- 1 of 7 Coordinated Agricultural Projects (CAPS)

**Structure/Organization**
- Task-Centered Across Multiple States and Institutions
- Project Management and Executive Team
- Independent Project Advisory Team

**BANR Governance and Guiding Principles**
- Collaborative and Multi-Disciplinary
- Science-based with Practical Applications
- What Communities Should Know, Not What They Should Do

**Focus Areas and Tasks**
1. Feedstock Supply
2. Harvesting and Processing
3. System Performance, Lifecycle and Financial Analysis
4. Education
5. Extension and Outreach
6. Health and Safety

For More Information on BANR Visit [http://banr.colostate.edu/](http://banr.colostate.edu/)

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Integrated Logistics Model?

Recoverable Biomass + Harvesting costs + Cost-effective logistics
The 3 Components

- Biomass Allometric Equations
- Cost Estimating Models
- Logistics Optimization
Component 1: Allometric Equations
Component 1: Allometric Equations

Live vs. Dead?
Component 1: Allometric Equations

- The amount of logging residues (top + branch + foliage) is significantly different between live and dead trees
Component 2: Harvesting Costs
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- Feller-buncher productivity: **Standing live > Standing dead > Downed**
- Live/Dead/Down has no effect on skidder, processor, delimber and loader

### Figure:

- **Cycle time (sec)**
- **Live only**
- **Dead only**
- **Downed only**
- **Live/Dead**
- **Mixed w/Downed**
Component 2: Harvesting Costs

- Lop & Scatter vs. Whole-tree Harvesting
Component 2: Harvesting Costs

<table>
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<th>System</th>
<th>Machine</th>
<th>Utilization (%)</th>
<th>Productivity (BDT SMH⁻¹)</th>
<th>Cost ($∙BDT⁻¹)</th>
<th>System</th>
<th>Productivity (BDT SMH⁻¹)</th>
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</tbody>
</table>

*Calculated for two delimiters

: System bottle neck

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: System bottle neck

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![Graph showing system cost vs. average skidding distance](image-url)
Component 3: Logistics Optimization

• What would be the most cost-efficient biomass feedstock logistics for given residue pile locations?

Grinding here? or Slash forwarding to where?
Component 3: Logistics Optimization

- Two alternative systems for forest residue recovery operation

1) **In-woods grinding system**

   - **Grinder cost ↑, Truck cost ↓**
   - **Grinder move-in cost**

2) **Slash forwarding system**

   - **Grinder cost ↓, Truck cost ↑**
   - **No grinder move-in**
Component 3: Logistics Optimization

- Slash forwarding system

Node hierarchy on forest roads
- **Landing**: a location that forest residues could be piled
- **Concentration yard**: a location that has access to chip vans
- **Bioenergy plant**: the destination of ground residues for bioenergy production
Component 3: Logistics Optimization

- **In-woods grinding system**

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Component 3: Logistics Optimization

- Mixed Integer Programming (MIP) approach

**Objective function**

\[
\min Z = \sum_{ij \in L} \sum_{s \in S} \sum_{p \in P} \sum_{t \in T} (cp_{ij}^{sp} + ct_{ij}^{tp}) \cdot X_{ij}^{tp} + \sum_{kl \in N} cm_{kl} \cdot Y_{kl} + \sum_{u \in N} cc_{u} \cdot D_{u}
\]

- \( cp_{ij}^{sp} \): variable processing cost of system \( s \) at location \( i \) (\$/BDT)
- \( ct_{ij}^{tp} \): variable transportation cost of transporting material type \( p \) with truck \( t \) on link \( ij \) (\$/BDT)
- \( cm_{kl} \): move-in cost of grinder mobilization on road segment \( kl \) ($)
- \( cc_{u} \): construction cost for concentration yard or landing at location \( u \) ($)
- \( L \): set of links in the network
- \( N \): set of nodes
- \( P \): set of material types (slash or ground residue)
- \( S \): set of processing equipment system (slash forwarding or in-woods grinding)
- \( T \): set of truck options
Component 3: Logistics Optimization

