U.S. Department of Energy (DOE)
Bioenergy Technologies Office (BETO)
2017 Project Peer Review

Waste to Wisdom: Utilizing forest residues for the production of bioenergy and biobased products

May 6th – 9th, 2017
Feedstock Supply and Logistics Session

Han-Sup Han
Humboldt State University

Forest Residues

Logging Slash

Forest Thinnings

103 million tons/year @ $60/bone dry ton (Billion-ton Report, 2016)

Forest residues are underutilized or wasted due to high collection and transportation costs and low market values.

Project Goal:

To develop biomass conversion technologies and in-woods operational logistics that facilitate utilization of forest residues for the sustainable production of bioenergy and biobased products.

WASTE TO WISDOM

Quad Chart Overview

Timeline

- Official start date: 9/30/2013 (Contract and funds available 5/14)
- Official end date: 12/31/2017
- Percent complete: 85%

Budget

	Total Costs FY 13 – 14	Costs FY 15	Costs FY 16	Total Planned Funding (FY 17-Project End Date)
DOE Funded	553,289	1,748,049	1,894,281	1,686,354
Project Cost Share	265,443	808,196	659,221	0

Barriers addressed

- Production of quality feedstocks
- Development of biomass conversion technologies
- Evaluation of environmental and economic benefits

Partners

- Partners/Collaborators
  - DOE
  - Forest Products Co.
  - USDA Forest Service
  - Land-Grant Universities
  - Biomass Engineering Co.
- Project Management:
  - Humboldt State University

1 - Project Overview

Forest Residues

↓

Production of Quality Feedstock

↓

In-woods Biomass Conversion

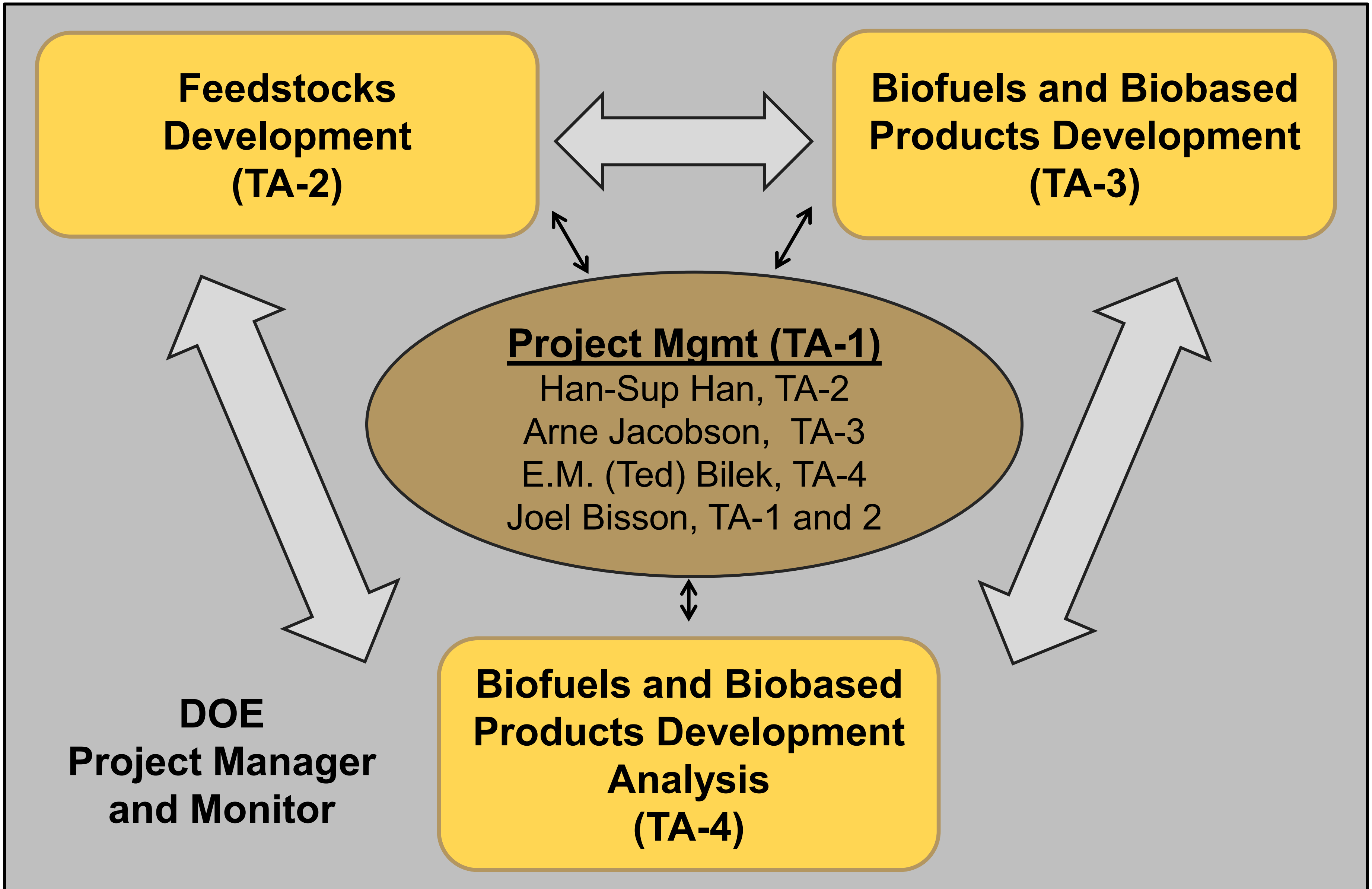
Biochar

Briquettes

Torrefied chips

- ✓ Improve transportation efficiency
- ✓ Increase product values
- ✓ Improve properties for production of energy

1 - Approach (Management – TA1)



2 – Approach (Technical)

TA2 - Feedstock Development:

- Sort and process forest residues to produce quality feedstocks
- Compress forest residues into high-density bales
- Develop logistics models integrating both in-woods biomass operations and conversion technologies

TA3 - Biofuels and Biobased Products Development:

- Evaluate the technical performance of three proven biomass conversion technologies (BCTs: biochar, torrefaction, and briquettes) that are designed to run near a forestry operations site
- Utilize the test results to refine and scale up the biomass conversion technologies

TA4 - Biofuels and Biobased Products Development Analysis:

- Evaluate financial feasibilities of stump-to-market operations
- Determine their socio-economic and environmental impacts
- Analyze ecological sustainability of the processes

3 - Technical Accomplishments and Results

Task Area 2 - Feedstock Development

Quality feedstock production:

- Developed a new logistics to produce high quality feedstock for BCTs: sorting and processing, comminuting, and screening forest residues
- Evaluated the productivity and cost of the machines used
- Evaluated feedstock quality: moisture content, size distribution, bulk density, and ash content

wood chips (<0.75”) micro-chips (<0.25”) sawdust (<0.16”)

Sort and Process

Comminute

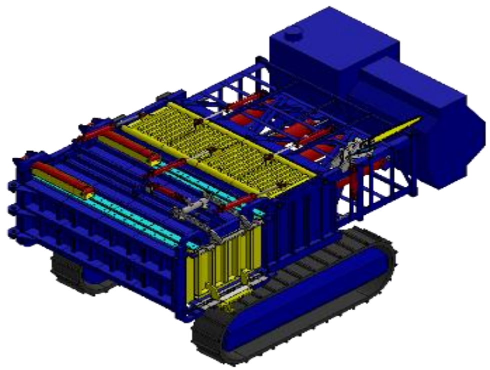
Screen

3 - Technical Accomplishments and Results (cont'd)

Task Area 2 - Feedstock Development

Baling technology development:

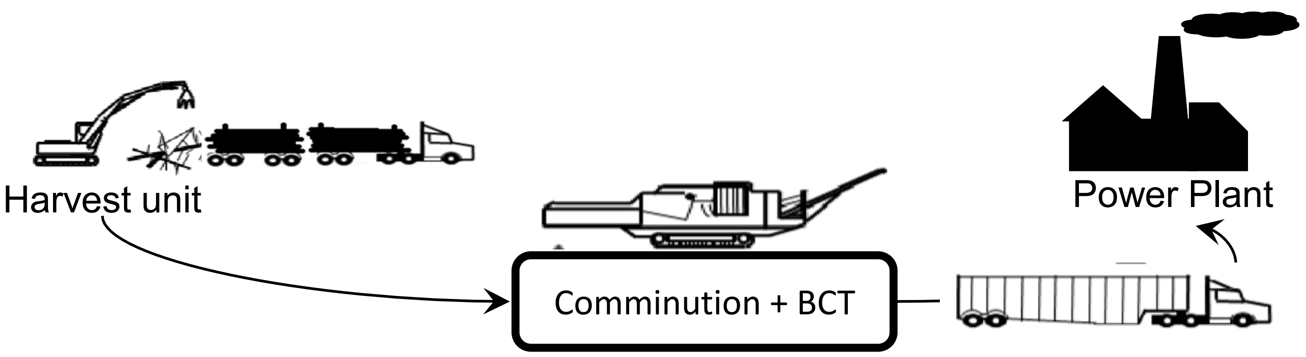
- Completed "conceptual design" reports for bales and two models of the baler
- Completed long-term bale weight tracking and storage integrity evaluation



Forest Biomass Large Baler

Operations logistics:

- Tested logistics of integrating BCTs into in-woods feedstock production operations
- Developed operational strategies to maintain a high level of balance between feedstock supply and BCT operations



3 - Technical Accomplishments and Results (cont'd)

Task Area 3 - Biofuels and Biobased Products Development

Biochar Production

Target	Achievement
Double throughput of machine	Built scaled-up machine. Increased throughput by 46% to 12 TPD input
Reduce operator effort	Automated reactor feeding system
Increase fire safety	Added spark arrestor
Additional improvements	Reduced criteria pollutant emissions Improved waste heat recovery system

Key milestones:

- Tested original design with a variety of feedstocks
- Integrated machine with belt dryer and gasifier generator
- Built scaled up machine with improvements; conducted validation testing

3 - Technical Accomplishments and Results (cont'd)

Task Area 3 - Biofuels and Biobased Products Development

Torrefaction

Target	Achievement
Adopt unit for field operation	Built mobile machine with 6 hour set up and tear down
Increase throughput to 20 TPD	Increased throughput by 100x to 16 TPD
Test unit at a field site	Tested demonstration 16 TPD torrefaction/briquetting plant

Key milestones:

- Tested pilot unit
- Identified areas for improvement
- Built improved machine
- Improved product quality and consistency

3 - Technical Accomplishments and Results (cont'd)

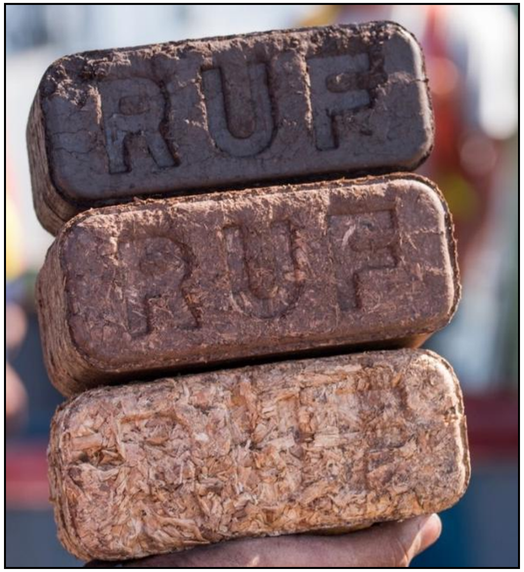
Task Area 3 - Biofuels and Biobased Products Development

Densification

Target	Achievement
Assess suitability for field use	Operated briquetter for 3 months in field environment
Produce briquettes from forest residues	Produced dense, durable briquettes from forest residues without binders
Produce briquettes from torrefied biomass	Produced torrefied briquettes without binders

Key milestones:

- Testing at industrial facility
- Testing at field site
- Torrefaction/briquetting demonstration plant



