Lifecycle Assessment and Economics of Torrefied Biomass

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U.S. DEPARTMENT OF ENERGY

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For more information please visit WasteToWisdom.com

Waste to Wisdom Project Overview

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Waste to Wisdom Project Overview

Forest residuals and slash are an immense, underutilized resource.

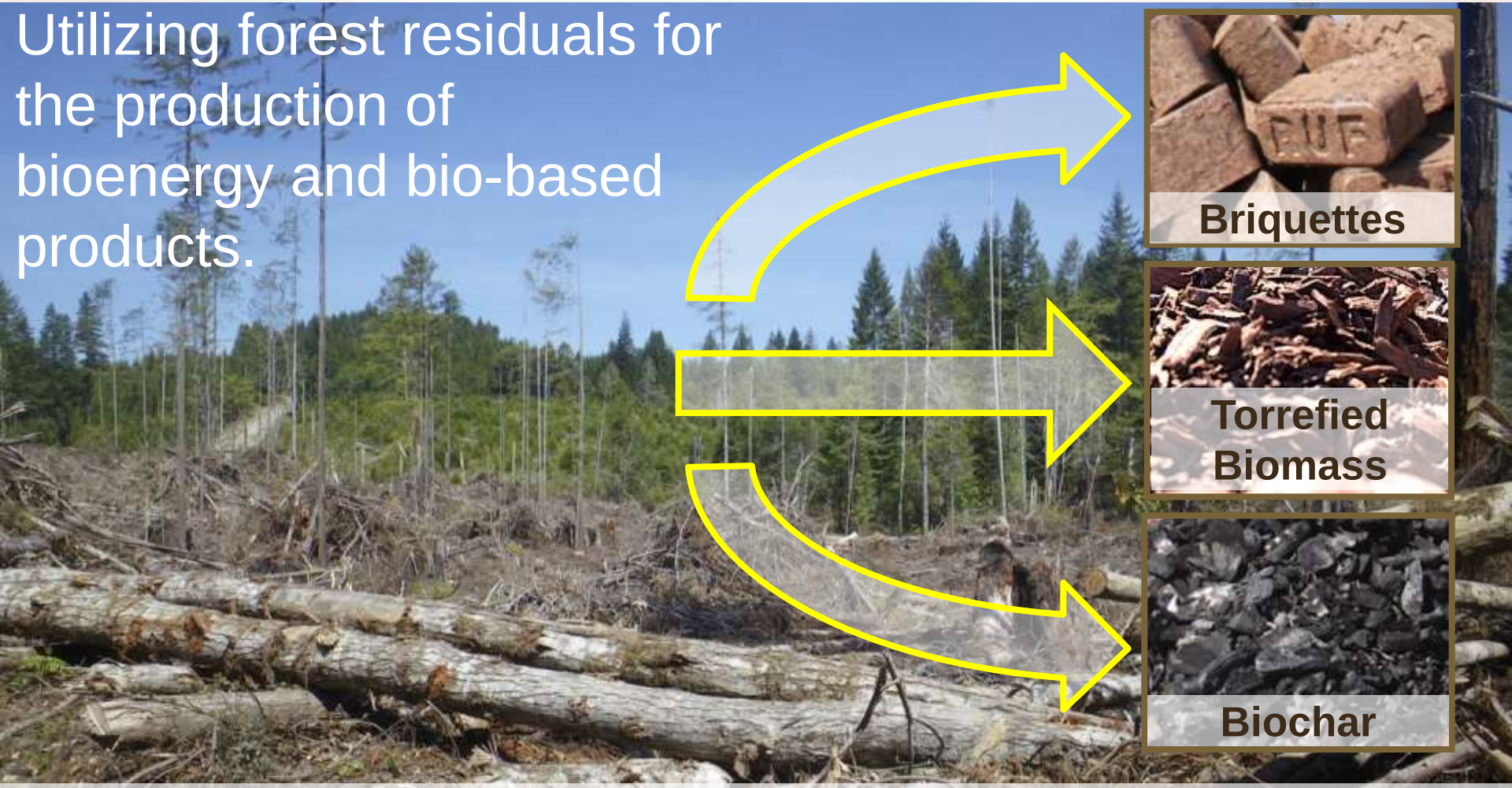
But transportation costs are prohibitively expensive due to their low bulk density and low market value.