- Mixed Integer Programming (MIP) approach

**Constraints**

\[ \sum_{j \in N} x_{ij}^{tp} - \sum_{j \in N} x_{ji}^{tp} = \begin{cases} z_i^p & i \in Z \\ 0 & i \in W \end{cases} \text{ for } \forall j \in N, \forall p \in P, \forall t \in T \]

\[ M \cdot D_u \geq \sum_{u \in N} x_{uw}^{tp} \text{ for } \forall v \in C \cup K, \forall p \in P_{grindings}, \forall t \in T \]

\[ \sum_{kl \in R_{uw}} y_{kl} \geq n_{uw} \cdot D_u \text{ for } \forall u \in N, \forall v \in K \]

\[ \sum_{j \in K} x_{ij}^{tp} \geq r_{min} \text{ for } \forall i \in N, \forall p \in P, \forall t \in T \]

\[ D_u \cdot y_{kl} = \{0, 1\} \text{ for } \forall k, l, u \in N \]

\[ x_{ij}^{tp} \geq 0 \text{ for } \forall i, j \in L, \forall p \in P, \forall t \in T \]

\[ C : \text{ set of concentration yards} \]

\[ K : \text{ set of bioenergy facilities} \]
### Conventional Logistics

- **Total cost:** $240,711
- **Unit cost:** $43.4 / BDT
- **Con. yard locations:** 0
- **On-site processing locations:** 52

#### Key Details
- **Grinder’s location**
- **Flow of ground residues**

#### Map Details
- **Forest stands**
- **Road speed**
  - 60 mph
  - 40 mph
  - 15 mph

#### Locations
- **Bioenergy plant**
- **Grinder’s location**
- **Flow of ground residues**
- **Road speed**
  - 60 mph
  - 40 mph
  - 15 mph
- Total cost: $162,223
- Unit cost: $29.2/BDT
- Con. yard locations: 2
- On-site processing locations: 2

- Grinder’s location
- Flow of slash residues
- Flow of ground residues

Bioenergy plant

Optimized

- 2,142 BDT
- 1,269 BDT
- 1,420 BDT
- 2,689 BDT
- 3,506 BDT
- 817 BDT

Graph showing:
- Unit cost ($/BDT)
- Optimized: 29.2
- Conventional: 43.4
- Decrease: (32.7%)
Integration – A Case Study

• Study forest (Colorado State Forest, CO)
• Total area: 36,428 acres
Integration – A Case Study

• Criteria: Lodgepole pine; Slope < 30%; average skidding distance < 2,000 ft
Integration – A Case Study

- Estimated logging residues
Integration – A Case Study

- Cost difference between WT and LS (WT – LS)

Average cost: $40.1/ BDT
(-$4.9 ~ $240.2/ BDT)
Integration – A Case Study

- Optimized Logistics

- Average cost: **20.5 $-BDT**
- Concentration yards: 2
- On-site processing location: 1

Flow of slash residues

Flow of ground residues

Grinder's location

Node
- Slash piles
- CY's
- Bioplant

Road speed (mph)
- 15
- 55
- Lodgepole pine

Node
- 14,336 BDT
- 16,236 BDT
- 6,742 BDT
- 1,900 BDT
- 1,900 BDT
- 6,742 BDT

Conventional

Optimized

(25.2%)
Concluding Remarks

• New allometric equations, new harvesting cost and new logistics optimization approach allow estimation of more realistic beetle-kill biomass supply and costs – addressing the existing uncertainties and knowledge gaps

• ‘Years since dead’ likely affect harvesting costs, timber product mix and therefore project net revenue – will be studied in collaboration with other task teams in BANR

• The logistics model will be further integrated with the downstream supply chain to incorporate facility locations and end-user products for minimum costs and maximum value recovery
Thank you
Questions?

Acknowledgement: This project was supported by the Agriculture and Food Research Initiative Competitive Grant no. 2013-68005-21298 from the USDA National Institute of Food and Agriculture.