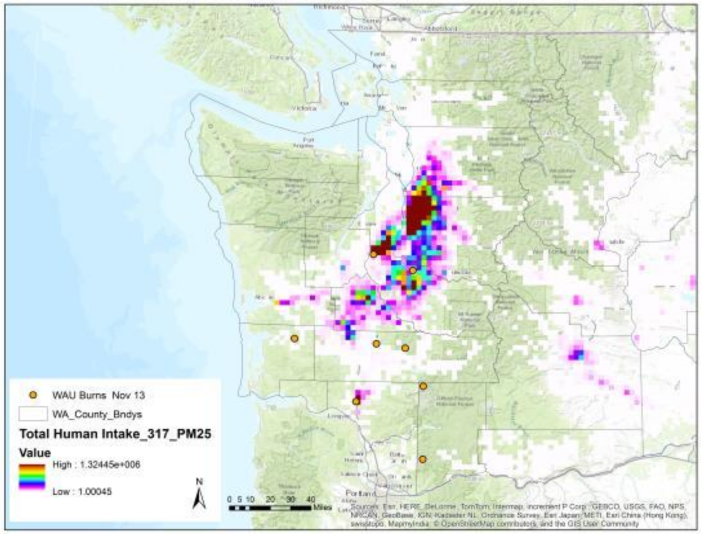
3 - Technical Accomplishments and Results (cont'd)

Task Area 4 - Biofuels and Biobased Products Development Analysis

Ecological impacts and lifecycle assessments:

- Showed that utilizing forest residues can significantly alleviate the adverse local and regional air quality impacts from pile burning
- Biochar application improved water holding capacity, carbon sequestration, and water quality in damaged soils
- Life cycle analysis (LCA) considers environmental impacts of the three biomass conversion technologies, biochar, briquettes, and torrefied wood over the entire life cycle from forest operations

Total Human Intake of PM2.5 for Scenario Pile Burns on Nov 13 2011



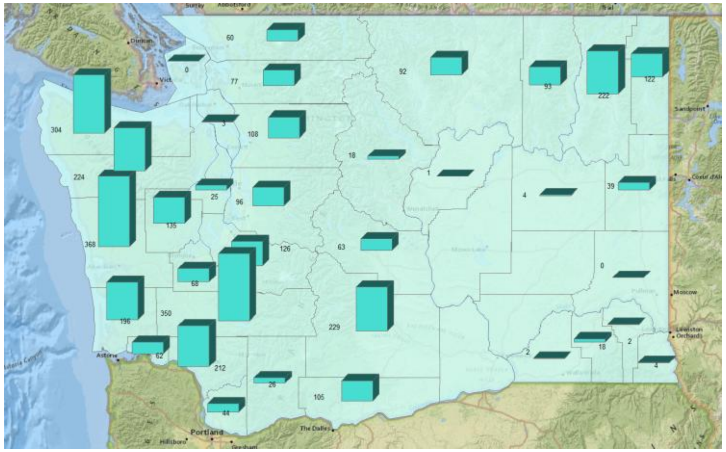
Biochar on forest site

3 - Technical Accomplishments and Results (cont'd)

Task Area 4 - Biofuels and Biobased Products Development Analysis

Financial analysis and economic impacts:

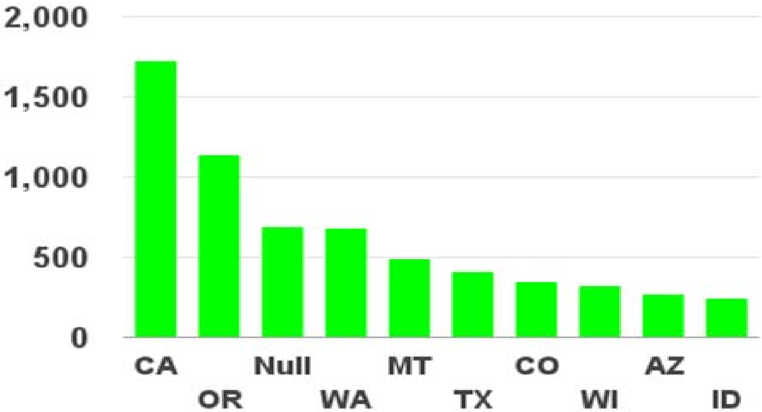
- Financial component analyses completed
    - in-woods operations
    - BCT operations
    - product market value analysis.
- In Washington alone, 3,000-3,500 jobs can be created at a biomass price of $50-60/BDT.



Potential jobs by county

Social acceptance and outreach:

- W2W survey shows that public is generally positive concerning bioenergy, though many currently not aware of these products
- Project website (www.wastetowisdom.com) has had 34,298 page views from April 29, 2015 to January 19, 2017



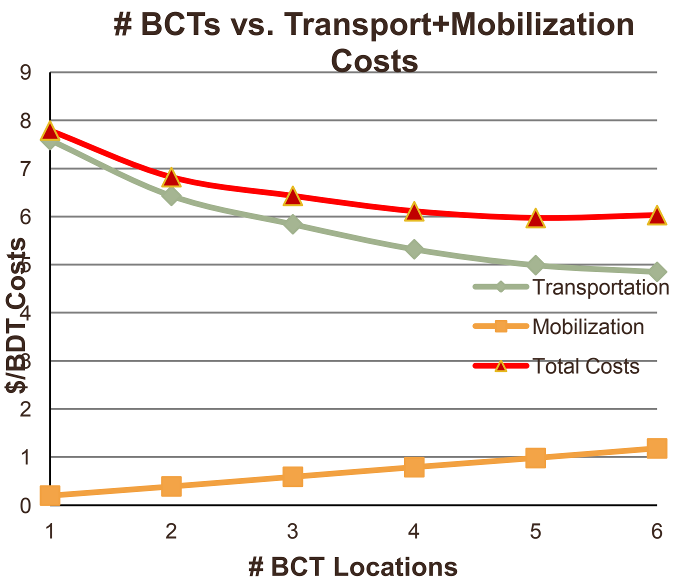
W2W website views by location

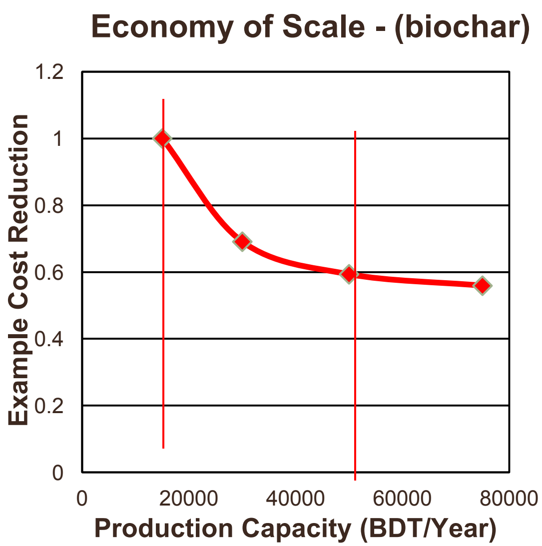
3 - Technical Accomplishments and Results (cont'd)

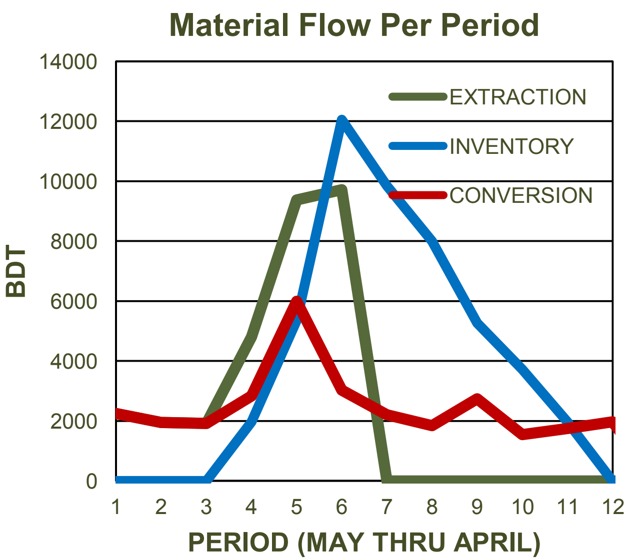
Landscape Model Overview

Objective: Maximize NPV for Investor

- ***Strategic Modeling*** - High Level Decisions (Scale/Mobility)
- ***Tactical Modeling*** - Detailed Analyses (Logistics/Pathways)
- ***Project Integration*** - Baseline Scenarios/Pathways







Key Questions to Answer:
Placement, Mobility Frequency and Transportation / Optimal Facility Scale / Processing, Conversion, Product Suite per Region?

4 - Project Relevance (to BETO MYPP)

This project aims to *"develop technologies to provide a reliable, affordable, and sustainable supply of terrestrial feedstocks to enable a nascent and growing bioenergy industry… and … develop commercially viable technologies to convert feedstocks into bioproducts and biopower."*

"Waste to Wisdom" – an integrated approach that will:

- Provide significant advancement in terrestrial feedstock supply and logistics that meet the price target ($50-$60/dry ton) with low ash contents (<1%)
- Show how integrating BCTs into feedstock logistics can increase transportation efficiencies and improve longer-term feedstock storage in depots or biorefineries
- Provide products that reduce physical and chemical variability to ensure a more reliable and efficient biofuel as a drop-in replacement for coal, compatible with existing infrastructure and reducing overall emissions
- Provide credible data and projections on current and future cost, social and environmental impacts, and quality of biobased products, which will reduce uncertainty to developing biorefinery technologies

4 - Project Relevance (to BETO MYPP)

Current summary of total dissemination activities

- Journal publications = 9
- Reports = 4
- Presentations = 41
- Live demonstrations = 3
- Webinars = 5
- Patents = 3

Project Impacts & Significance: Examples

- **Green Diamond Resource Company** has chosen to sort out and process small diameter stems based on the economic evaluation provided by this study. With a favorable market, the company saw value in merchandising another product and reducing the amount of forest residues on the landscape.

- Through knowledge generated from this project, **Redwood Forest Foundation, Inc. (RFFI)** has improved their biochar production facility by integrating a waste heat dryer and gasifier generator set.
  By integrating the drying system, RFFI is able to extend its operation from 6 to 9 months, thereby increasing their revenue from biochar sales by 50%.

5 – Future Work

- **Tasks to be completed (through December 30, 2017):**
  - Refine all the tasks completed through publication process with refereed journals
  - Complete the tasks related to financial/socio-economic and environmental analysis
  - Focus on extension & outreach activities disseminating the project outcomes

- **Key milestones**
  - PI meeting/a team-wide workshop in May, 2017
  - All the sub-contracts to be completed by 09/31/2017: no project extension will be allowed and requested
  - Final report and supporting documents to be submitted by 12/31/2017

- **The remaining budget ($1.6 million) is sufficient to complete the work to be done. The cost share requirement has been met.**

Summary

- ✓ **Overview:** Utilization of forest residues for the sustainable production of biofuels, bioenergy, and biobased products
- ✓ **Approach:** Integration of new biomass conversion technologies with in-woods feedstock production and supply operations
- ✓ **Technical Accomplishments/Progress/Results:**
  - Developed new operations logistics of supply quality feedstock from forest residues
  - Produced biochar, torrefied wood, and briquettes near the forest operation sites
  - Socio-economic and environmental benefits from utilization of forest residues are being performed.
- ✓ **Relevance:** Significant advancement in meeting the MYPP goals of sustainable supply of terrestrial feedstock and development of innovative biomass conversion techs.
- ✓ **Future work**: Continue working to complete the project tasks by the project end date (12/31/2017)

Questions?