These economic barriers can be overcome by

- increasing the transportation efficiency, or
- increasing the value of the residuals before transport.

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. Torrefaction background (Mark Severy)
   a) Characteristics
   b) Production
2. Lifecycle assessment of torrefied biomass (Sevda Alanya-Rosenbaum and Richard Bergman)
   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 Richard Bergman)

Torrefied Biomass – Properties and Uses

Torrefaction improves the fuel properties of raw biomass to make it more suited for power generation and long-distance transportation.

Raw Biomass

Torrefied Biomass

» Lower moisture content
» Reduced grinding energy
» Increased energy density
» Increased density in briquettes
» Hydrophobicity
» Homogeneity

Benefits of torrefied biomass as a power source:

» Renewable fuel for baseload power

» Low net carbon energy source

» Can use existing coal power infrastructure

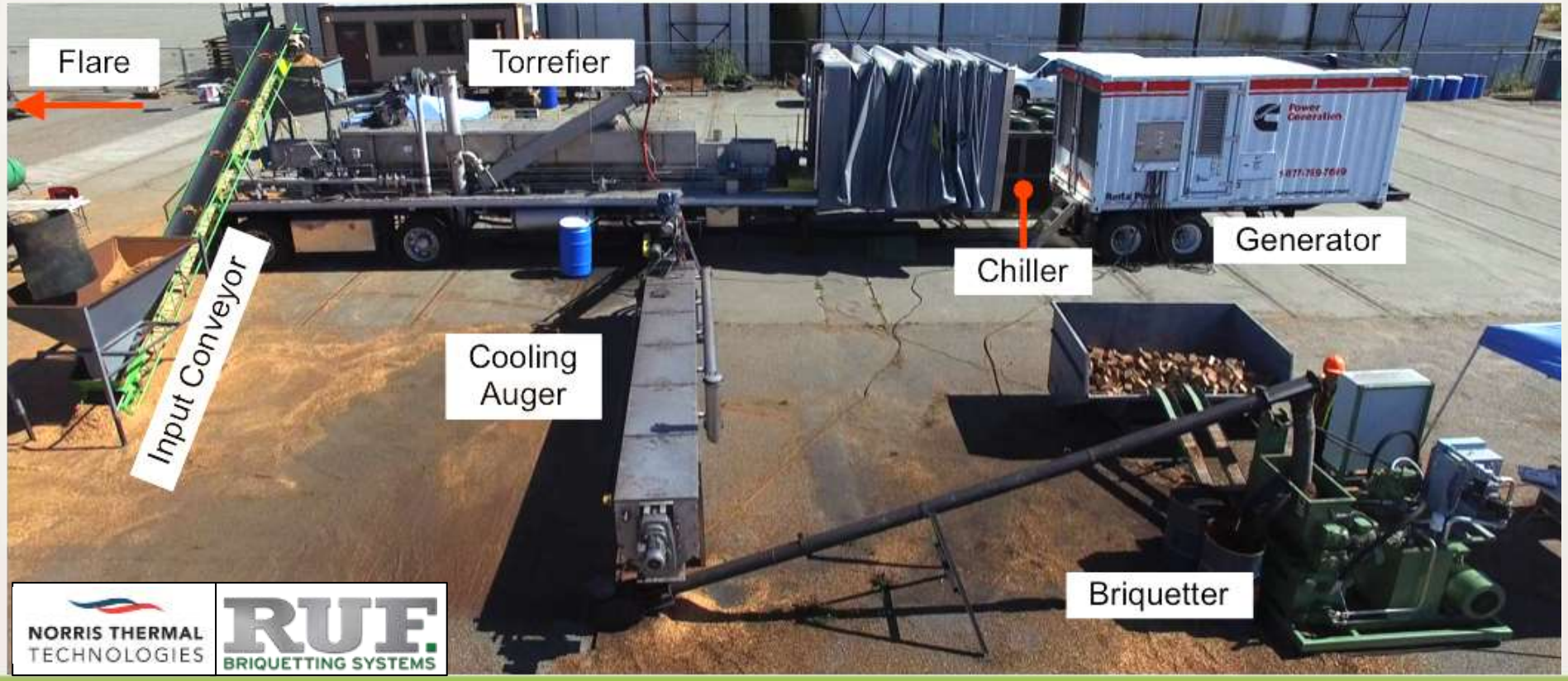
Process Description

Torrefied biomass is produced by heating to 250 – 320ºC in the absence of oxygen.

