



Lifecycle Assessment and Economics of Biochar from Forest Residues

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For more information please visit WasteToWisdom.com

Waste to Wisdom Project Overview

This material is based upon work supported by a grant from the U.S. Department of Energy under the Biomass Research and Development Initiative program: Award Number DE-EE0006297.

Waste to Wisdom Project Overview

Forest residuals and slash are an immense, underutilized resource.

Creating biochar is one by-product that can be created from these residues using small-scale near-woods production.

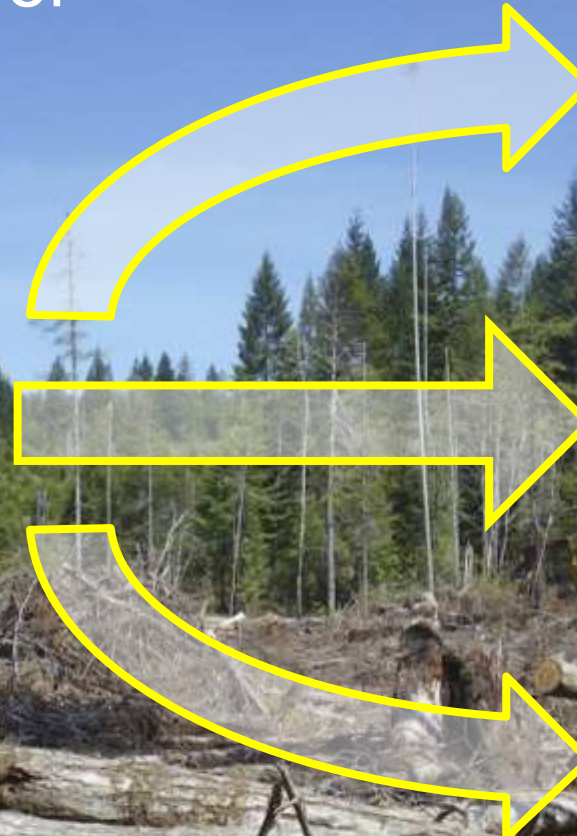
Our presentation will include information on

- Biochar applications
- Lifecycle analyses
- Biochar economics



Waste to Wisdom Project Overview

Utilizing forest residuals for the production of bioenergy and bio-based products.



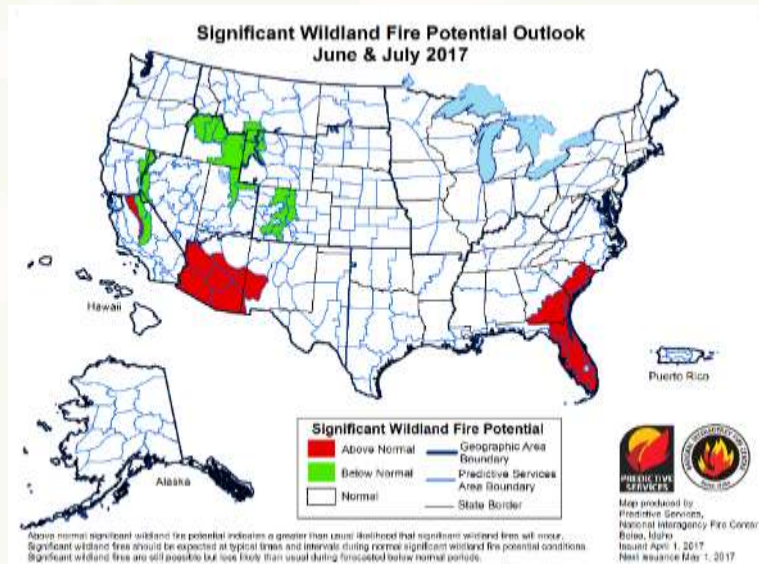
- Project Focus areas:**
- Feedstock development
 - Biomass conversion technologies
 - Economic and environmental assessment

Webinar Outline

1. Environmental impacts of biochar application (Deb Page-Dumroese)
 - a) Why biochar?
 - b) Ecosystem responses
2. Lifecycle assessment of biochar (Maureen Puettmann)
 - a) Methods
 - b) Results - Global Warming Impact
3. Economics of torrefied biomass production (Ted Bilek)
 - a) Analysis methodology
 - b) Economic results
4. Question and answer period (moderated by Ted Bilek)

What is happening?

- Millions of acres of overstocked forests in the western US
- Millions of acres of beetle-killed forests in Canada and western US
- Longer fire season and increasing fire severity
- Smaller burn windows



What to do with the non-merchantable wood?



Current land management

- Forest restoration: thinning and salvage logging
- Pile and burn excess woody biomass
 - Cheap, easy, reduces fire risk
- Pile burning can alter soil properties
 - Long-term impacts



Other concerns

- Bioenergy harvesting could degrade long-term productivity
- **HOWEVER**
 - Biochar applications can replace C removed during harvesting
 - Improve soil conditions to lessen drought or nutrient stress



Reducing Risks and Increasing Benefits



- **Increase soil water**
 - Decreased wildfire
 - Decrease insect risk
 - Decrease disease risk
- **Increase soil carbon**
 - Climate change
 - Carbon credits
 - Decrease GHG emissions

The Role of Biochar

Residual biomass converted to biochar can:

- Provide value to unmerchantable material
- Increase tree growth
 - ~5-20% (or more)
- Restore
 - skid trails, log landings, road beds
 - water relations
 - carbon sequestration
- Improve soil resiliency
 - less erosion and leaching; improved infiltration; more resilient to floods and droughts



LCA of Biochar

Presented by:

Maureen Puettmann
WoodLife Environmental Consultants
Corvallis, OR



Collaborators

Elaine Oneil

Consortium for Research on Renewable Industrial Materials
(CORRIM)



Mark Severy and David Carter
Schatz Energy Research Center
Humboldt State University



LCA of Biochar

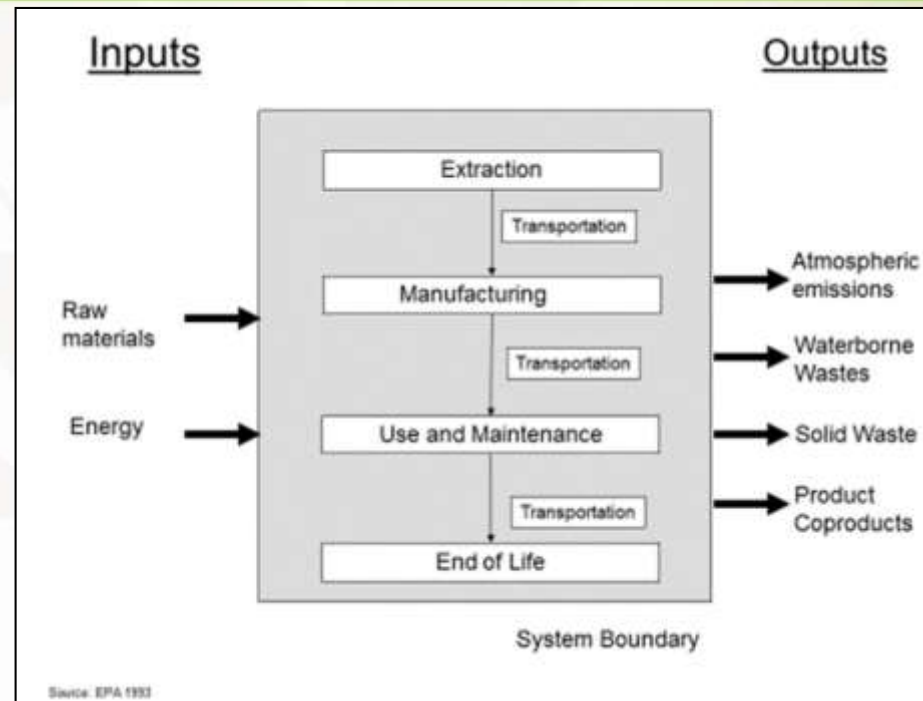
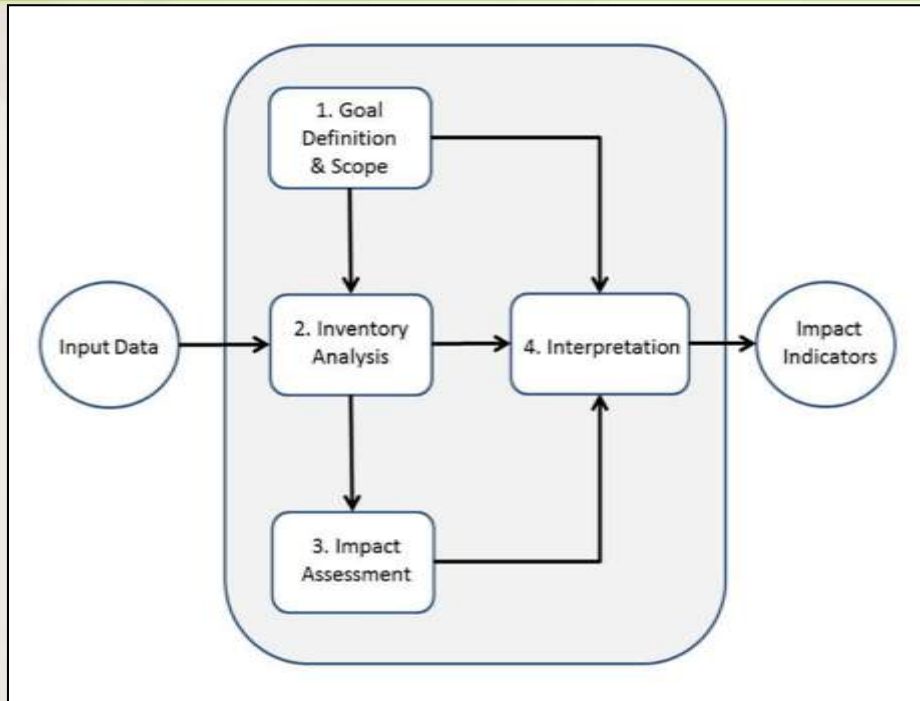
- Task:
 - What are the environmental impacts of producing biochar?
 - Is there a relationship between biochar quality and environmental impacts?
 - Is there a relationship between feedstock quality and environmental impacts?
 - Comparison of different biochar production systems
 - **BSI system**
 - Oregon Kiln
 - Air burners