Additional Slides

List of Abbreviations

- BCT – Biomass Conversion Technology
- BDT – Bone Dry Ton
- BETO – Bioenergy Technologies Office
- BSI - Biochar Solutions Inc.
- CORRIM - Consortium for Research on Renewable Industrial Materials
- DOE – U.S. Department of Energy
- LCA – Life Cycle Analysis
- LCI – Life Cycle Inventory
- MYPP – Multi-Year Program Plan
- PI – Principal Investigator
- SOPO – Statement of Project Objectives
- TA – Task Area
- TPD – Tons per Day
- W2W – Waste to Wisdom

Principal Investigators (PI) and Partners

<table>
<tr><th>PI Name</th><th>Institution</th><th>Expertise</th></tr>
<tr><td>Han-Sup Han</td><td>Humboldt State University</td><td>Forest Operations</td></tr>
<tr><td>John Sessions</td><td>Oregon State University</td><td>Transportation</td></tr>
<tr><td>James Dooley</td><td>Forest Concepts Inc.</td><td>Forest Engineering</td></tr>
<tr><td>Arne Jacobson</td><td>Humboldt State University</td><td>Env. Engineering</td></tr>
<tr><td>Jonah Levine</td><td>Biochar Solutions Inc.</td><td>Gasification</td></tr>
<tr><td>Aaron Norris</td><td>Norris Thermal Tech.</td><td>Torrefaction</td></tr>
<tr><td>John Crouch</td><td>Pellet Fuels Institute</td><td>Briquette Equipment</td></tr>
<tr><td>E.M. Bilek</td><td rowspan="3">USDA Forest Service</td><td>Forest Economics</td></tr>
<tr><td>Debbie Page-Dumroese</td><td>Forest Soils</td></tr>
<tr><td>Richard Bergman</td><td>Life Cycle Analysis</td></tr>
<tr><td>Ivan Eastin</td><td>University of Washington</td><td>Forest Marketing</td></tr>
<tr><td>Elaine Oneil</td><td>CORRIM</td><td>Life Cycle Analysis</td></tr>
<tr><td>Craig Rawlings</td><td>For. Business Network</td><td>Public Outreach</td></tr>
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WASTE TO WISDOM

Responses to Previous Reviewers' Comments

- *"Inappropriate placement in BETO's program"*

  => It would have fit better within the Feedstock Portfolio.

- *"Broad scopes and goals of the project"*

  => We have assembled a diverse group of researchers with different technical skills, geographic locations, and organization affiliations.

- *"Very large number of PIs and project partners"*

  => We will manage the project through effective project coordination and management

- *"Difficult to determine progress and accomplishments"*

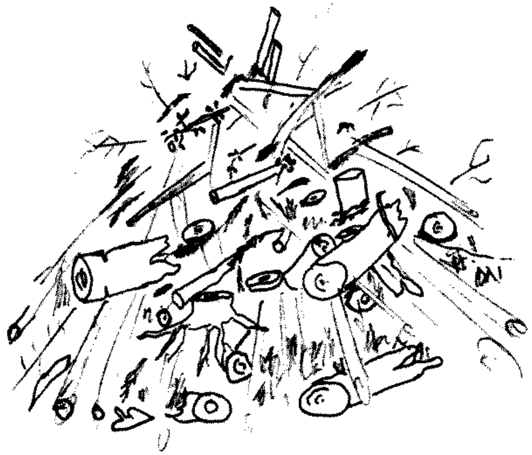
  => We have made measurable progress consistent with our proposed schedule, and will carefully meet the timelines and milestones to completion.

Task Area 2:

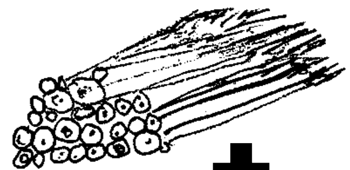
Feedstock Development

Processed Tops and Slash Generated from Sorting

Forest residues



Processed tops



Slash piles

The amount of tops and slash generated is directly related to:

- Minimum diameter for sawlog
- Species processed (hardwood vs. conifer)
- Trees per acre
- Non-merchantable trees

	Percentage (%)	
	Processed Tops (stem wood only)	Slash
Unit 1	24.7	75.3
Unit 2	19.1	80.9
Unit 3	24.4	75.6

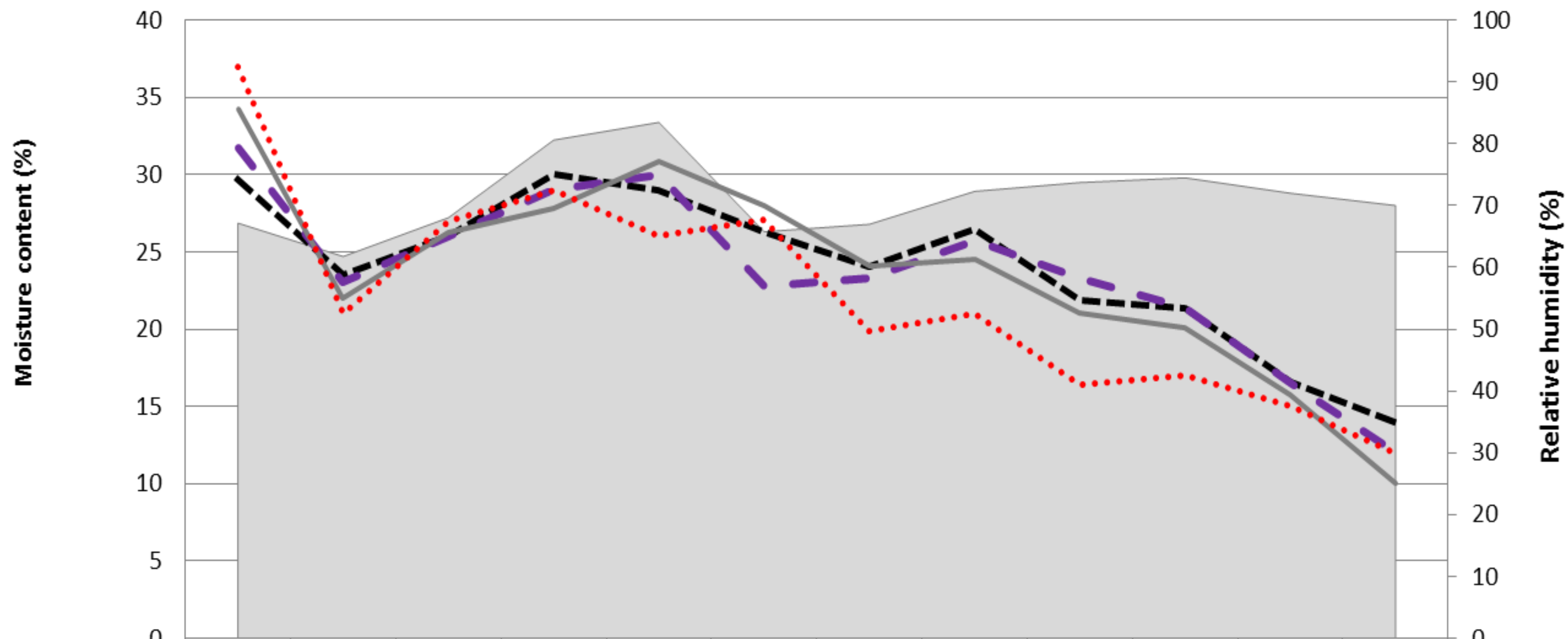
Managerial Impacts

- ✓ High quality feedstock production can be economically integrated to typical timber harvesting operations
- ✓ Increase in cost due to sorting and processing of forest residues : $ 465/acre
- ✓ Enhanced value for processed tops allows for economic long distance hauling
- ✓ Utilizing forest residues can reduce cost of site preparation
  => $300 - $800/acre

Additional revenue

- ✓ Production of higher quality comminuted feedstock
- ✓ Market for “tree-top” logs as dowel, post-pole, etc.

Moisture Content in Forest Residues

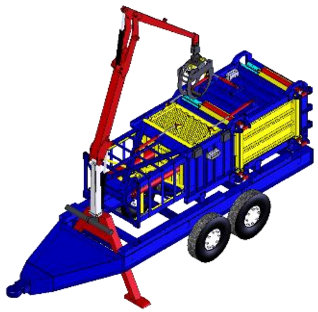


	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July
Relative humidity (%)	67	62	68	81	83	66	67	72	74	74	72	70
Teepee	30	23	26	30	29	26	24	26	22	21	17	14
Criss cross	32	23	26	29	30	23	23	26	23	21	17	12
Processor pile	34	22	26	28	31	28	24	24	21	20	16	10
Scattered	37	21	27	29	26	27	20	21	16	17	15	12

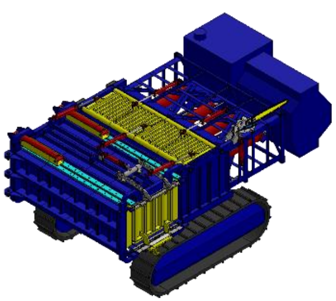
Conceptual Forest Residuals Balers

(Updated October 1, 2016)

			Conceptual BRDI Project Balers	
	FCLLC Engineering Prototype (FCEP)	**Urban Chipper Replacement**	**Forest Biomass Utility Baler**	**Forest Biomass Large Baler**
Bale Size (inches)	32x48x56	36x48x72	32x48x56	34x48x96
Bale Density (lb/cu.ft – @ 50% MC wb)	15-25	15-20	20-30	20-30
Bale Weight (lb)	800 – 1,400	1,000 – 1,400	1,000 – 1,500	2,000 – 2,700
Loader	Self-loading grapple	Self-loading grapple	Self-loading grapple	Track-hoe with brush grapple
Theoretical/Operational Capacity (bales/hr)	3/2	5/3	10/4	18/10
Horsepower	28	49	49	260
Crew	2 (manual tie)	2 (manual tie)	1 (auto-tie)	0 (remote-operated)
Running Gear	5^{th} Wheel Trailer	Category 3 trailer	Modular	Tracked
Capital Cost ($) Est.		$110,000	$130,000	$350,000



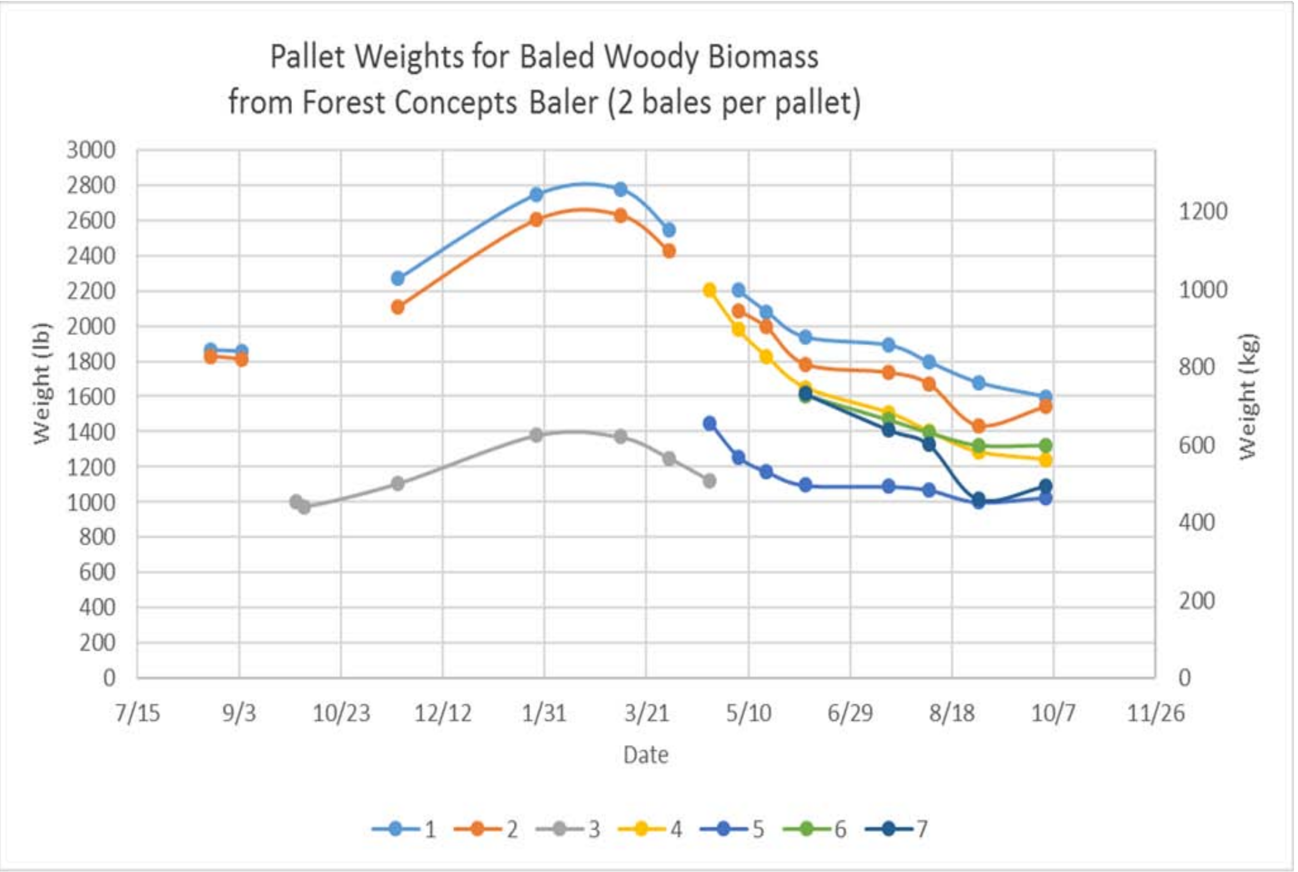
Forest Biomass Utility Baler



Forest Biomass Large Baler

Bale Dry-Down Data

- Gained up to 1,000 lb/pallet of water during winter season
- Dried back to as-baled MC by mid-May
- Continued to dry during summer
- Trending up in October
- Actual % MC will be determined after grinding and back-calculated to each period
- Plan conference or journal paper in 2017