The product can be densified into briquettes or pellets through compression.

Data Collection

- As part of this project, Schatz Energy Research Center implemented a 0.5 ton/hour demonstration plant in Samoa, CA
- Objectives:
  - Determine optimal operating conditions
  - Collect data for economic and environmental lifecycle assessment



Life-cycle analysis of torrefying post-harvest wood residues

Waste to Wisdom Webinar
August 9, 2017

Sevda Alanya-Rosenbaum and Richard Bergman
Forest Service, Forest Products Laboratory

For more information please visit WasteToWisdom.com

Goals of Conducting Life Cycle Assessment (LCA)

Perform environmentally sustainable assessment of torrefied briquette supply chain

Torrefaction

Produce high quality solid biofuel

- to quantify environmental impacts using life cycle assessment (LCA) tool
- assess environmental performance across all life-cycle stages
- identify areas for improvement to enhance environmental sustainability

Life Cycle Assessment (LCA)

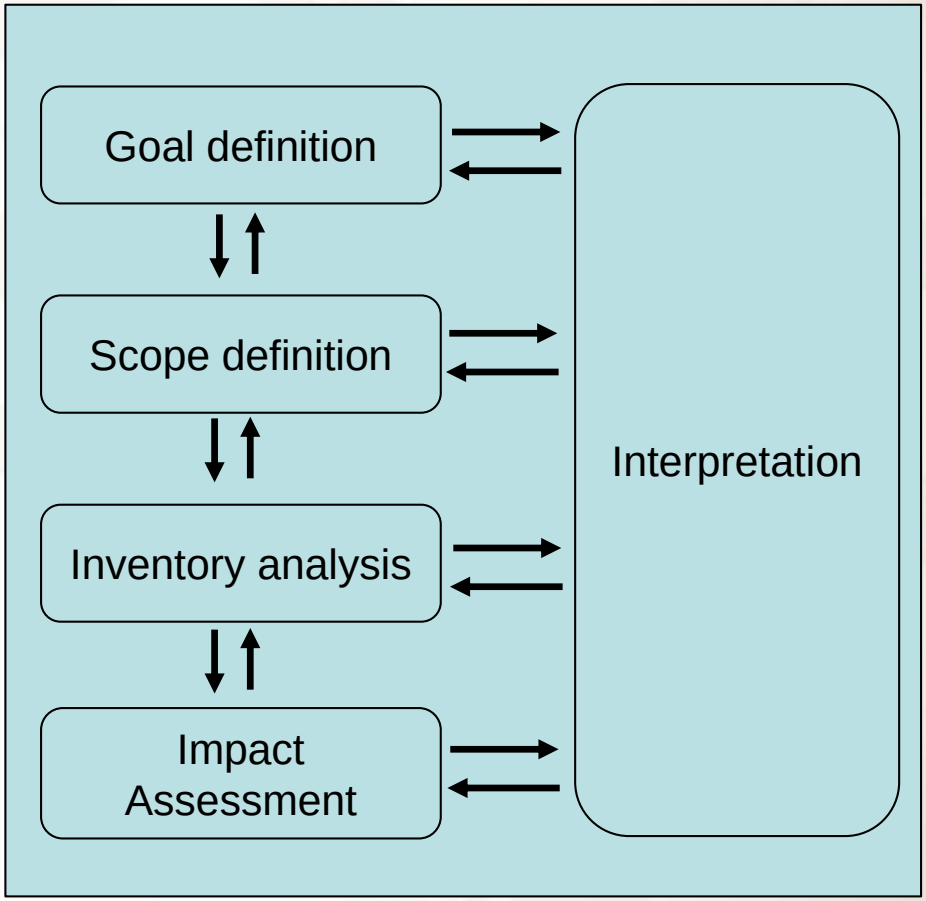
A quantitative decision-making tool used to identify potential environmental impacts of a product system throughout its entire life cycle

Environmental management tool:

- to quantify the environmental impact of goods or services
- identifying and quantifying energy and materials used, emissions and wastes released to the environment
- promote continuous environmental improvement