LCA of Biochar

- What environmental impacts are we looking at?
 - Energy consumption
 - Emissions generated? (eg. CO, CO₂, particulates, NO_x, CH₄, SO₂)
 - Impact categories such as:
 - **Global Warming Potential (GWP),**
 - Ozone Depletion Potential
 - Smog Potential

LCA Method

Life cycle inventory

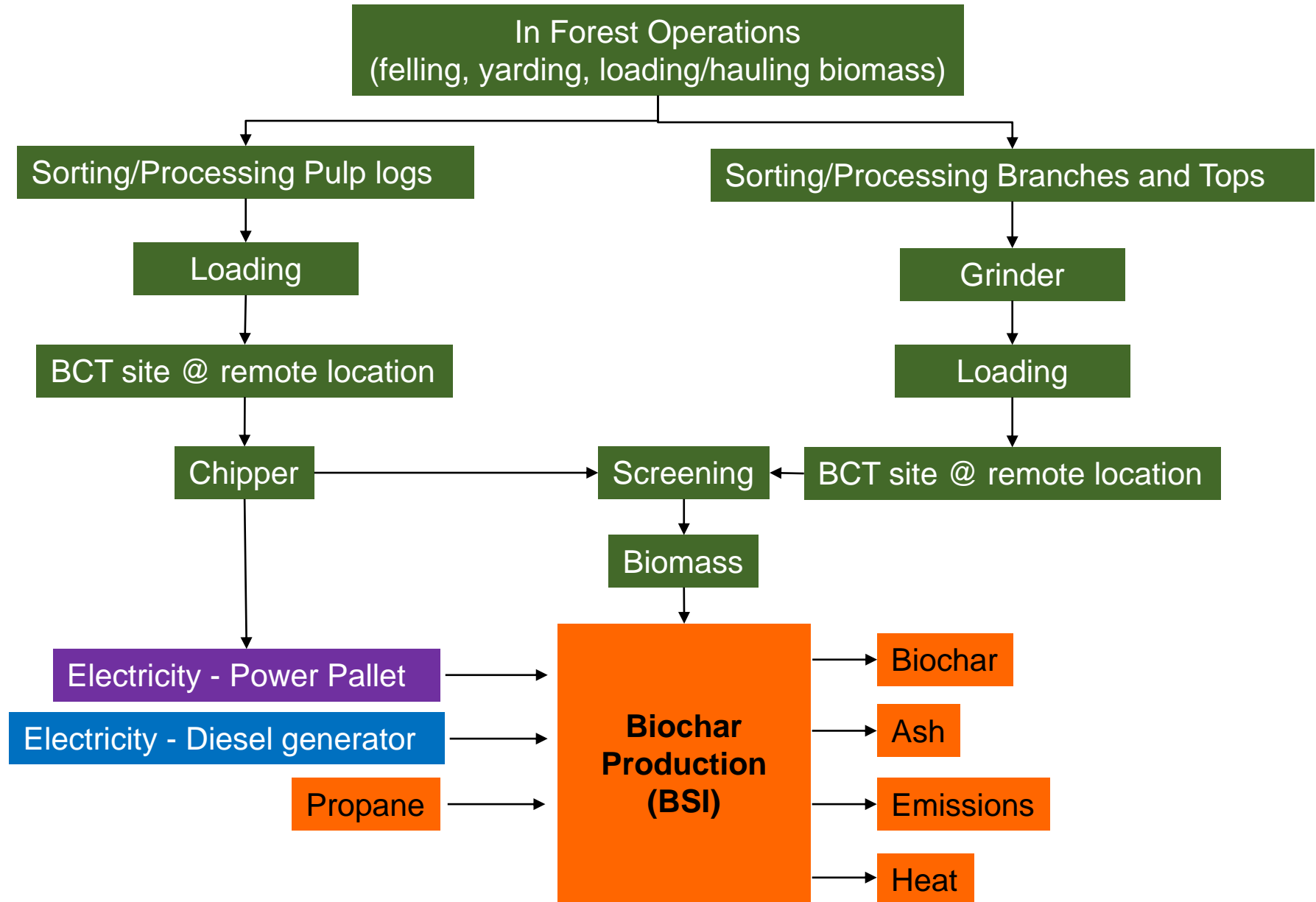


LCA of Biochar

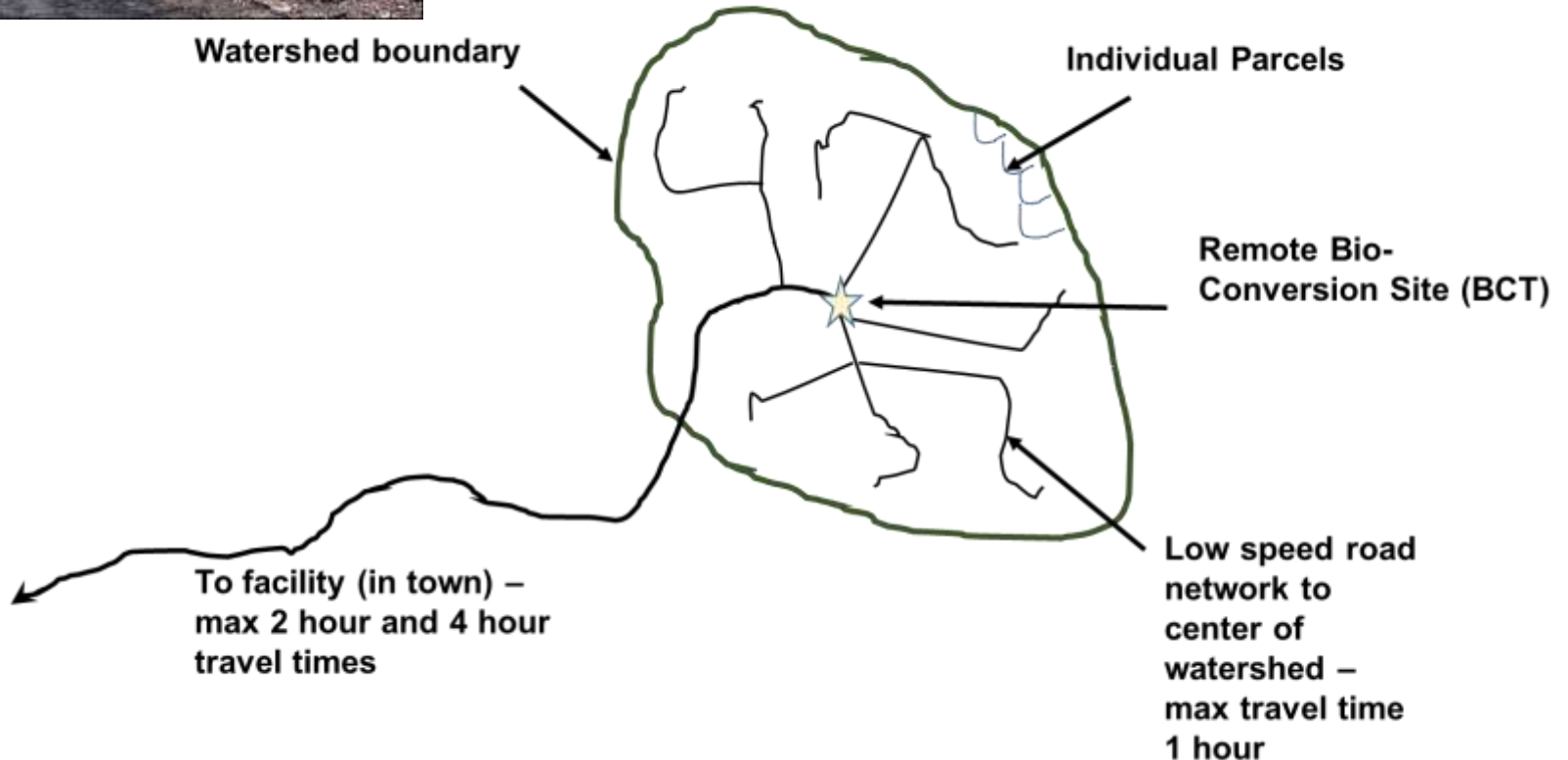
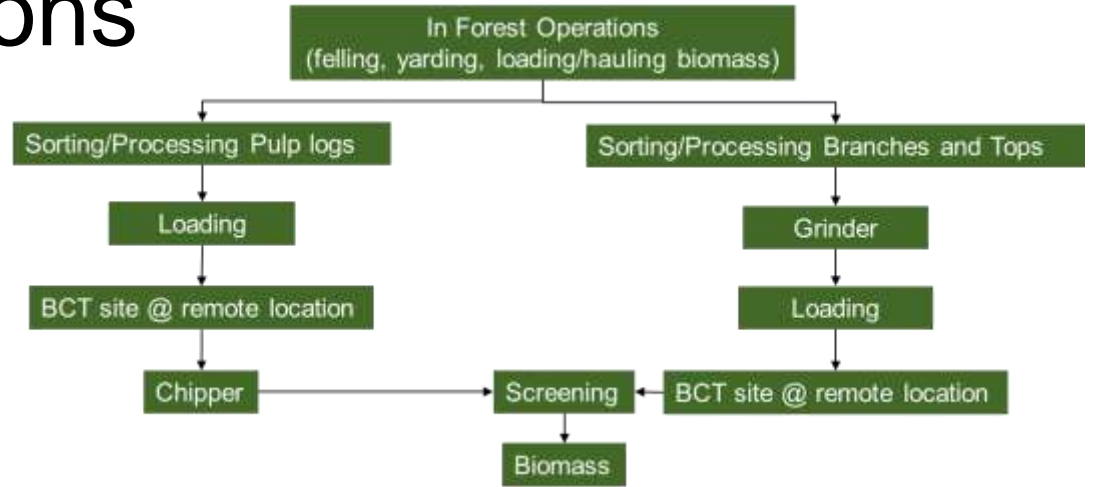
- **Functional Unit**
 - 1 mt of Biochar
- **Cradle to gate (collection through production)**
- **Life cycle data**
 - Forestry operations, feedstock collection, feedstock processing, and transportation (*from Oneil, Waste to Wisdom PI*)
 - Biochar production runs were performed by engineers at the Schatz Energy Center (*Humboldt State U.*)
 - US LCI database
 - Calculations