Feedstock Quality Results

Material type	Machine*	Age (months)	Average moisture content (%)	Geometric mean particle length (inches)	Average bulk density (lb/ft^3)	Average ash content (%)
PS	C	2	26	0.7	14.2	0.27
	C	12	18	0.5	12.7	0.26
	M	12	18	0.2	14.7	0.25
PH	C	2	29	0.6	20.1	1.03
	C	12	21	0.7	15.7	0.69
	M	12	23	0.2	18.7	0.88
US	C	2	27	0.7	14.9	0.64
	C	12	22	0.6	13.5	0.43
	M	12	20	0.2	14.2	0.35
UH	C	2	27	0.8	19.4	1.07
	C	12	19	0.6	15.7	0.99
	M	12	20	0.3	18.3	1.18
Slash	G	2	19	1.9	8.6	1.50
PS	S	2	32	0.2	15.8	NA
PH	S	2	29	0.2	17.6	NA

* C = Chipper, M = Micro-chipper, G = Grinder, S = Sawdust machine

Results of Screening Study

		Wood chips		Hog fuel	
		Deck	Star	Deck	Star
Productivity (tons/hour)		29.76	64.1	15.37	55.61
Fuel consumption (gallons/ton)		0.23	0.03	0.4	0.04
Size distribution (%)	Under (< 3/8 in.)	15.07	8.04	29.75	32.03
	Accept (3/8 – 2 in.)	84.74	91.35	67.75	60.73
	Over (> 2 in.)	0.19	0.61	2.5	7.24

Improving the Deck Screener's Performance

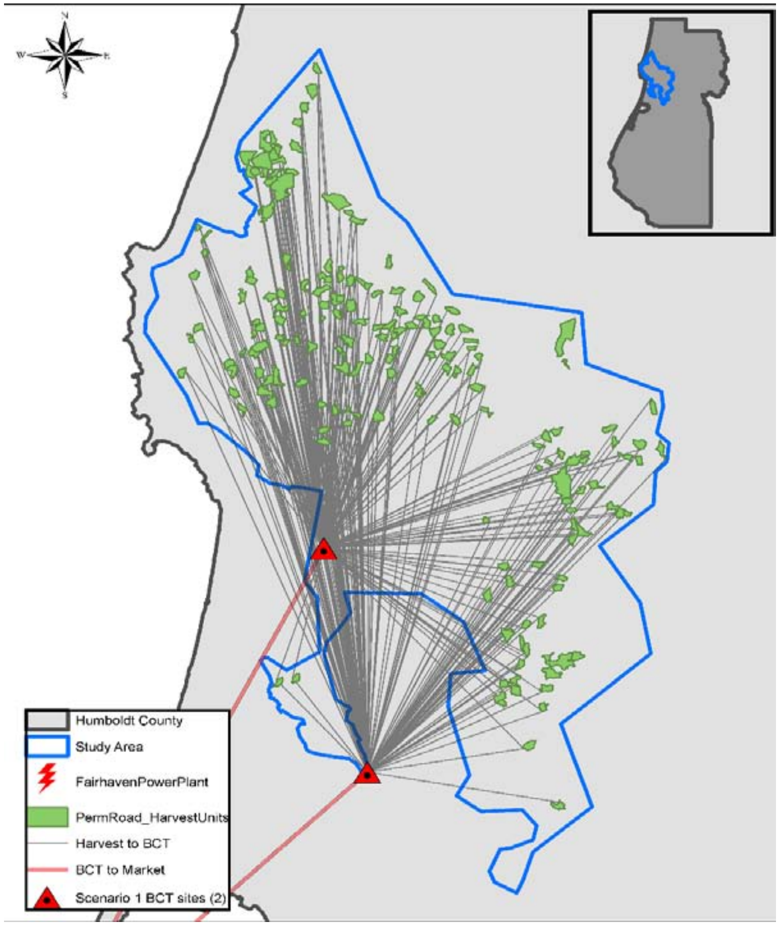
- To reduce diving problems (spear shape) during deck screen operation
- Different screen settings did not affect productivity and fuel consumption
- Combination screen setting improve screening performance

Screen Setting 1(SS1); *4 sets of 2 in.* screens

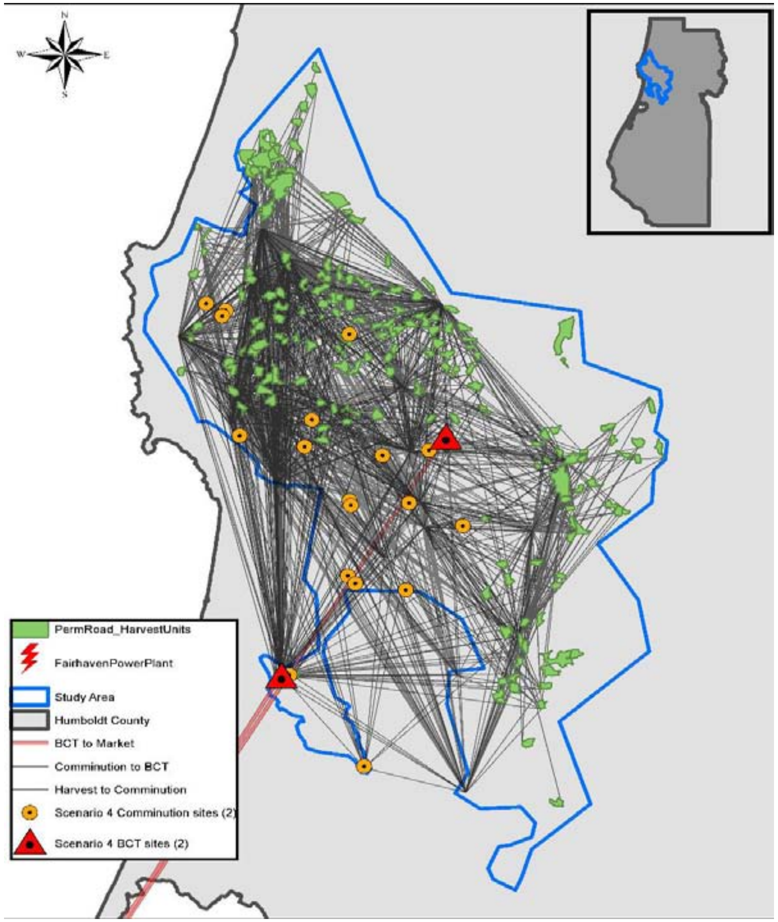
Screen Setting 2 (SS2); one *3/8 in.* and 3 sets of *2 in.* screens

Operations Logistics

Comminution and BCT operations at the same location



Comminution site with a separate BCT Site



3 - Technical Accomplishments and Results (cont'd)

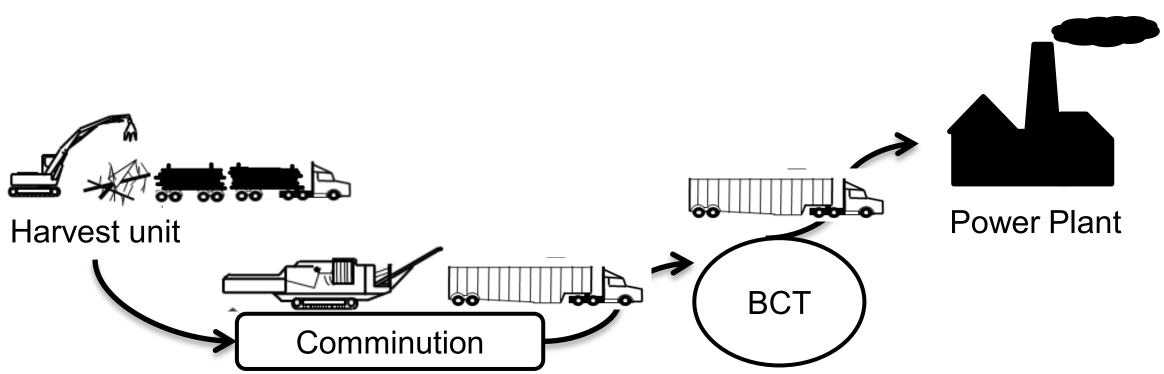
Task Area 2 - Feedstock Development

In Progress:

- Finalizing logistics needed to support BCTs with a centralized biomass feedstock operation
- Refining models to integrate the collection, processing, and transportation of material on a landscape level

Key milestones:

- Published two journal articles detailing the cost to sort and arrange forest residues, and the quality of feedstock that can be produced. Thirteen journal manuscripts in the process of being published
- Received three patents from the US Patents Office for two baler systems



Task Area 3:

Biofuels and Biobased Products Development

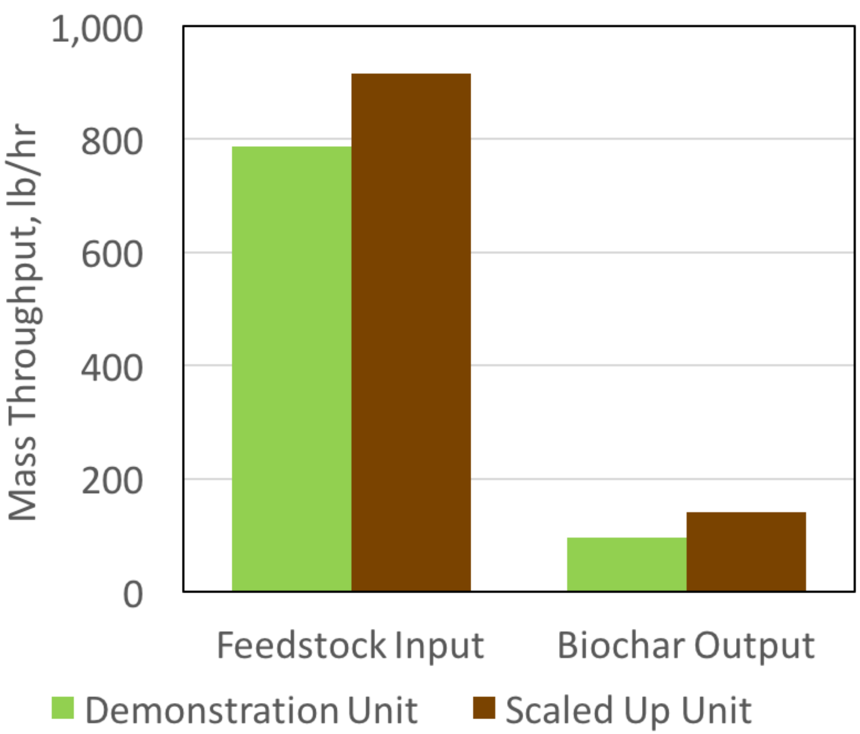
Biochar Scaled-Up Machine

Test Objectives

- Validate production rate
- Measure gas and particulate matter emissions

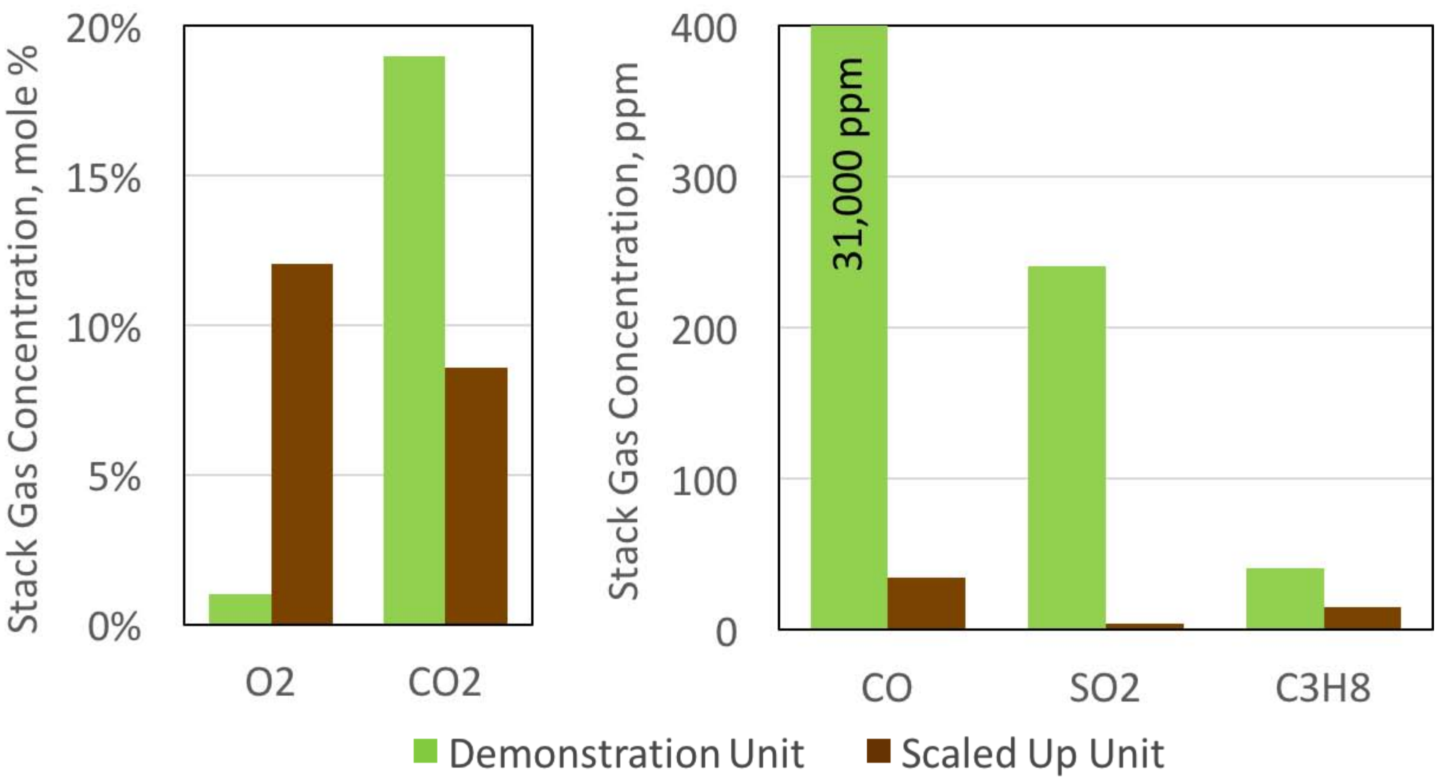
Primary Improvements

- Increased production rate by 46%
- Lower emissions from flare
- Automated feeding system
- Increased yield from 12% to 15%



Biochar Emissions Reductions

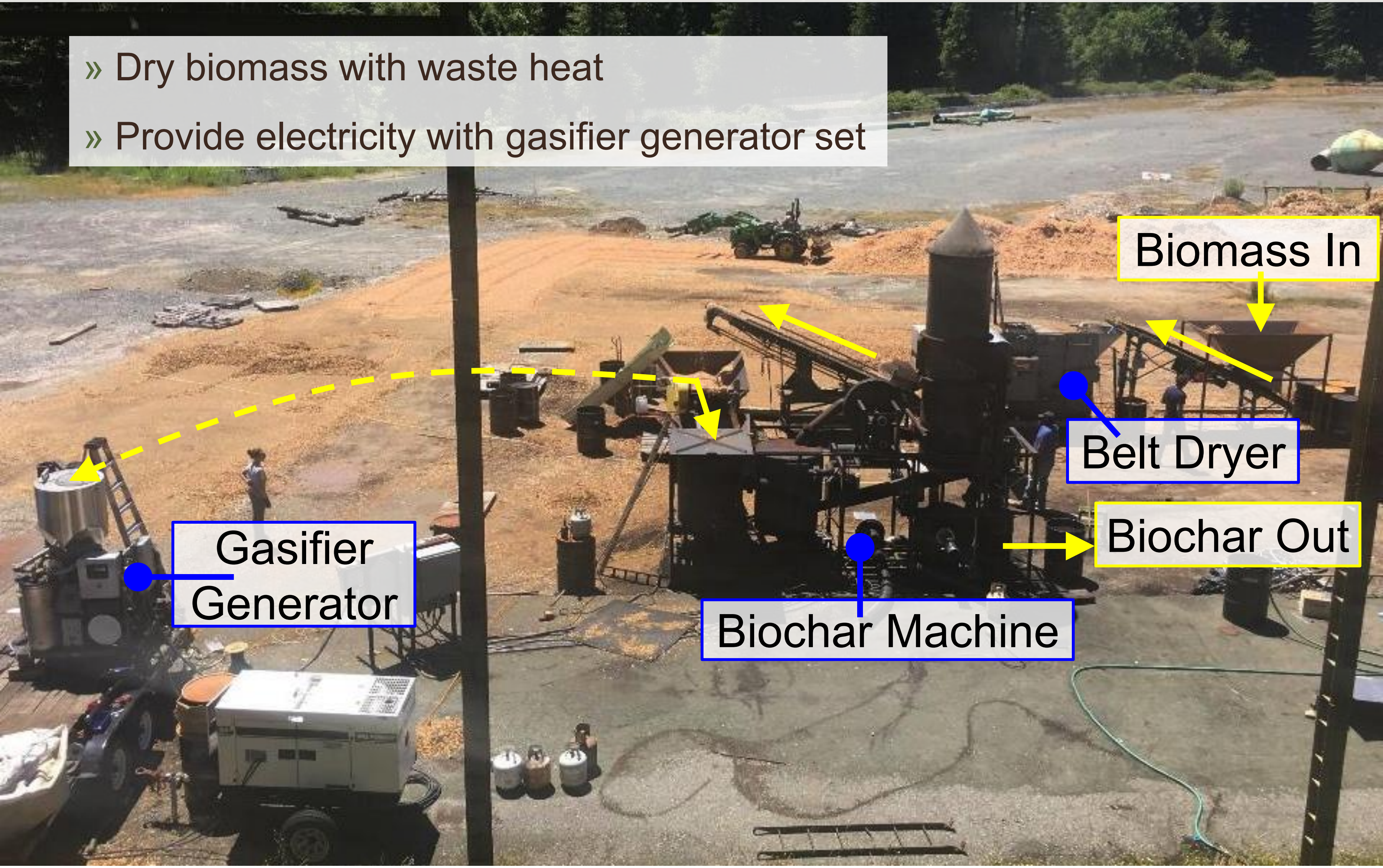
» The scaled-up biochar machine showed a substantial decrease in CO, SO_2, and hydrocarbon emissions based on recommendations for improved flare design.



Biochar Integrated System Design

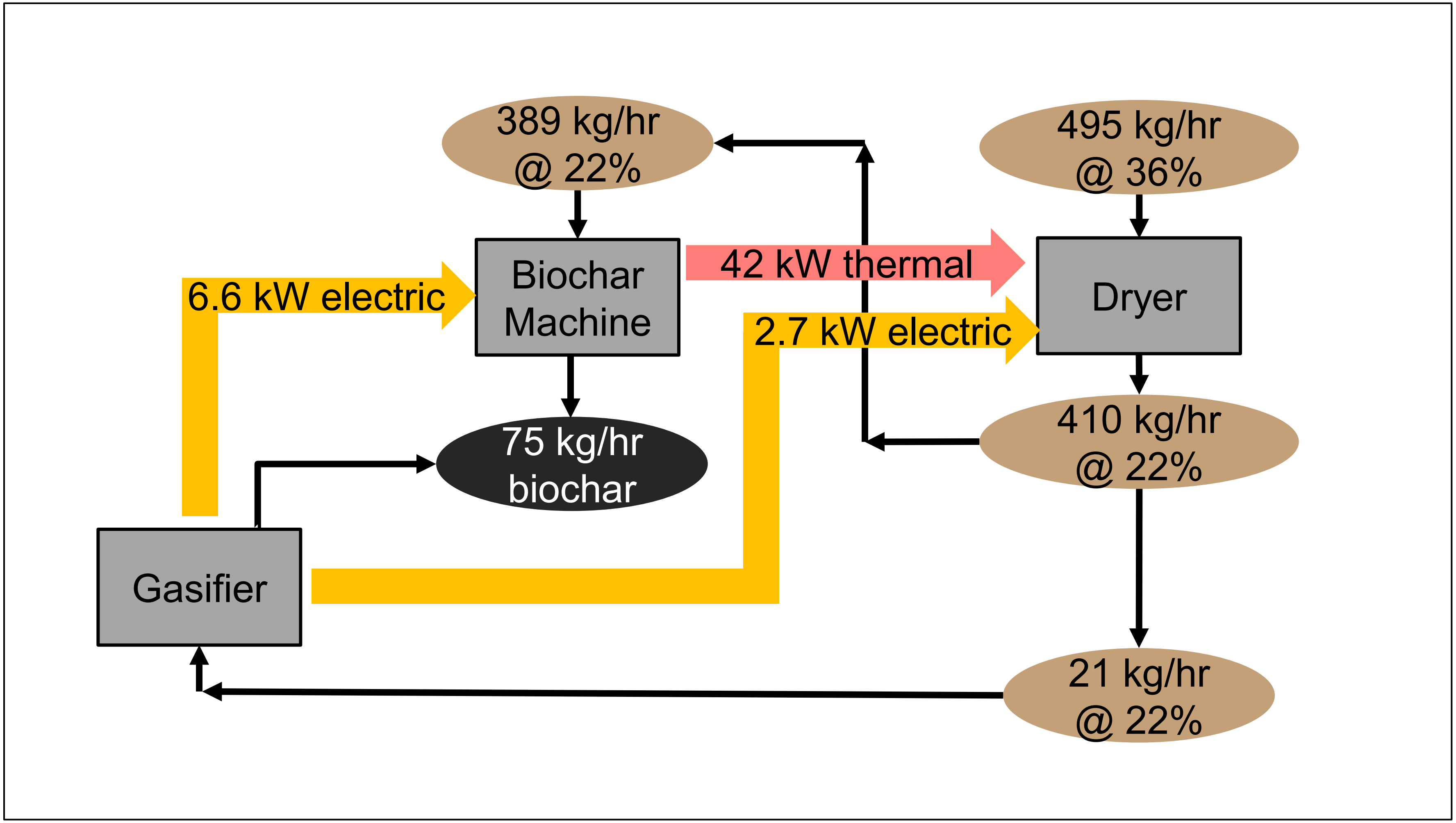
» Dry biomass with waste heat

» Provide electricity with gasifier generator set



Biochar Integrated System Design

- Produced 75 kg/hr of biochar with no external inputs.
- System can be operated by one person.