Life Cycle Assessment (LCA) Method

- International Organization for Standardization (ISO) 14040 and 14044 standards (ISO, 2006a; 2006b)
- LCA analyses were modeled using SimaPro 8.3 software
- *Environmental impact assessment*: TRACI impact assessment method



Life Cycle Assessment (LCA)

Functional Unit

- 1 kWh of electricity generated at power plant

Scope Definition

- “Cradle-to-grave” from extraction of the raw material through product production to end-of-life
- Manufacturing and disposal of the equipment and infrastructure is not considered

Data Inventory

- Operational runs were performed at Samoa, California by Schatz Energy Research Center (SERC)
- Existing literature on biomass torrefaction and previous LCA studies
- USLCI database (Ecoinvent, 2010)
- Theoretical calculations and estimations

Cradle-to-grave System Boundary

Logging Residues

↓

Feedstock procurement

↓

Bioconversion Site

↓

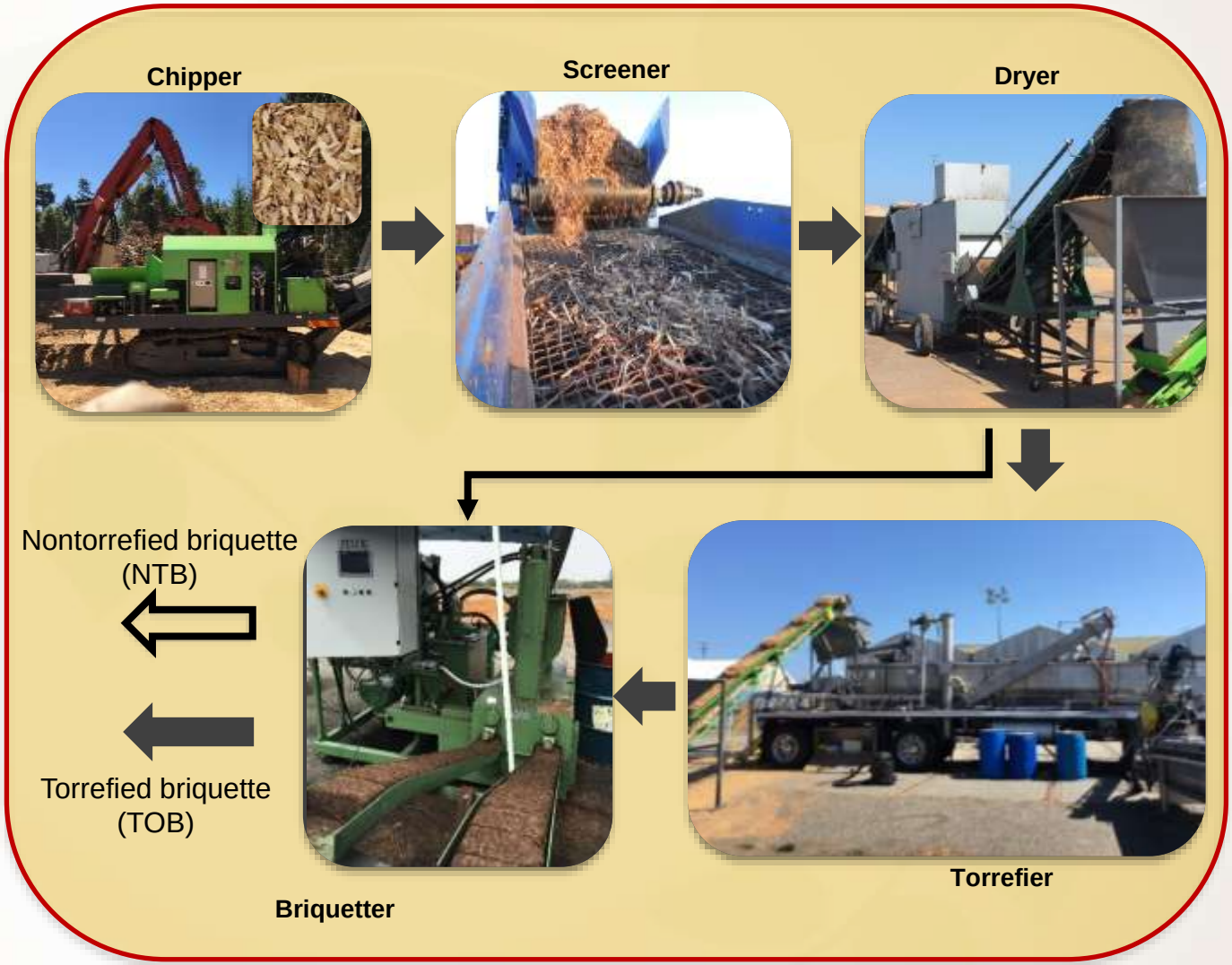
Distribution

↓

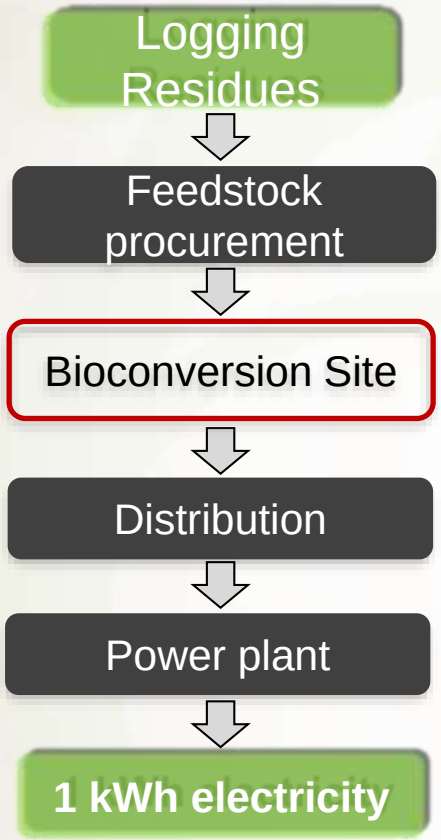
Power plant

↓

1 kWh electricity



Cradle-to-grave System Boundary



Environmental impacts resulting from use of torrefied briquette (TOB) and nontorrefied briquette (NTB) was investigated

Scenario analysis:

- Remote power generation using wood gasification and diesel electricity was compared
- Utilization of torgas within the system
- Pile and burn credit

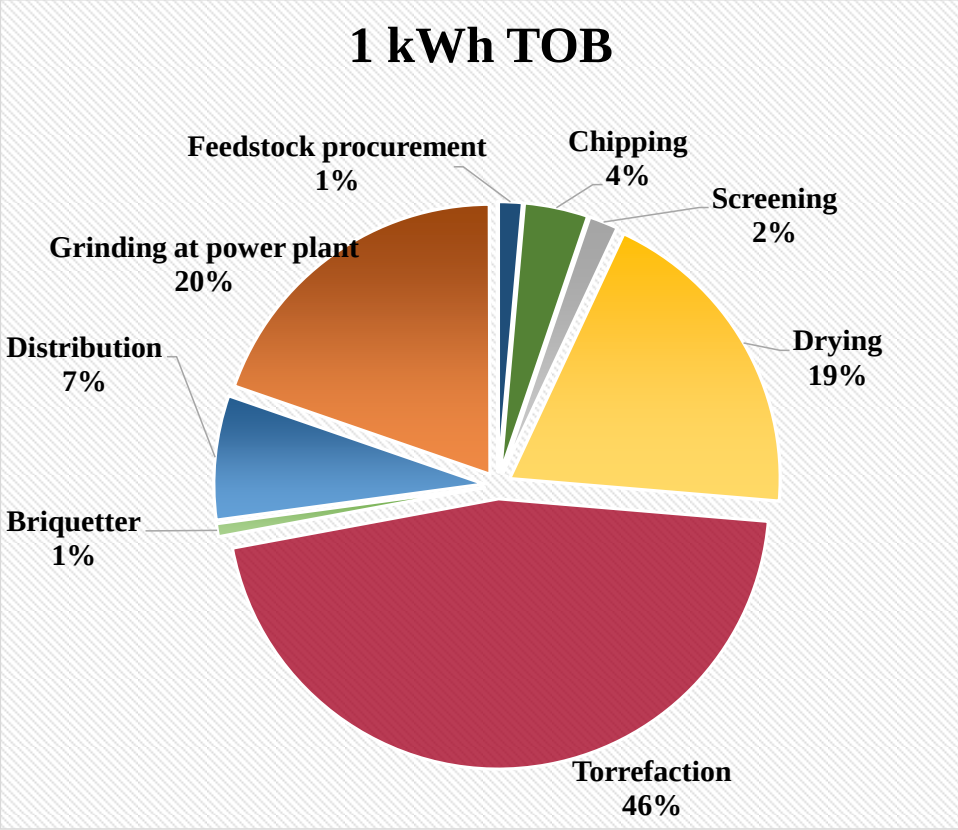
Process Contribution to Global Warming Impact- torrefied briquette (TOB)