LCA System Boundary



Forestry Operations



Biochar Production - BSI System

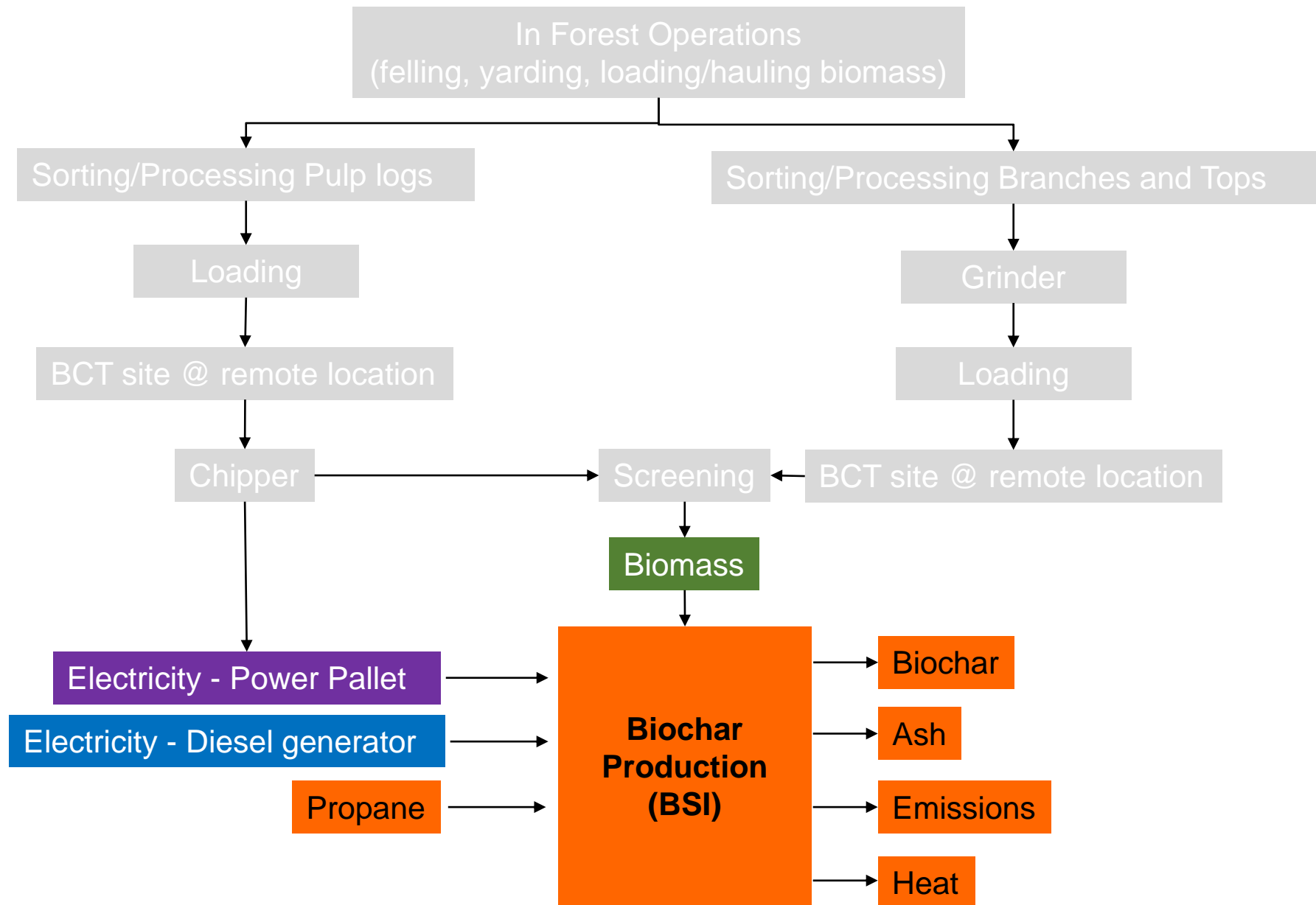
- Testing Goals
 - Develop feedstock quality specifications
 - Measure consumption and production rates
 - Document operational intensity and labor requirements
 - Determine energy requirements
 - Assess environmental impact and fire hazards



Work credit: David Carter, and Mark Severy



LCA System Boundary



Feedstocks

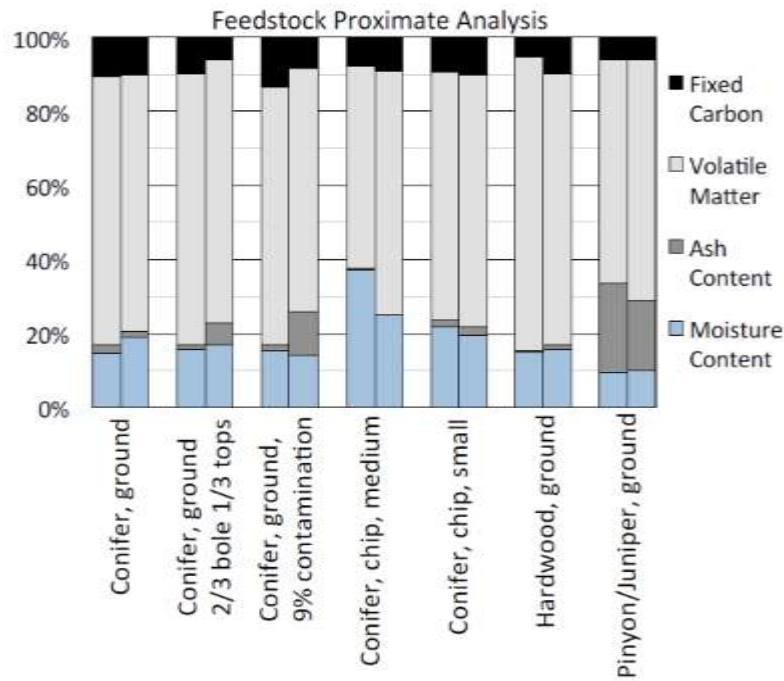


Figure 8. Proximate analysis of feedstock.