Biomass Dryer Test Results

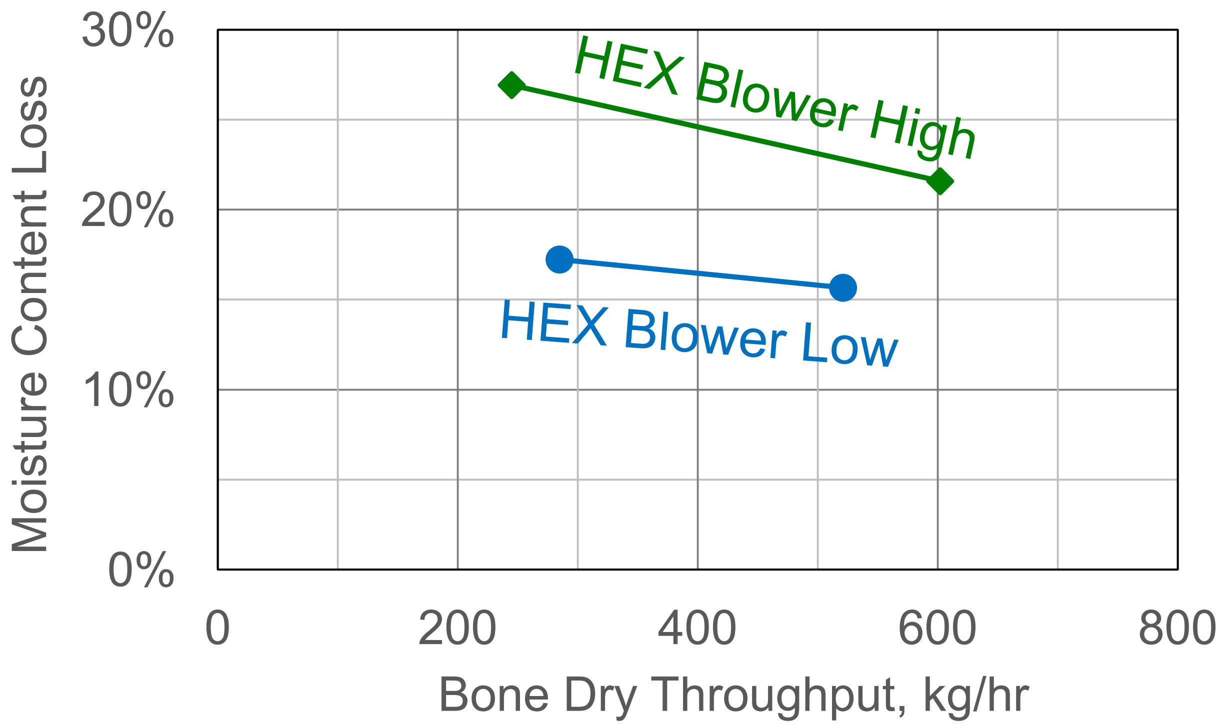
Dryer tests using waste heat from biochar machine

» Tested two heat exchanger (HEX) blower speeds; higher flow → lower temperature

» Tested two dryer belt speeds; higher belt speed → higher throughput

» Best drying achieved at high blower speed.

» Adjust dryer belt speed to match consumption rate of biochar machine.



Torrefaction Pilot Unit Testing – Lessons Learned

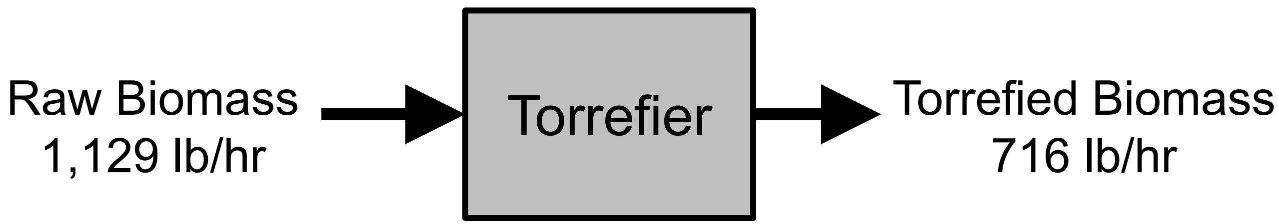
- Air locks leaked excess oxygen into the reactor causing combustion.
  - New system includes improved air locks and automated control to maintain neutral pressure in the reactor.
- Torrefier intolerant of larger particles > 1” due to bridging in the hopper.
  - Feeding system is redesigned to widen the range of acceptable feedstocks.
- Temperature control thermocouple was inadvertently electrically heated.
  - New system insulates the thermocouple from electrical heating.

Inconsistent Product

Small Air Locks

Scaled up Torrefier – Biomass Properties

» Properties of biomass torrefied at a 425°C setpoint for 10 minutes.



9.1%	Moisture Content	0.9%
18.0 MJ/kg	HHV	22.8 MJ/kg
14% mass	Water Absorption	6.8% mass
170 Wh/kg	Grinding Energy	53 Wh/kg

Torrefied Briquettes Demonstration Plant

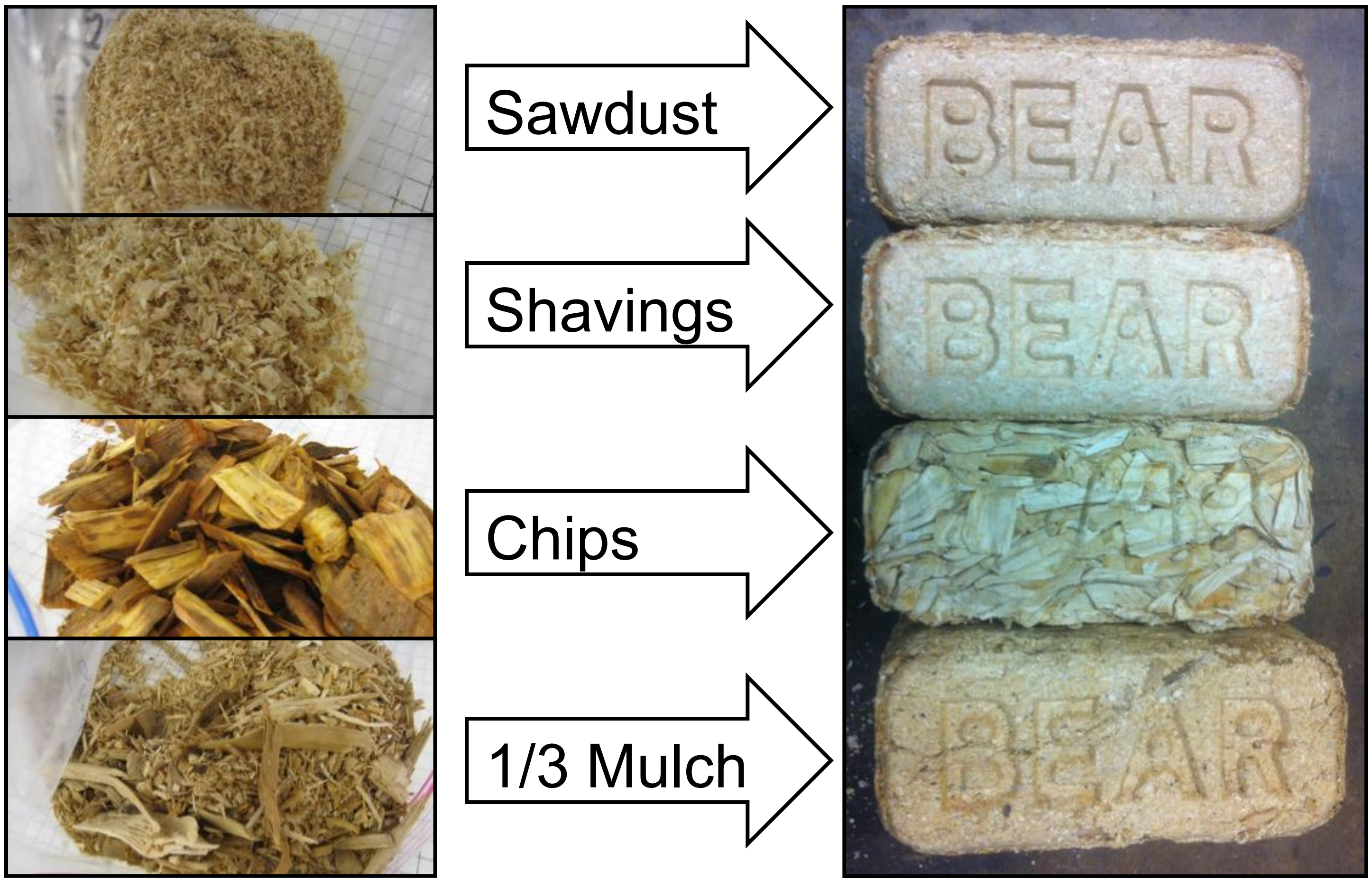
Torrefier/Briquetter Demonstration Plant

Comparison between raw and torrefied briquettes

Torrefied briquettes display more desirable properties than raw biomass briquettes.

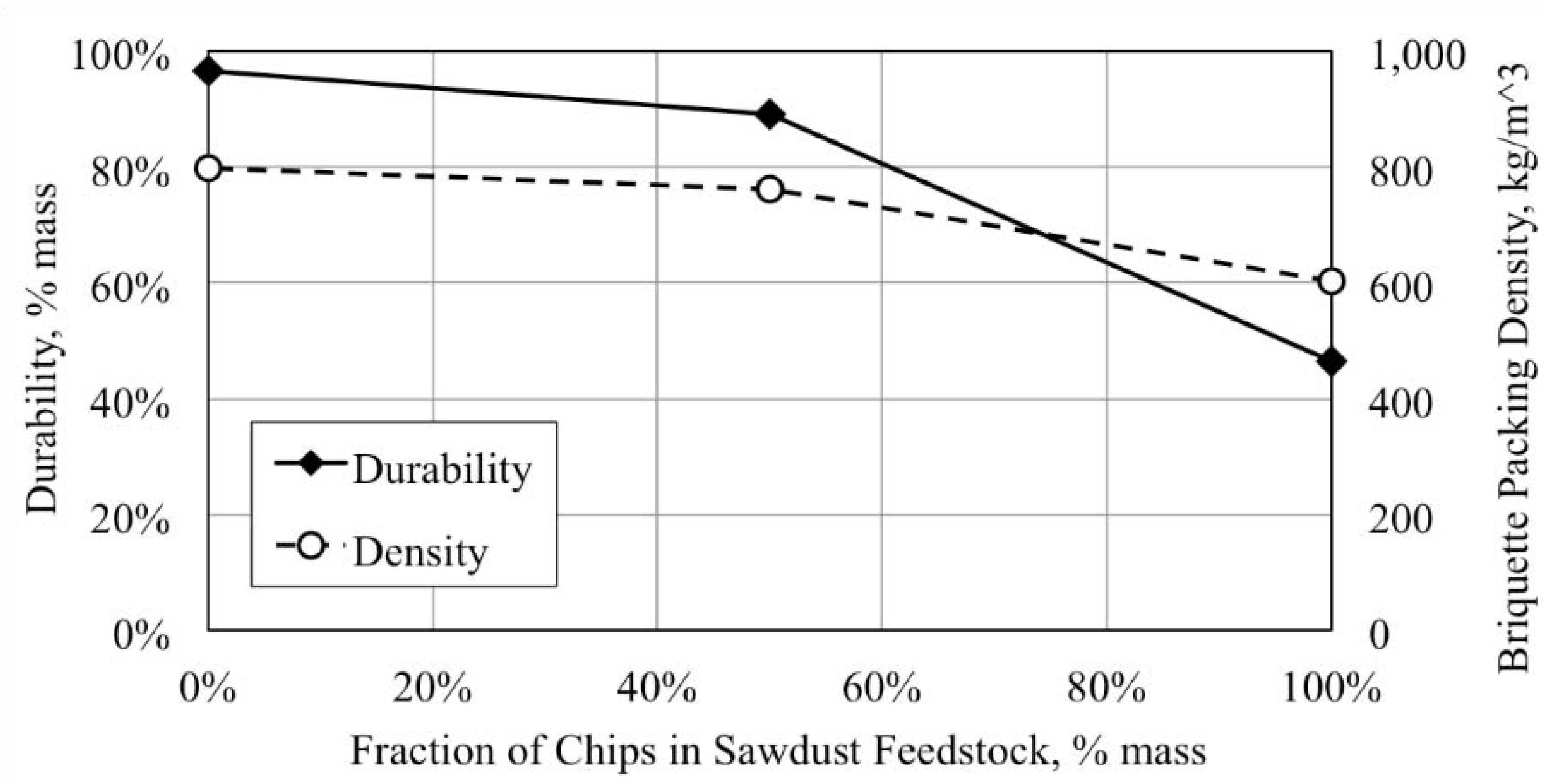
	Raw Briquettes	Torrefied Briquettes
HHV	19.6 MJ/kg	23.0 MJ/kg
Energy Density	113 MJ/brick	132 MJ/brick
Durability	85%	93%
Grinding Energy	320 Wh/kg	120 Wh/kg
Moisture Content	8.3%	0.6%
Moisture Content after Transportation	10.9%	5.7%

Briquetting Testing Phase 1 - Feedstocks



Briquetter Testing Phase 1 - Results

» Pure chips produce briquettes with low density and durability, but mixing with 50% sawdust improves both of these attributes.