- Feedstock moisture content around 20%

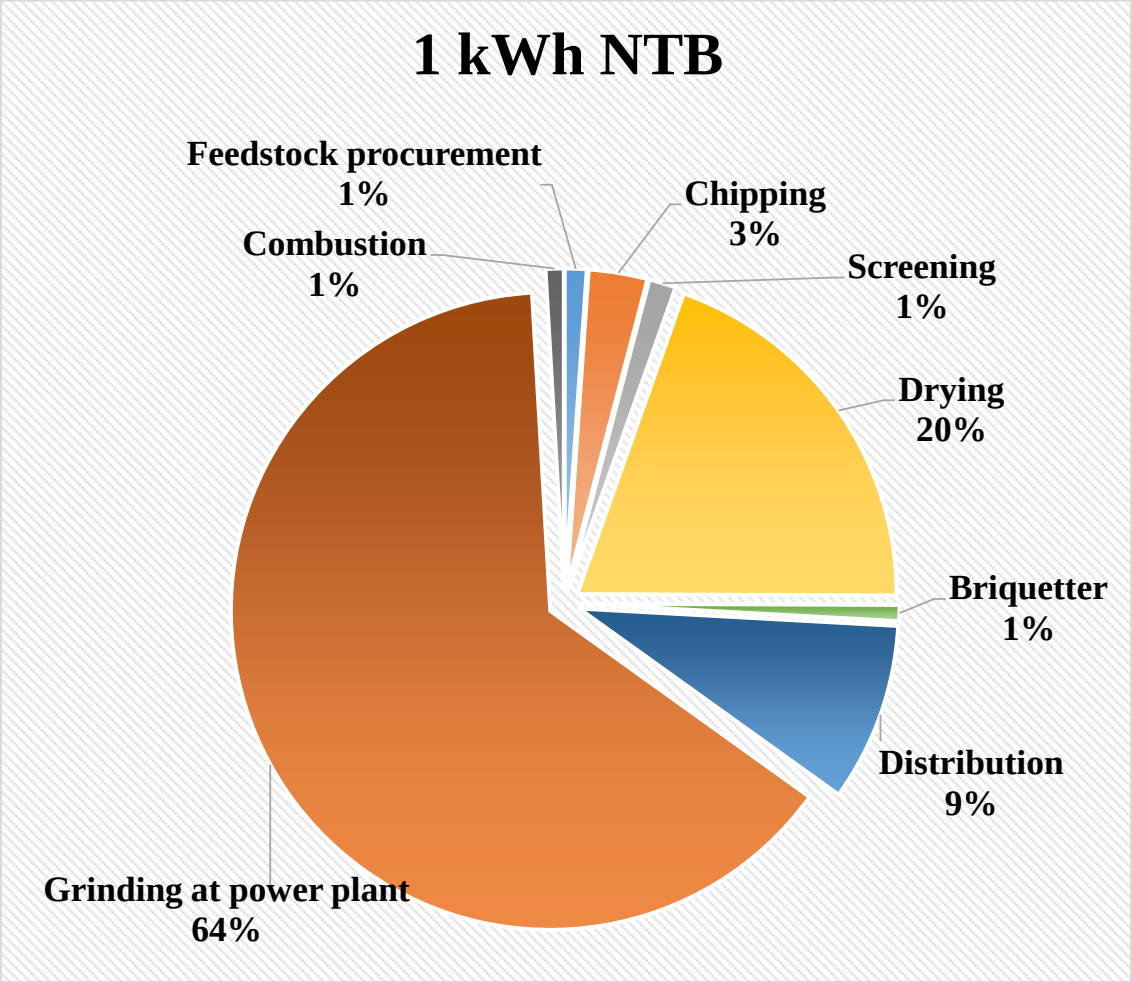
Properties	TOB	NTB
MC, % wb	0.6	8.3
Ash Content %, db	2.5	3.4
VM %, db	71	81
HHV, MJ/kg wb	22	18
Durability %	93	85