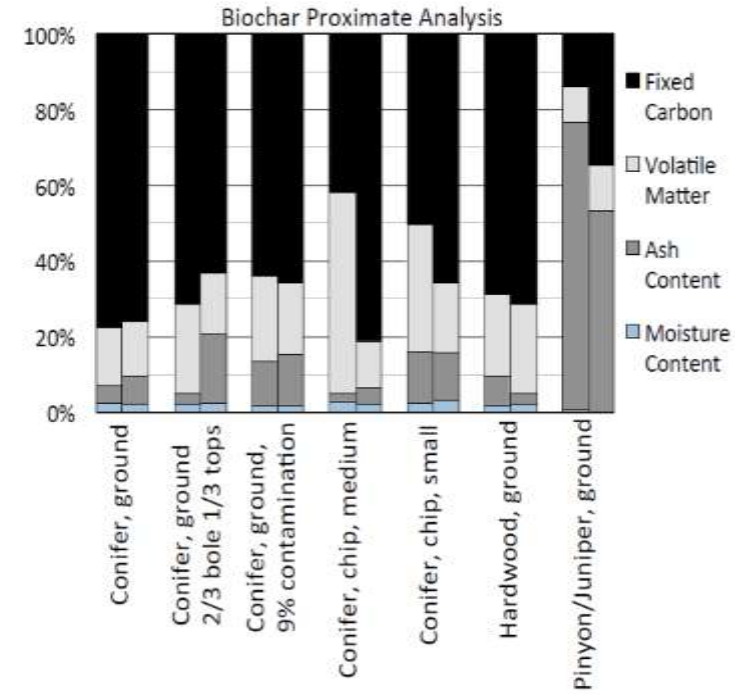


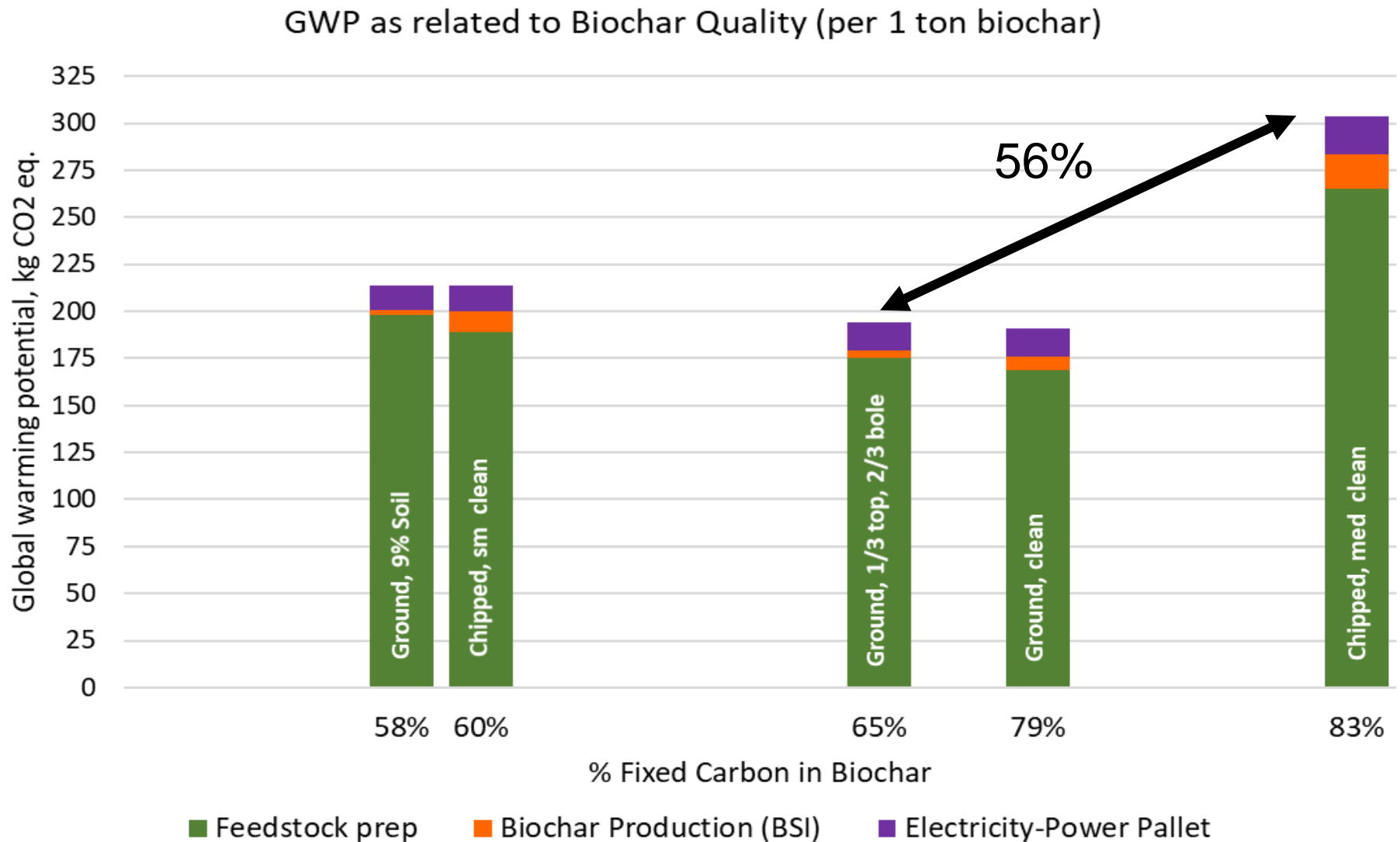
Figure 9. Proximate analysis of biochar.

LCA feedstock criteria
< 25% MC wb
<15% ash

Feedstocks

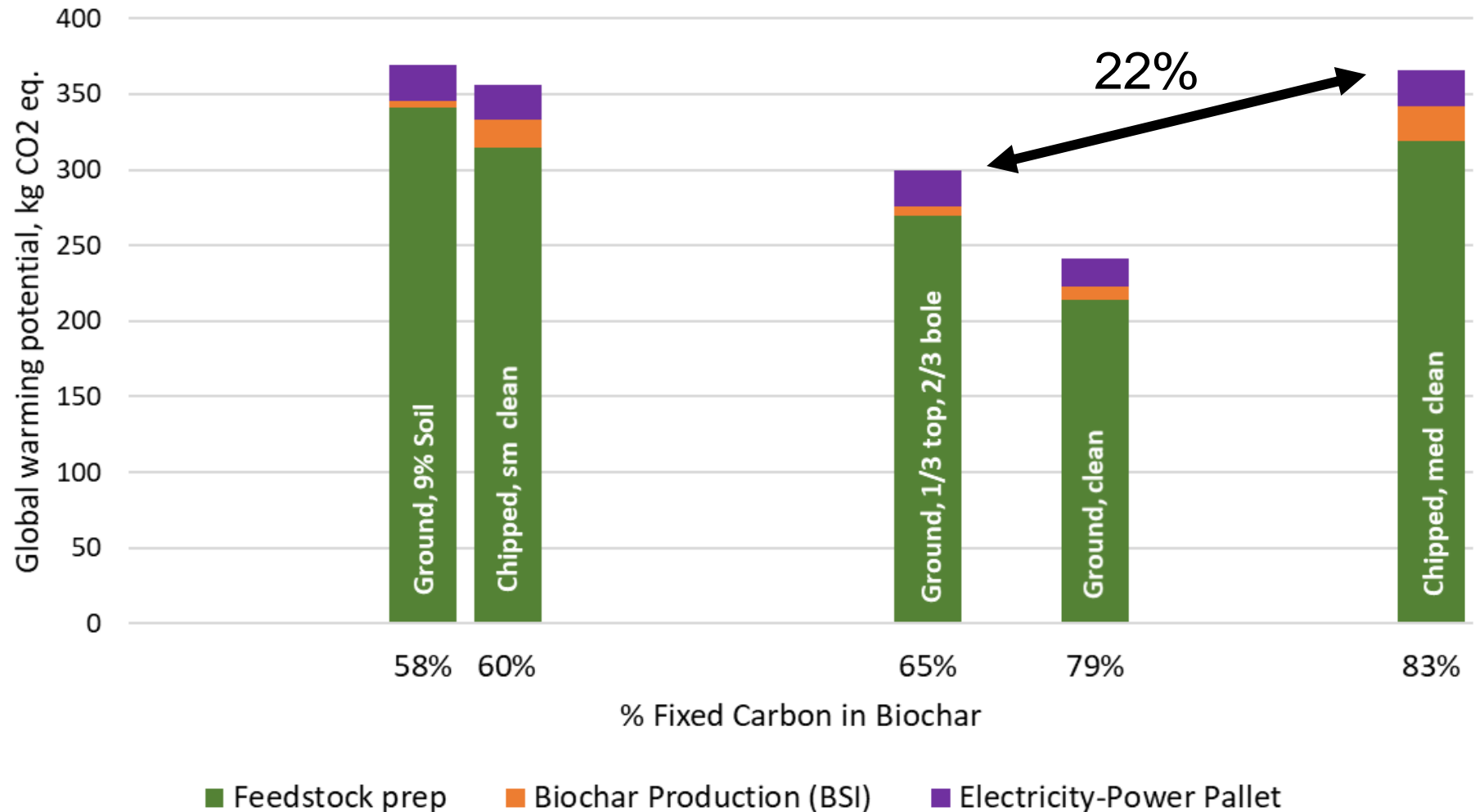
Species	Conifer		Conifer		Conifer		Conifer		Conifer		Hardwood		Juniper	
Comminution Method	Ground		Ground		Ground		Chip med		Chip small		Ground		Ground	
Contaminant	none		2/3 bole, 1/3 tops		9% soil		none		none		none		as received*	
Moisture Content	15%	19%	17%	15%	14%	16%	37%	25%	22%	20%	15%	16%	10%	10%
Ash Content	2%	2%	7%	2%	14%	14%	0.7%	0.1%	3%	3%	0.3%	1%	26%	21%
Particle Size (% mass) (<0.1"/0.1"-1"/>1")	12/80/9		14/77/9		14/77/8		1/99/0		31/69/0		20/79/1		28/64/8	