Briquetter Field Testing - Results

Accepts feedstocks over a range of particle sizes and is tolerant of modest contamination levels.

• Feedstocks with moisture content above 15% makes poor quality briquettes

• Chip sizes greater than 4 inches may jam the machine

Task Area 4:

Biofuels and Biobased Products Development Analysis

Comminution Equipment Owning & Operating Costs

Cost per Scheduled Machine Hour	Peterson Pacific 2700C Horizontal Grinder (475 HP)	Peterson Pacific Horizontal Grinder (1050 HP) (e.g. 5700C)	Morbark Beever M20R (400 HP)	Morbark Chipper (875 HP)	Peterson Microchipper Model 4300	Beaver Korea Sawdust Machine
Fixed or ownership costs	$ 47	$ 80	$ 44	$ 74	$ 59	$ 36
Variable or operating costs	$ 73	$ 149	$ 38	$ 68	$ 105	$ 33
Subtotal: Machine owning & operating costs	$ 120	$ 229	$ 82	$ 142	$ 163	$ 70
Labor costs	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal: Machine operation costs	$ 120	$ 229	$ 82	$ 142	$ 163	$ 70
Feedstock costs	$ 109	$ 243	$ 128	$ 281	$ 113	$ 49
TOTAL HOURLY COSTS	**$ 229**	**$ 472**	**$ 210**	**$ 423**	**$ 277**	**$ 118**
MACHINE THROUGHPUT (BDT/SMH)	**14.5**	**32.3**	**17.1**	**37.4**	**26.5**	**6.8**
MACHINE COST PER BDT OF OUTPUT	**$ 8.26**	**$ 7.09**	**$ 4.78**	**$ 3.79**	**$ 6.16**	**$ 10.30**
TOTAL COST PER BDT OF OUTPUT	**$ 15.76**	**$ 14.60**	**$ 12.28**	**$ 11.30**	**$ 10.44**	**$ 17.53**

Screening Costs

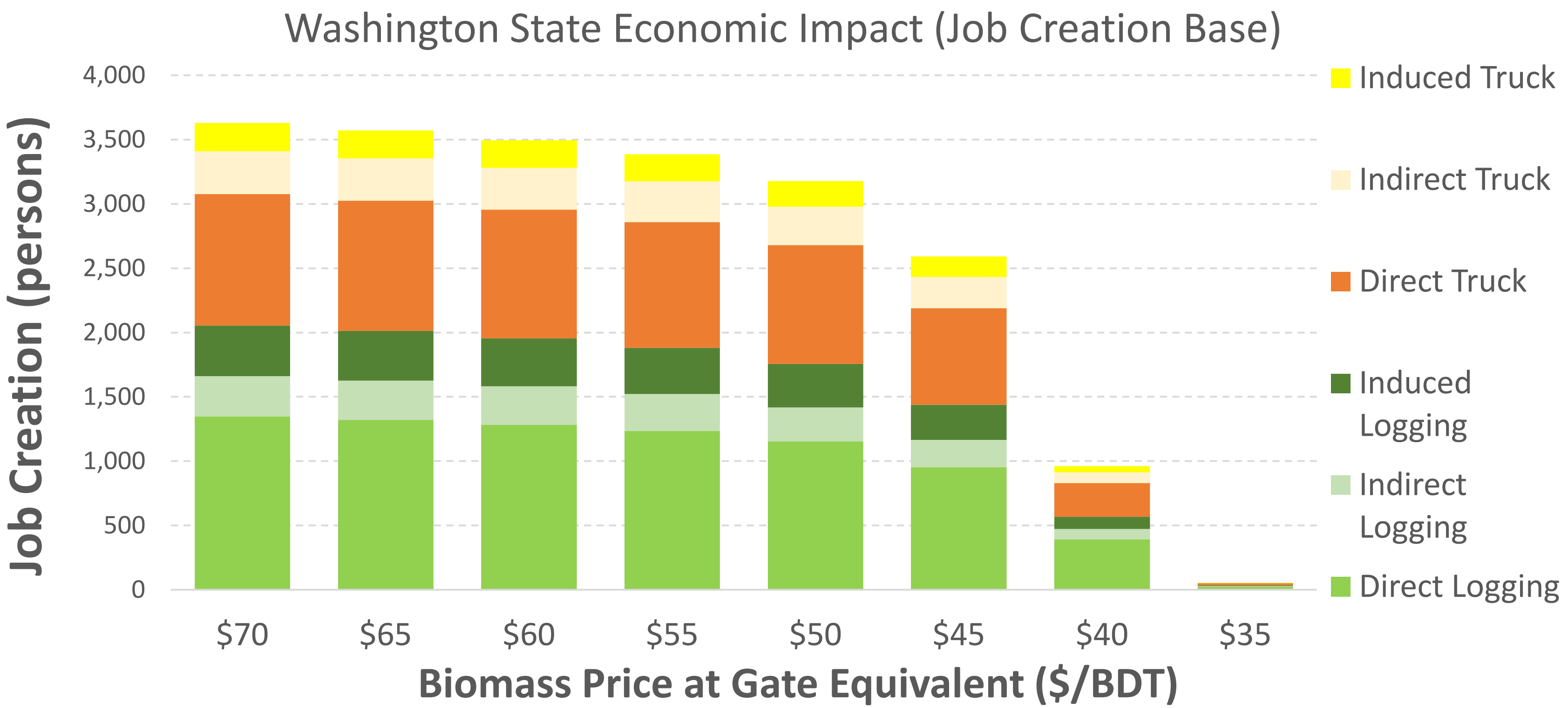
Cost per Scheduled Machine Hour	Deck Screen (Peterson Pacific) Deck Screen	Star Screen (Peterson Pacific) Star Screen
Fixed or ownership costs	$ 61.95	$ 80.17
Variable or operating costs	43.37	37.51
Subtotal: Machine fixed and variable costs	$ 105.32	$ 117.68
Labor costs	-	-
Subtotal: Machine operation costs	$ 105.32	$ 117.68
Feedstock costs	$ 174.10	$ 250.63
TOTAL HOURLY COSTS	**$ 279**	**$ 368**
MACHINE THROUGHPUT (BDT/SMH)	**11.40**	**22.80**
MACHINE COST PER BDT OF OUTPUT	**$ 9.24**	**$ 5.16**
TOTAL COST PER UNIT OF OUTPUT	**$ 25/BDT**	**$ 16/BDT**

Biomass Conversion Technology Equipment Owning & Operating Costs

	Biochar machine (Biochar Solutions)	Biochar machine (Biochar Solutions)	Biomass dryer (Norris Thermal Technologies)	Torrefaction machine (Norris Thermal Technologies)	Briquette Press (RUF-400)	Briquette Press (RUF-400)
Cost per Scheduled Machine Hour	unique	unique (scaled-up version)	Belt-o-matic 123B	CM 600 with dried microchips	RUF 400 with dried microchips	RUF 400 with torrefied chips
Fixed or ownership costs	$ 11.39	$ 18.22	$ 1.56	$ 27.33	$ 3.65	$ 3.65
Variable or operating costs	4.45	4.45	0.13	49.14	5.44	5.44
Subtotal: Machine fixed and variable costs	$ 15.84	$ 22.67	$ 1.69	$ 76.46	$ 9.09	$ 9.09
Labor costs	24.94	24.94	2.08	4.16	4.16	4.16
Subtotal: Machine operation costs	$ 40.77	$ 47.61	$ 3.77	$ 80.62	$ 13.25	$ 13.25
Feedstock costs	$ 4.50	$ 6.37	$ 3.29	$ 20.74	$ 11.29	$ 71.48
TOTAL HOURLY COSTS	**$ 45**	**$ 54**	**$ 7**	**$ 101**	**$ 25**	**$ 85**
MACHINE THROUGHPUT (BDT/SMH)	**0.04**	**0.07**	**0.22**	**0.56**	**0.35**	**0.38**
MACHINE COST PER BDT OF OUTPUT	**$ 971.80**	**$ 680.08**	**$ 16.93**	**$ 145.11**	**$ 37.99**	**$ 34.50**
TOTAL COST PER UNIT OF OUTPUT	**$ 1,079/BDT**	**$ 771/BDT**	**$ 32/BDT**	**$ 182/BDT**	**$ 70/BDT**	**$ 221/BDT**

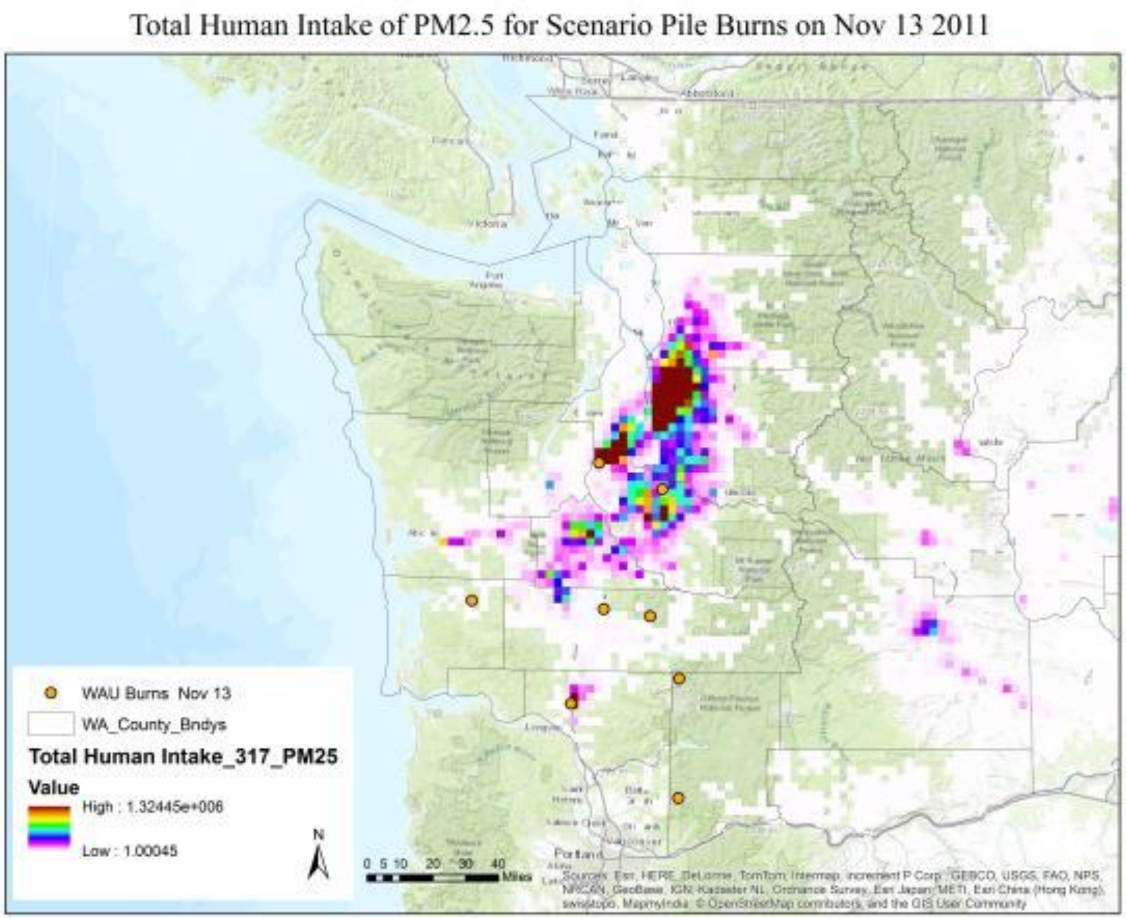
Input/Output Results: Job Impacts

- Once biomass exceeds $50, job growth is leveled off.
- Indirect: about 27%   Induced: about 26% of Direct Effect