Process Contribution to Global Warming Impact- torrefied briquette (TOB)

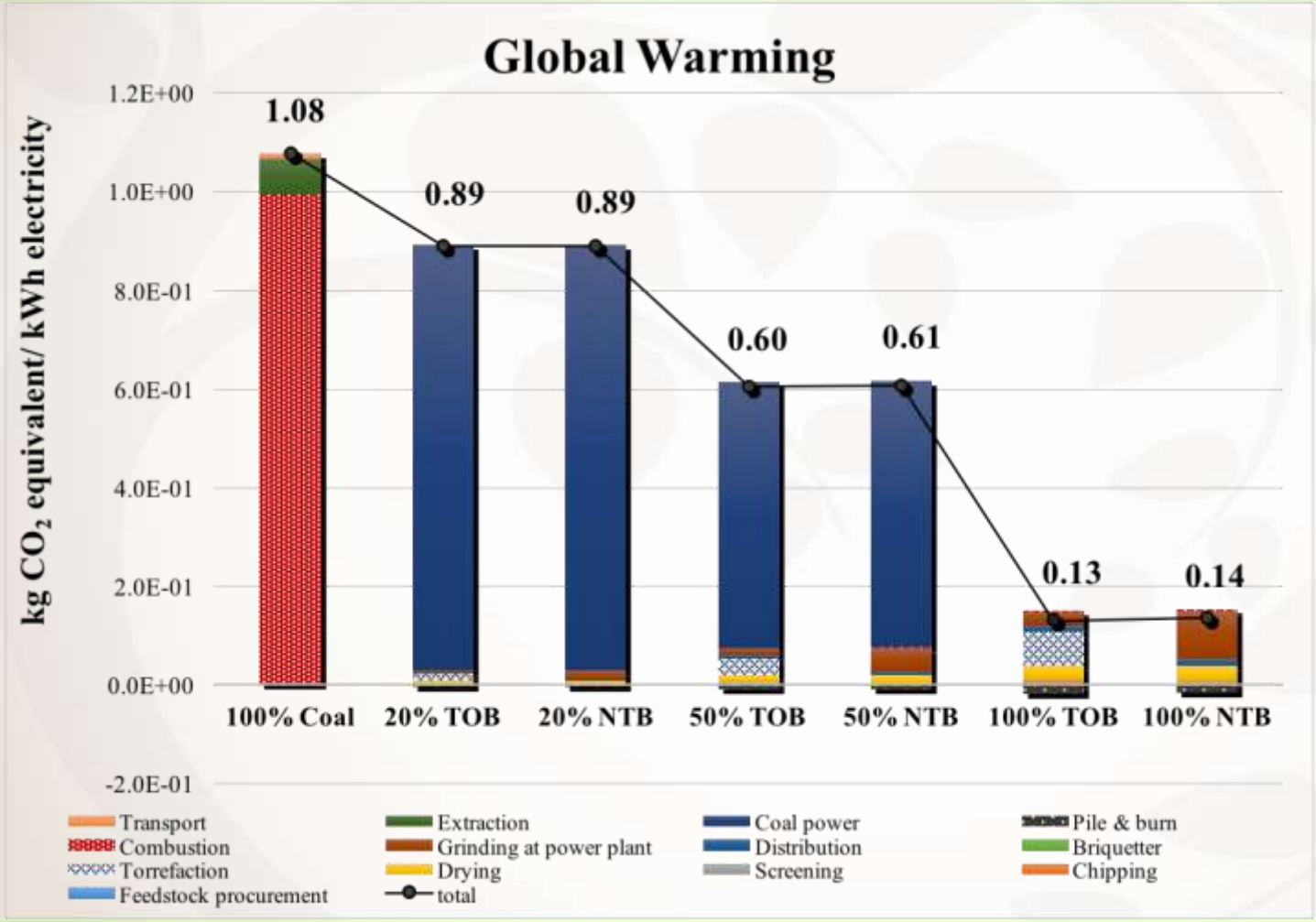
0.16 MJ of fossil fuel consumed
to generate 1 MJ of torrefied briquette