Results - Power Pallet – 1 mton of Biochar

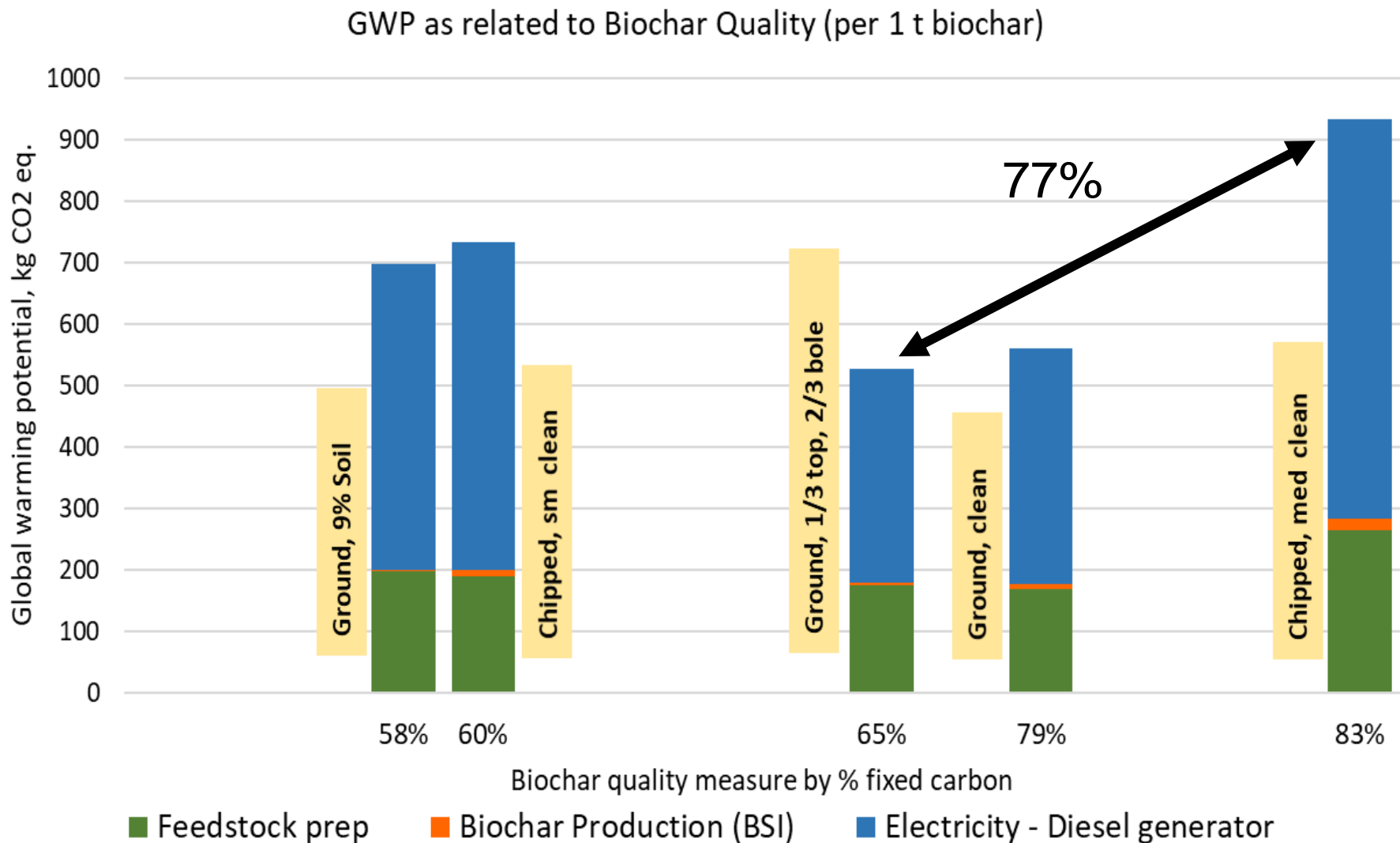


Results – Power Pallet - 1 mton of Fixed Carbon

GWP as related to Biochar Quality
(per 1 ton fixed carbon in the biochar)

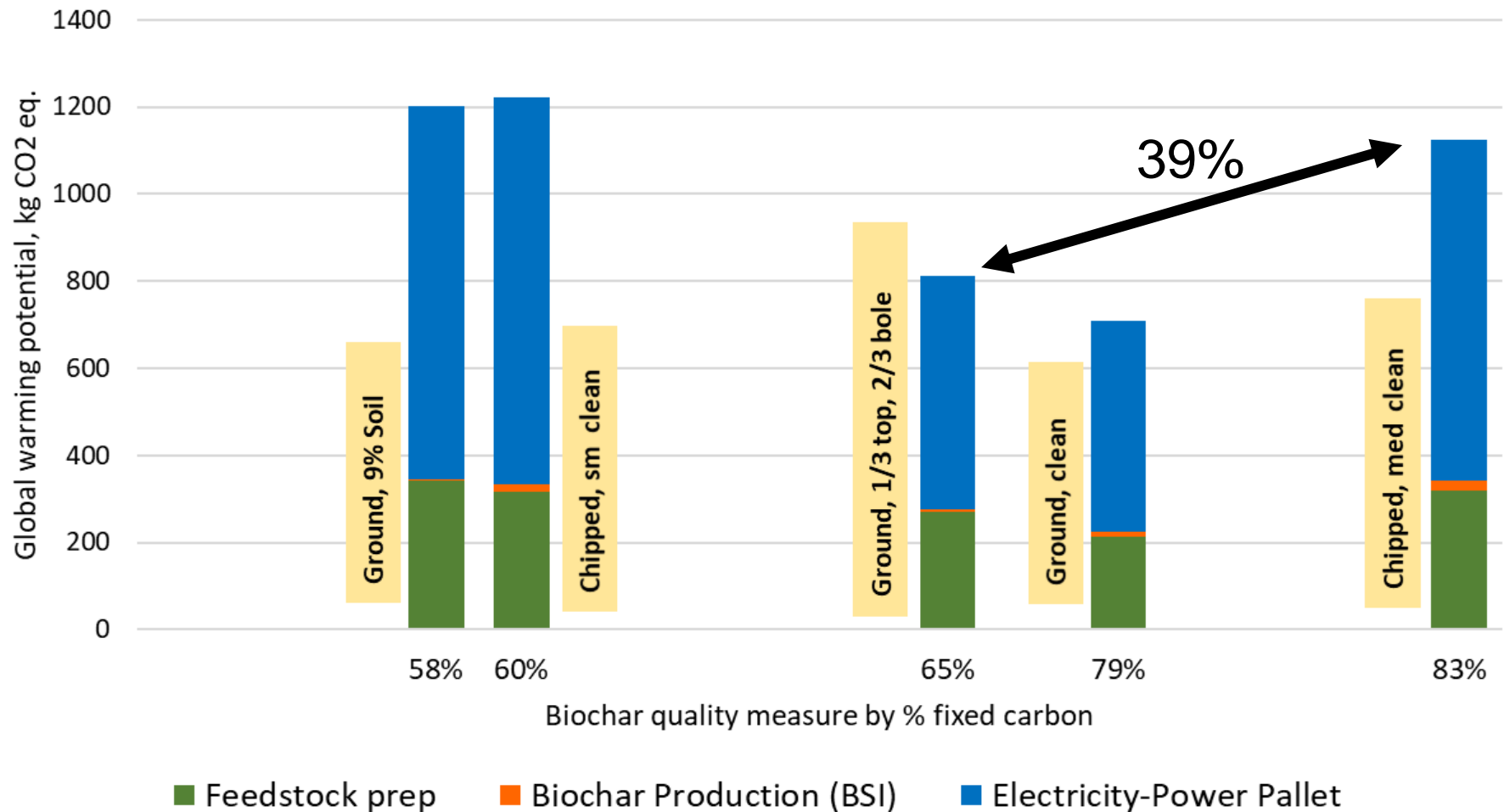


Results-Diesel Generator- 1 mton of Biochar



Results-Diesel Generator-1 mton of Fixed Carbon

GWP as related to Biochar Quality
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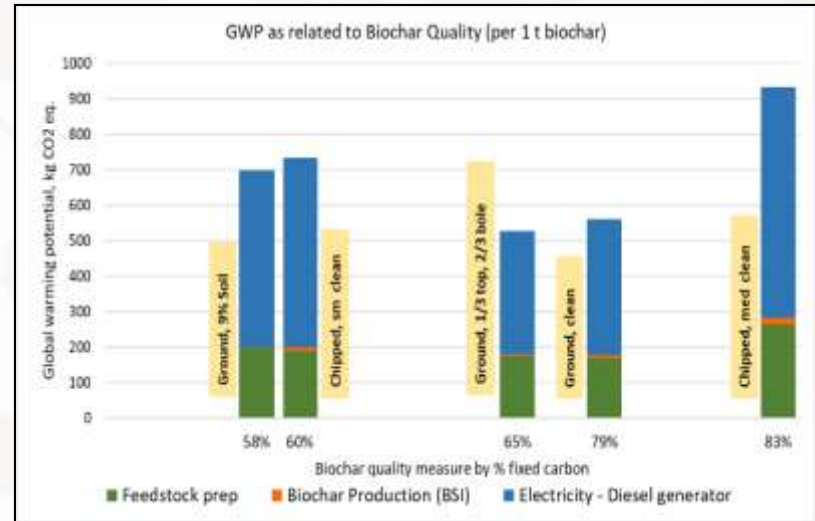
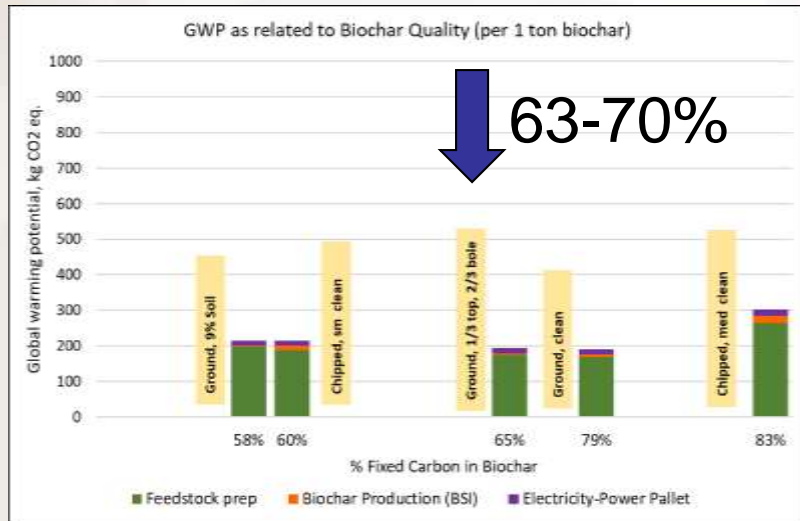


Conclusions - LCA of Biochar

- Relationship between biochar quality and CO₂ emissions
- Biochar Production (BSI): Feedstock should have <25% MC_{wb} and <15% ash



Conclusions - LCA of Biochar



Power Pallet (small gasification generator used to power the biochar machine and/or the drying system) reduced overall kg CO₂ eq (GWP) emissions by 63-70% over use of a diesel generator, depending on the feedstock used.