Human Intake from Pile Burns: Combining Pollution and Population

Result example Nov. 13th $PM_{2.5}$

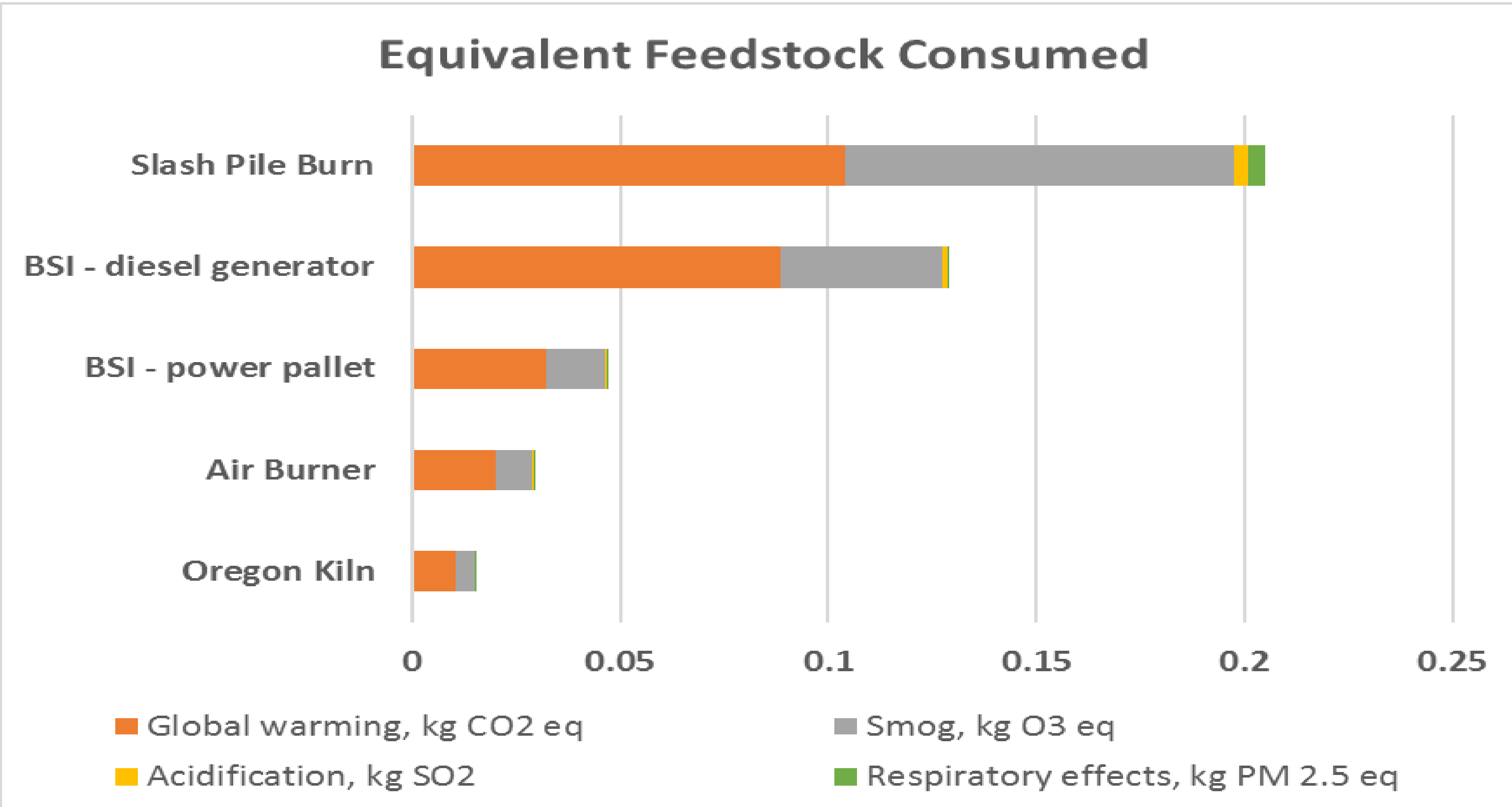


Human intake was estimated by multiplying the concentrations by the breathing rate (**Human breathing rate =13 m^3/day**, (USEtox 2.0), then by the population for each pixel

The result is the estimated $PM_{2.5}$ intake by the underlying population and spatially represented


10/22/2014

Biochar Production Systems' Ecological Impacts



Market Analysis

- Export price of wood pellet

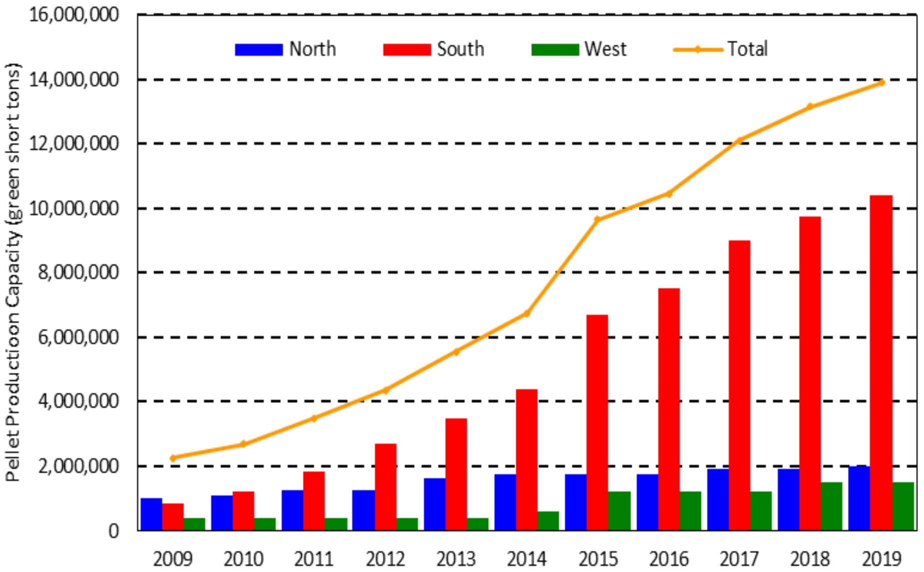
2012: $136.05/mt

2013: $128.69/mt

2014: $128.81/mt

2015: $146.28/mt

2016: $129.01/mt (est)



83.9% of US wood pellets exported to UK in 2015. Given continued growing in the demand for bioenergy products in Europe and emerging growth in the Asian markets, particularly Japan and Korea, the outlook for the market for both white and black bioenergy products appears to be promising.

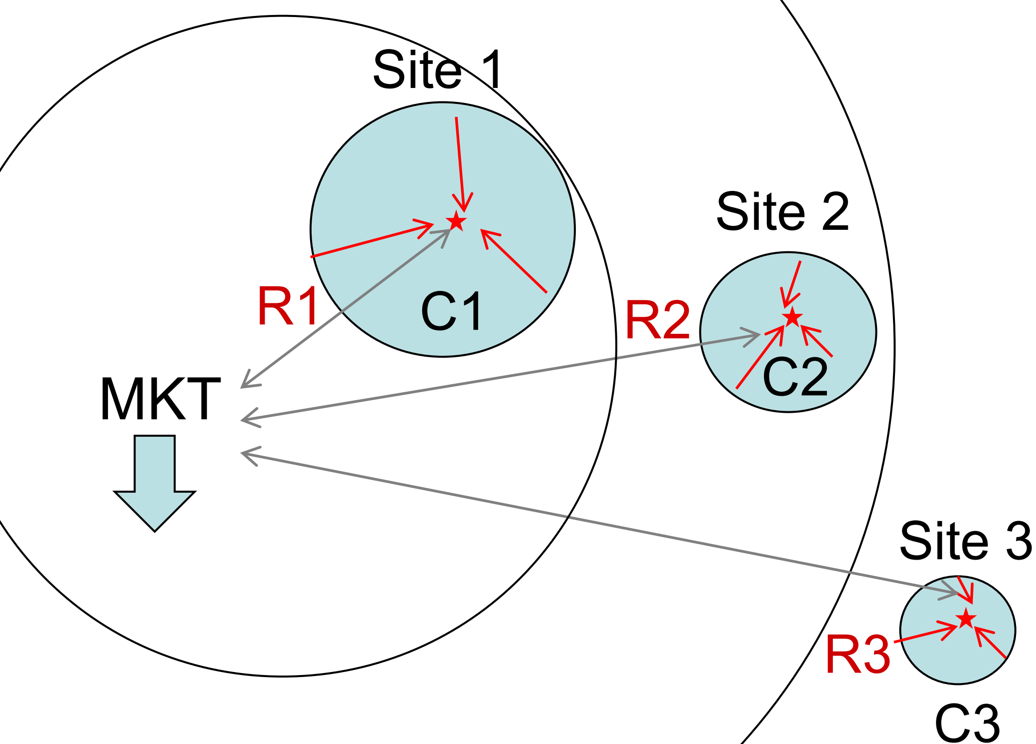
3 - Technical Accomplishments and Results (cont'd)

Landscape Model Overview

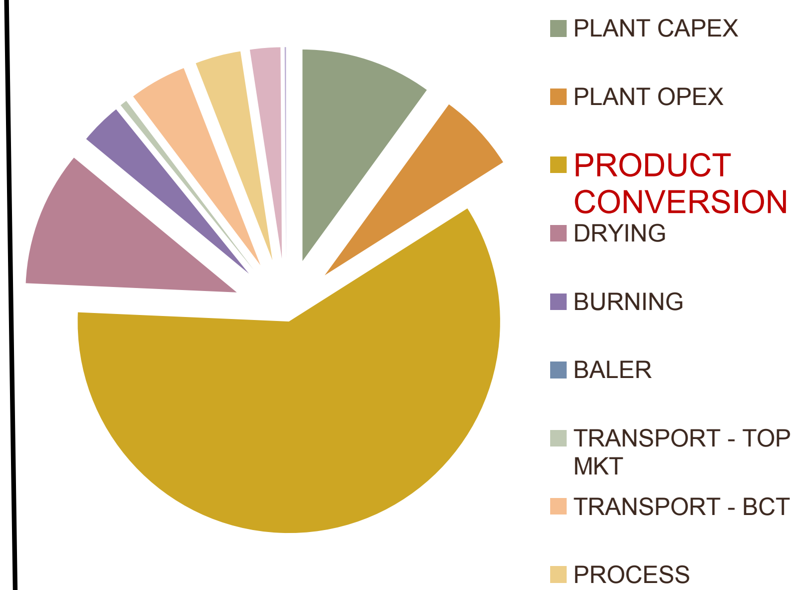
Unprocessed Biomass and Product Transportation at Different Zones

As product travel cost from plant INCREASES, maximum allowable travel cost for unprocessed biomass is REDUCED

Costs Depend on Plant Configuration, Logistics, Processing, Conversion, Transportation, Energy and Mobilization



Example Cost Summary OUTPUT



Costs and Logistics depend on Product, Region and Biomass Availability