Conclusions - LCA of Biochar

- Does quality come with an environmental cost?
 - Biochar equivalent output - higher quality biochar resulted in a higher GWP impacts
 - When the impact was scaled to a ton of fixed carbon
 - the differences in overall impact based on biochar quality was reduced
 - Lower biochar quality had the highest environmental cost.



Conclusions – Next steps

- Setting standards for biochar (% fixed carbon)
 - What amount of environmental impact are we willing to accept for biochar quality?
 - What is an acceptable quality of feedstock and biochar to make the production process a “carbon benefit”
 - Do other impacts categories respond to biochar quality like GWP?
- Impact of taking the forest residues (feedstocks) to town for processing?
- Other biochar production systems (eg. Oregon Kiln, Air Burners)?

The Economics of Near-Forest Woody Biomass Biochar Manufacture

E.M. (Ted) Bilek

Economist

USDA Forest Service, Forest Products Laboratory

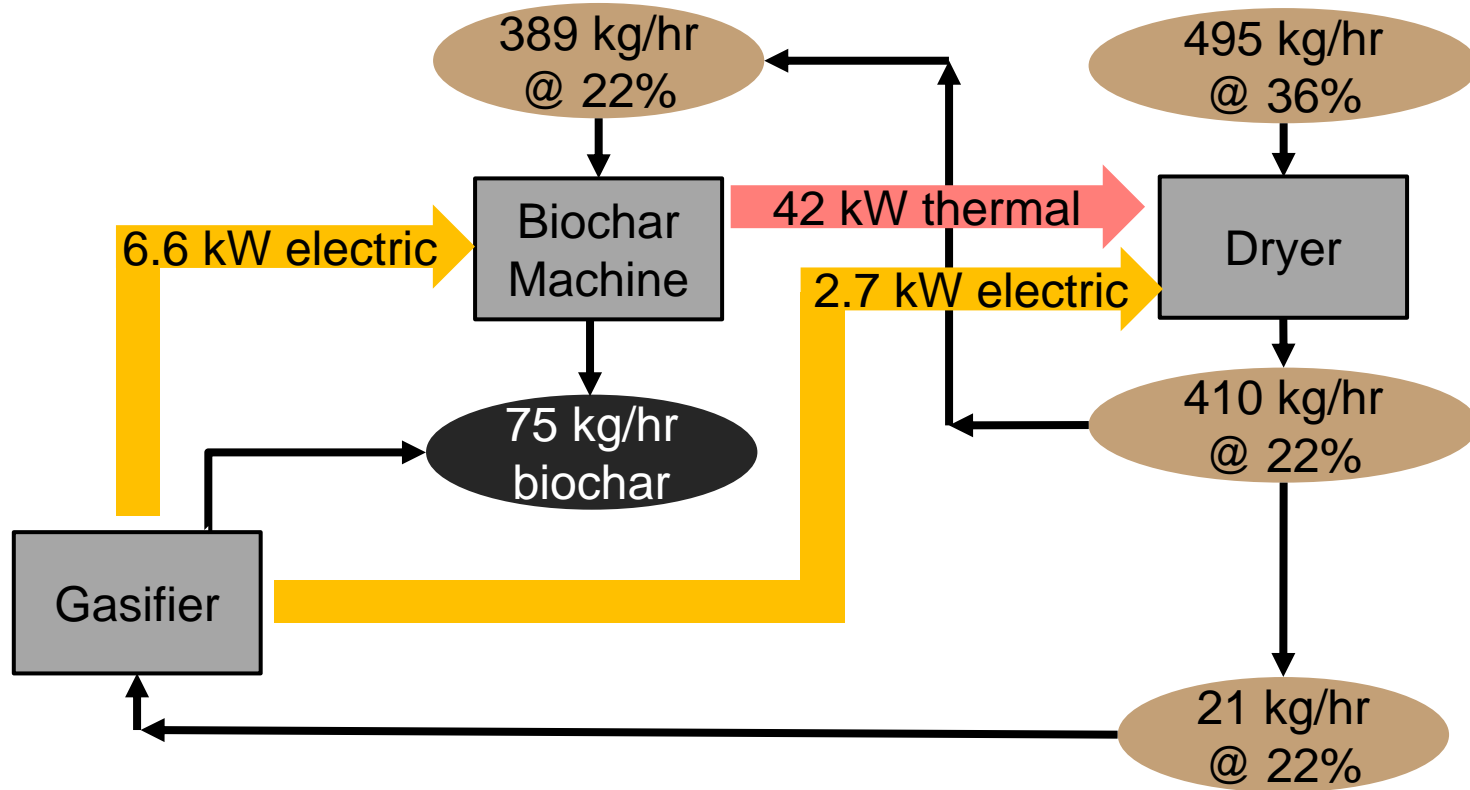
p. 608-231-9507

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www.fs.fed.us

Biochar Integrated System Design

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



» Dry biomass with waste heat

» Provide electricity with gasifier generator set

Biomass In

Belt Dryer

Biochar Out

Biochar Machine

Gasifier Generator

The image shows an aerial view of a biomass processing facility. A yellow dashed line indicates the flow of biomass from the 'Biomass In' point, through the 'Belt Dryer', to the 'Biochar Machine', and finally to the 'Biochar Out' point. A 'Gasifier Generator' is also shown, which provides electricity for the process. The facility is located in a wooded area, and a large pile of biomass is visible in the background.

-
- » Dry biomass with waste heat
- » Provide electricity with gasifier generator set
- Biomass In
- Belt Dryer
- Biochar Out
- Biochar Machine
- Gasifier Generator

» Dry biomass with waste heat

» Provide electricity with gasifier generator set

Biomass In

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Biomass In

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Biochar Out

Biochar Machine

Gasifier Generator

Economics outline

- » Biochar overview and system logic;
- » Analysis methodology;
- » Results;
- » Conclusions.

Temperature (°C)		Torrefied Solids															Raw Biomass	
Test #		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
275 °C																		

- » Biochar overview and system logic;
- » Analysis methodology;
- » Results;
- » Conclusions.

What to use to make biochar?

Preferably, a feedstock without much variation...



wood chips
($<3/4$ inch)

micro-chips
($<1/4$ inch)

sawdust
($<5/32$ inch)

Biochar-ready feedstock production costs



Sawdust machine (Beaver Korea)

(Gu)estimated machine rate = \$12.80/BDT (w/loader)

Productivity = BDT/PMH (23.8 BDT/PMH)

**Biochar feedstock
input is 0.50 BDT/PMH**



Microchipper (Peterson 4300):

Machine rate = \$13.12/BDT (w/loader)

Productivity = 33.85 BDT/PMH

Basic biochar production assumptions:

- » Commercial-scale system cost: \$489,500 (120 tons/year)
 - » Biochar unit: Biochar Solutions machines @ \$250,000 & \$400,000
 - » Dryer: Norris Thermal Technologies Belt-o-matic 123B @ \$45,000
- » Economic life: 10 years (8 hours/day, 250 days/year)
- » Salvage value: 20%
- » Feedstock throughputs: 0.354 & 0.502 BDT/PMH
- » Biochar mass conversion = 13.5% & 15.9%
- » Operation = 2,500 SMH @ 80% productivity
- » Feedstock = Microchips @ \$13.12/BDT (= \$8.43/green ton, including loader, but not transport)

Other important assumptions:

- » Electricity supply: PowerPallet (PP20) gasifier genset from All Power Labs @ \$0.3869/kWh – also provides drying heat
- » Loader cost @ \$22.57/SMH
(machine cost calculation w/o labor)
- » Discount rate: 10%
(pre-tax nominal w/ cost & revenue inflation @ 1% & 0% respectively)
- » Product value: \$2,000/BDT, FOB plant
- » Tax losses are: recognized immediately
(not carried forward or lost)
- » Loan = 40% of initial capital cost
- » Loan terms: 6 years at 6.00% with monthly payments

Methodology: Discounted Cash Flow Analysis

BASIC ASSUMPTIONS				Note: all costs and revenues are in Year 0 dollars.			
Overall project assumptions				Variable operating costs			
	Project planning life	10	years		Plant operators		1.00
	Standard operating days/year	250			Variable labor cost (\$/worker/scheduled hour)	\$	33.25
	Scheduled daily machine operating hours (daily SMH)	8.0			Electricity cost (\$/kWh)	\$	0.3869
	Cost inflation rate	1.0%			Binder cost (\$/lb)	\$	-
	Revenue inflation rate	0.0%			Standardized repairs & maintenance percentage		20.0%
					Repairs & maintenance function		Uniform
					Liquid propane (\$/gallon)	\$	2.39
					Periodic consumables cost		
					Additional periodic consumables	cost	
					Misc. variable operating costs (\$/scheduled hr.)	\$	22.570
					Other variable consumables cost (\$/ton biochar)	\$	-
					Finished goods transport cost (\$/ton)	\$	-
Project financing				Conversion variables			
	Required minimum nominal pre-tax risk premium on invested capital	8.5%			Biochar system feedstock throughput (bone-dry tons/PMH)		0.50
	Deposit interest rate (APR)	1.50%			Biochar system mass conversion/bone-dry ton of feedstock (%)		15.9%
	Initial gearing (% of total start-up cost that is financed)	40.0%			Feedstock removal (bone-dry tons/acre)		18.00
	Loan interest rate (APR)	6.00%			Electrical energy required		9 kW
	Loan term	6.00	years		Binder required (lb/Biochar ton)		-
	Loan and deposit payments per year	12			Liquid propane (gallons/productive hour)		-
	Working capital required as a percentage of next year's sales	2.0%			Thermal production (million Btu/Bone-dry ton feedstock throughput)		2.94
					Feedstock moisture content		35.8%
					System start-up time (hours/day)		1.21
					System shut-down time (hours/day)		0.79
Capital assets							
	Depreciation code	DB					
	Terminal asset value multiplier	100%					
Fixed operating costs							
	General administration (\$/year)	\$	2,000				
	Administration staff (number)		-				
	Site lease (\$/year)	\$	-				
	Equipment lease (\$/year)	\$	-				
	Annual insurance percent		1.6%				
	Other annual fixed costs (\$/year)	\$	-				
Taxes							
	Income tax rate	40.0%					
	Tax losses or net tax credits are...	recognized immediately					
	Biomass utilization tax credit	\$	-				
	Ad valorem (property) tax mill rate		-				

Demonstration-scale Results (72 tons/year)

(w/product price = \$2,000/BDT)

Summary Financial Measures:	Before-finance		
Semi-mobile Biochar Conversion System from Biochar Solutions	& tax	Before-tax	After-tax
<i>NPV (\$000)</i>	\$ (351)	\$ (338)	\$ (210)
<i>Real IRR (adjusted by cost inflation at 1.0%)</i>	-21.4%	-26.2%	-17.3%
<i>Nominal IRR</i>	-20.6%	-25.5%	-16.4%
NOTE: Nominal discount rates used to calculate NPVs and B-E values (Assuming 1.0% cost inflation, 0.0% revenue inflation, and 40.0% gearing at 6.00%)	10.00%	8.40%	5.04%
		<i>IRR seed =</i>	-50%
<i>Break-even avg. Biochar product value (\$/ton)</i>	\$ 2,839	\$ 2,750	\$ 2,662
<i>Break-even delivered yr. 1 feedstock cost (\$/green ton)</i>	\$ (62)	\$ (54)	\$ (47)
<i>Medium-term operating B-E avg. product value (\$/ton)</i>		\$ 2,171	
<i>Short-term operating B-E avg. product value (\$/ton)</i>	\$ 2,040		

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For-profit biochar production at a demonstration scale (72 tons/year) is not recommended without additional capital or operating subsidies.

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- Break-even product values are the prices at which NPVs=\$0

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- Break-even product values are the prices at which NPVs=\$0
- Break-even feedstock costs are the costs (or subsidies) at which NPVs=\$0

Demonstration-scale Results (72 tons/year)

(w/product price = \$2,000/BDT)

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- Break-even product values are the prices at which NPVs=\$0
- Break-even feedstock costs are the costs (or subsidies) at which NPVs=\$0
- Medium and short-term product values will keep the plant open either for the next year or for the next day.

Commercial-scale Results (120 tons/year) (w/product price = \$2,000/BDT)

Summary Financial Measures:		Before-finance		
Semi-mobile Biochar Conversion System from Biochar Solutions		After-tax	Before-tax	After-tax
NPV (\$000)		\$ 8	\$ 68	\$ 90
Real IRR (adjusted by cost inflation at 1.0%)		9.2%	10.8%	8.8%
Nominal IRR		10.3%	11.9%	9.9%
NOTE: Nominal discount rates used to calculate NPVs and B-E values (Assuming 1.0% cost inflation, 0.0% revenue inflation, and 40.0% gearing at 6.00%)		10.38%	8.18%	5.84%
Break-even avg. Biochar product value (\$/ton)		\$ 1,989	\$ 1,910	\$ 1,831
Break-even delivered yr. 1 feedstock cost (\$/green ton)		\$ 10	\$ 17	\$ 25
Medium-term operating B-E avg. product value (\$/ton)			\$ 1,384	
Short-term operating B-E avg. product value (\$/ton)		\$ 1,277		

- NPVs are positive and nominal IRRs are all above the discount rates;

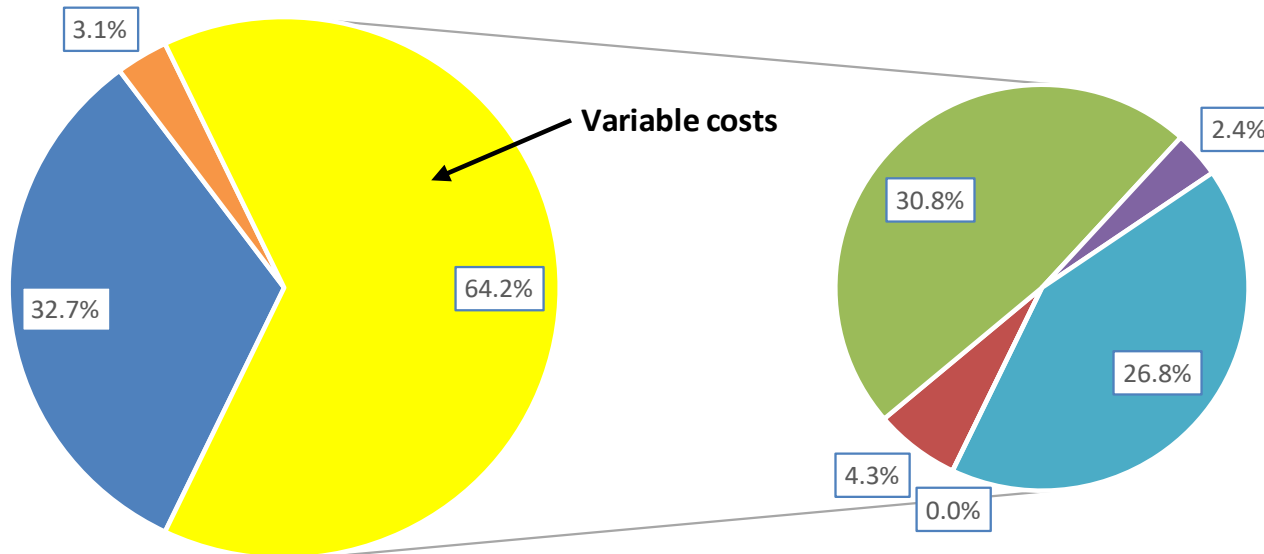
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- NPVs are positive and nominal IRRs are all above the discount rates;
- Break-even product values are below the target price.
- Feedstock prices are positive.

Cost breakdown: Before-finance & tax

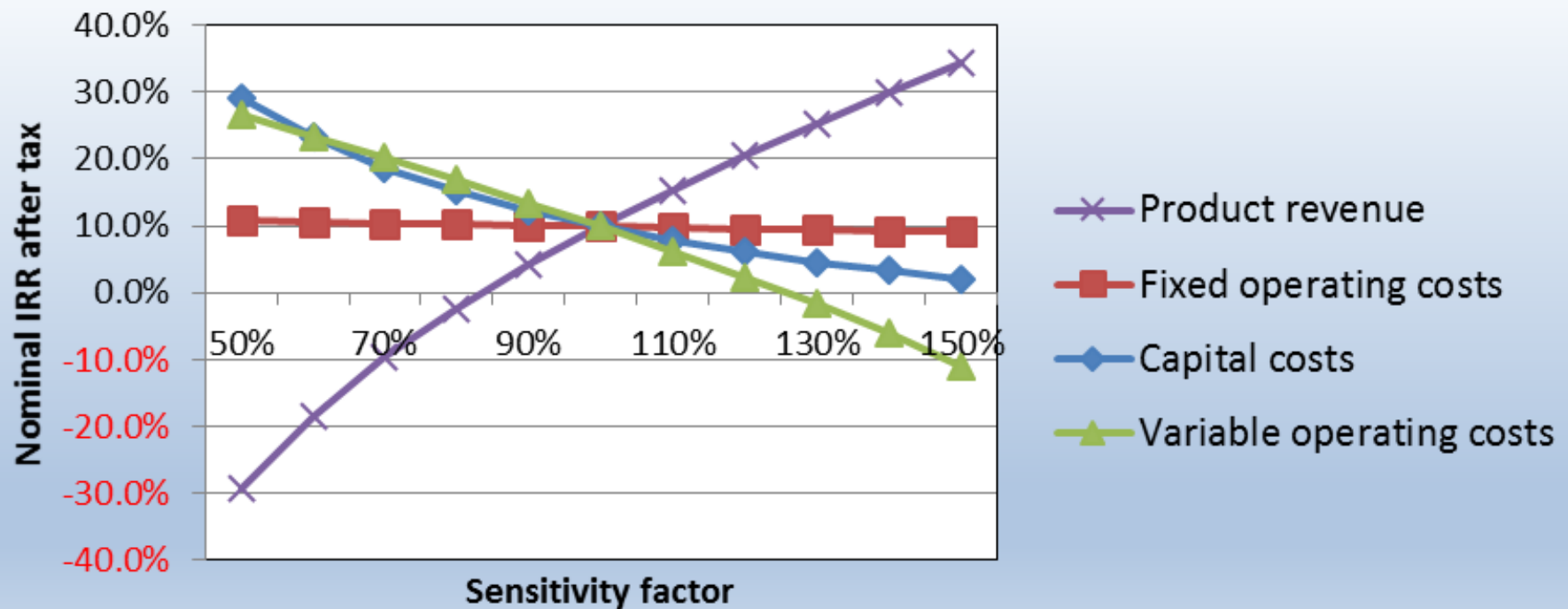


- Capital assets (dryer & biochar reactor)
- Wood feedstock (@ \$8.43/green ton)
- Labor (1 operator(s) @ \$33.25/worker/scheduled hour)
- Electricity (@ \$0.3869/kWh)
- Other variable operating costs
- Fixed operating costs & working capital

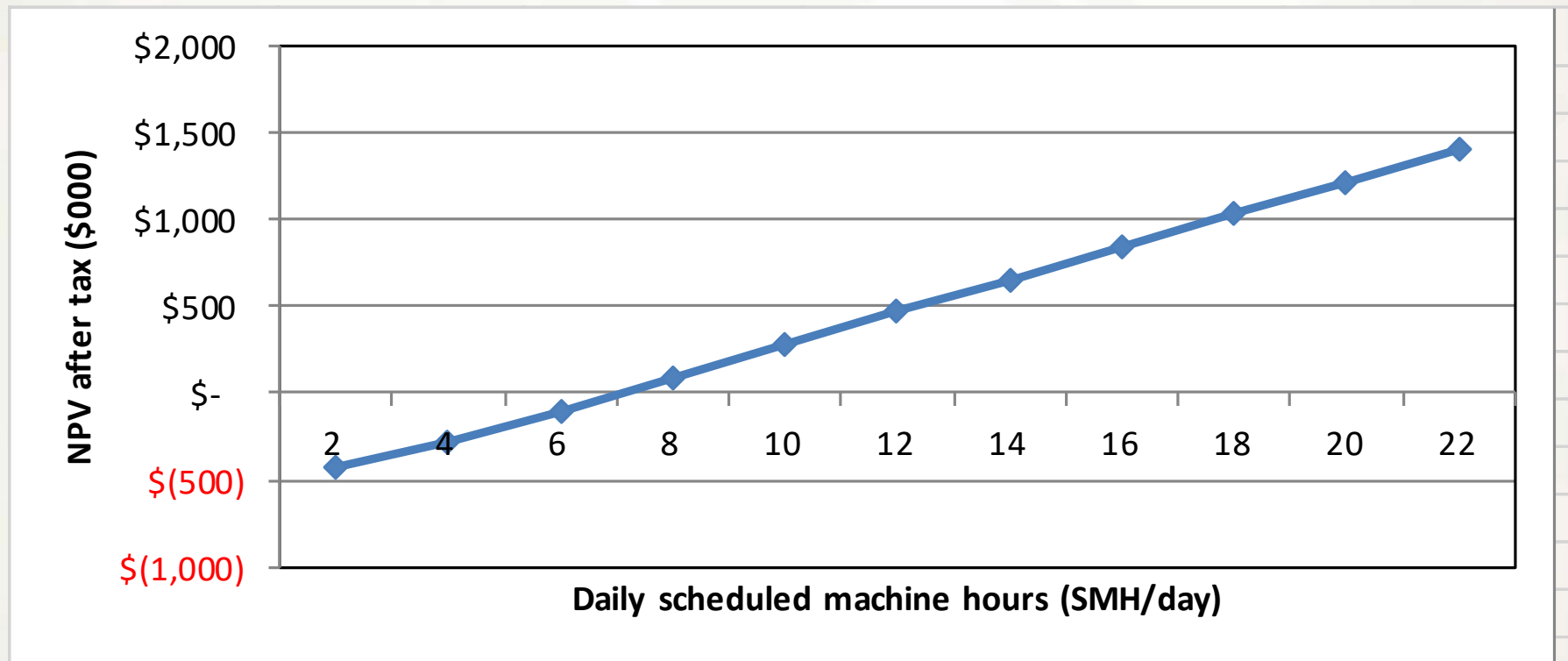
Total costs discounted at 10.00% nominal before-finance & tax over 10 years with variable costs highlighted

NOTE: Total annualized costs = \$226,595 and total annualized revenues = \$227,895

Biochar plant's simple sensitivity analysis



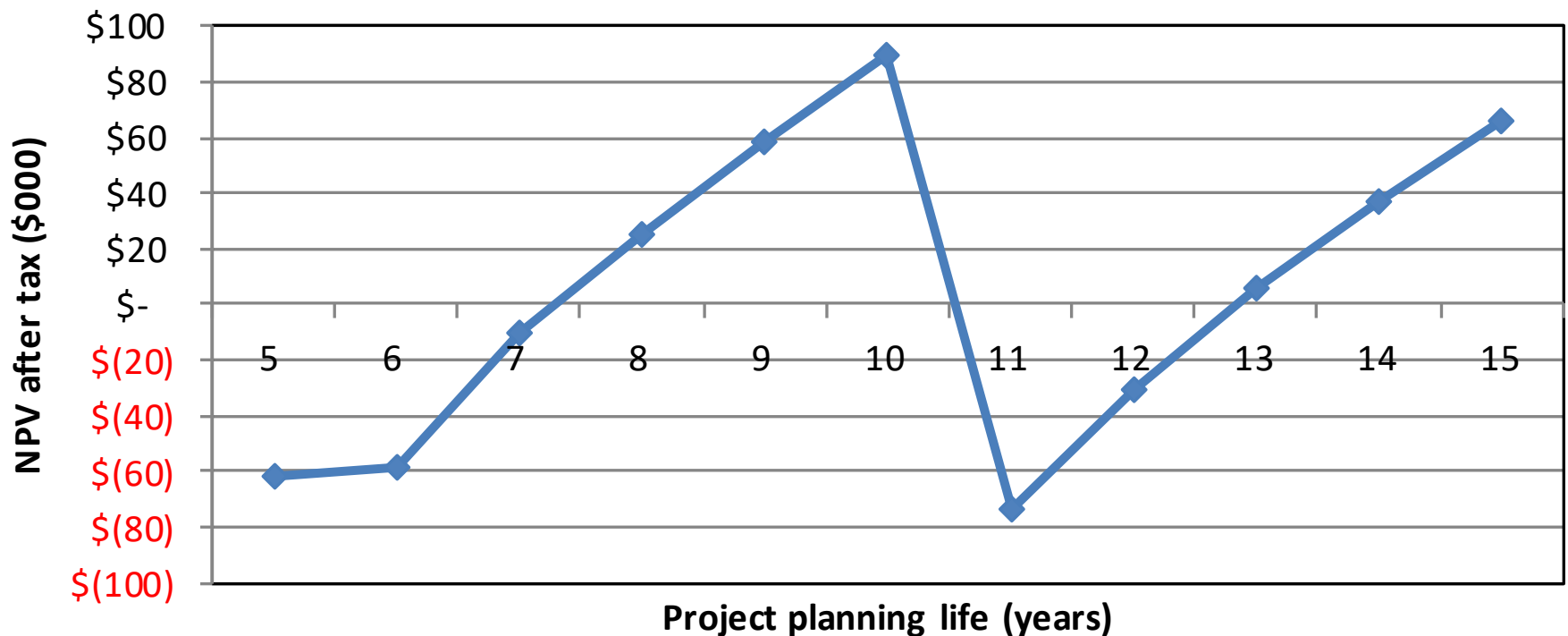
Biochar plant's profitability sensitivity to the operating day length



Sensitivity of Biochar Plant's NPV after tax to the Standard operating day (scheduled hours/day)

NOTE: NPV after-tax discount factor is 4.00% real, or 5.04% nominal with 1.00% cost inflation

Biochar plant's profitability sensitivity to the project planning life



Sensitivity of Biochar Plant's NPV after tax to the Project planning life (years)

NOTE: NPV after-tax discount factor is 4.00% real, or 5.04% nominal with 1.00% cost inflation

Economic Drivers

- Alternative disposal costs
 - Pile burn (\$150-\$850/acre)
 - Torrefaction (value = \$200-\$250/ton delivered)
 - Other energy
- Markets...

Biochar Markets

» Soils (primary market)

- » Need to match specific biochars to crops and soil types
- » Biggest potential lies where crops are higher-valued, especially where water is scarce or costly
- » Even larger value-added potential lies in possible replacement for activated carbon (esp. trace mercury removal or soil decontamination, water or air filtration, public health/sanitation, etc.)

» Composting (can reduce composting time, GHG emissions, and odors)

» Growing media (i.e. vermiculite and perlite and peat moss substitutes)

» Other bio-based wastes can also be made into biochar

» Chicken & egg issues with respect to biochar's cost-effectiveness (which lead to financing issues which limit scale economies)

» Carbon sequestration

Conclusions

- » Small-scale near-woods biochar production may make economic sense.
 - » Costs are relatively high;
 - » Labor is a big part of the total cost.
 - » Costs as presented could be lowered.
- » Biochar represents a highly value-added product made from waste resources. It can be used directly and offers the opportunity to be combined with other ingredients to create additional value. It can be produced near a forest and offers opportunities to concentrate biomass value to facilitate more cost-effective transport.

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More research
is needed.

Thank You

Questions?



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