Process Contribution to Global Warming Impact- nontorrefied briquette (NTB)



Global Warming Impact- Cofire

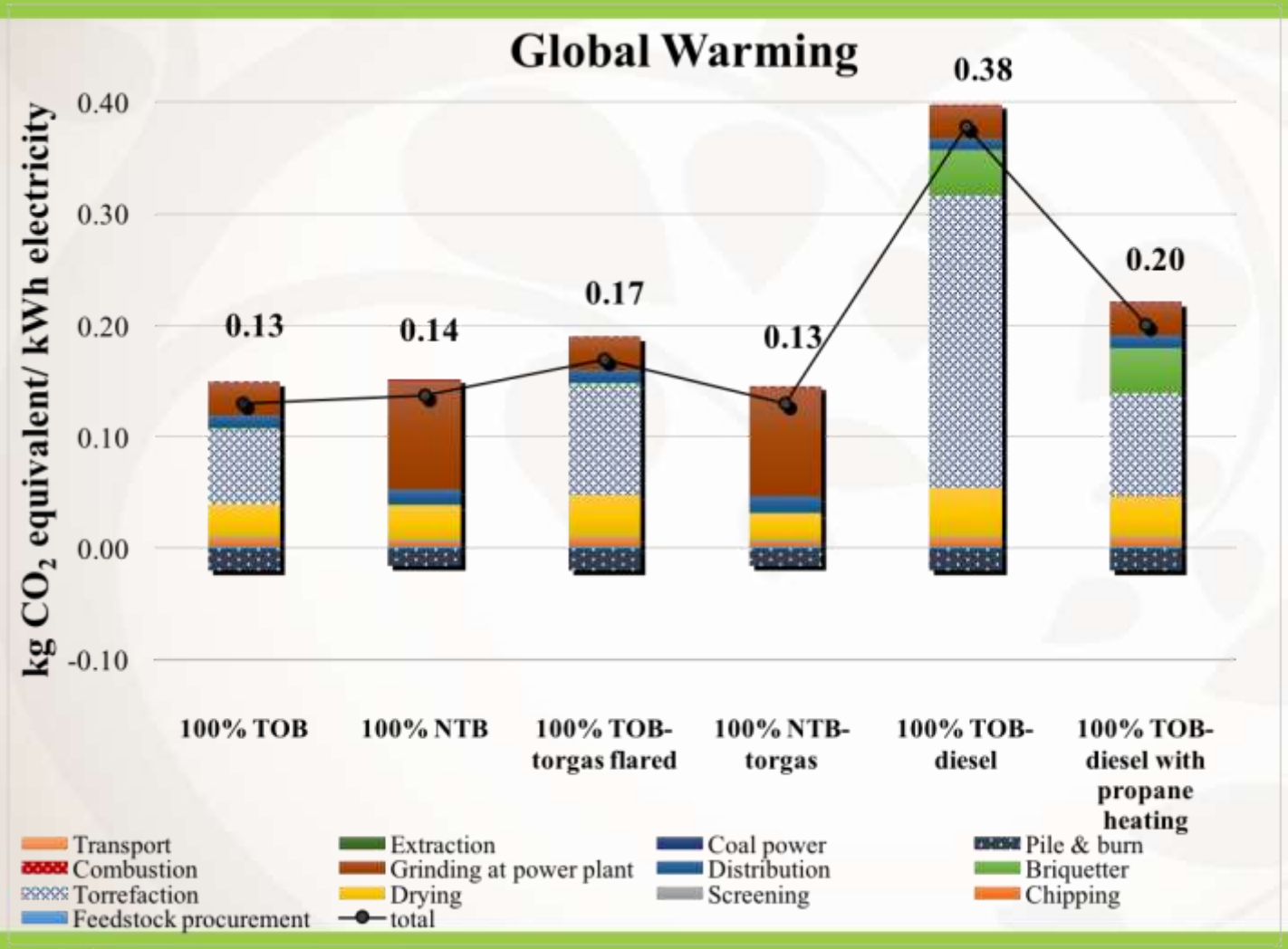


100% substitution

88% lower GHG-emissions from TOB compared to coal

5% lower GHG-emissions from TOB compared to NTB

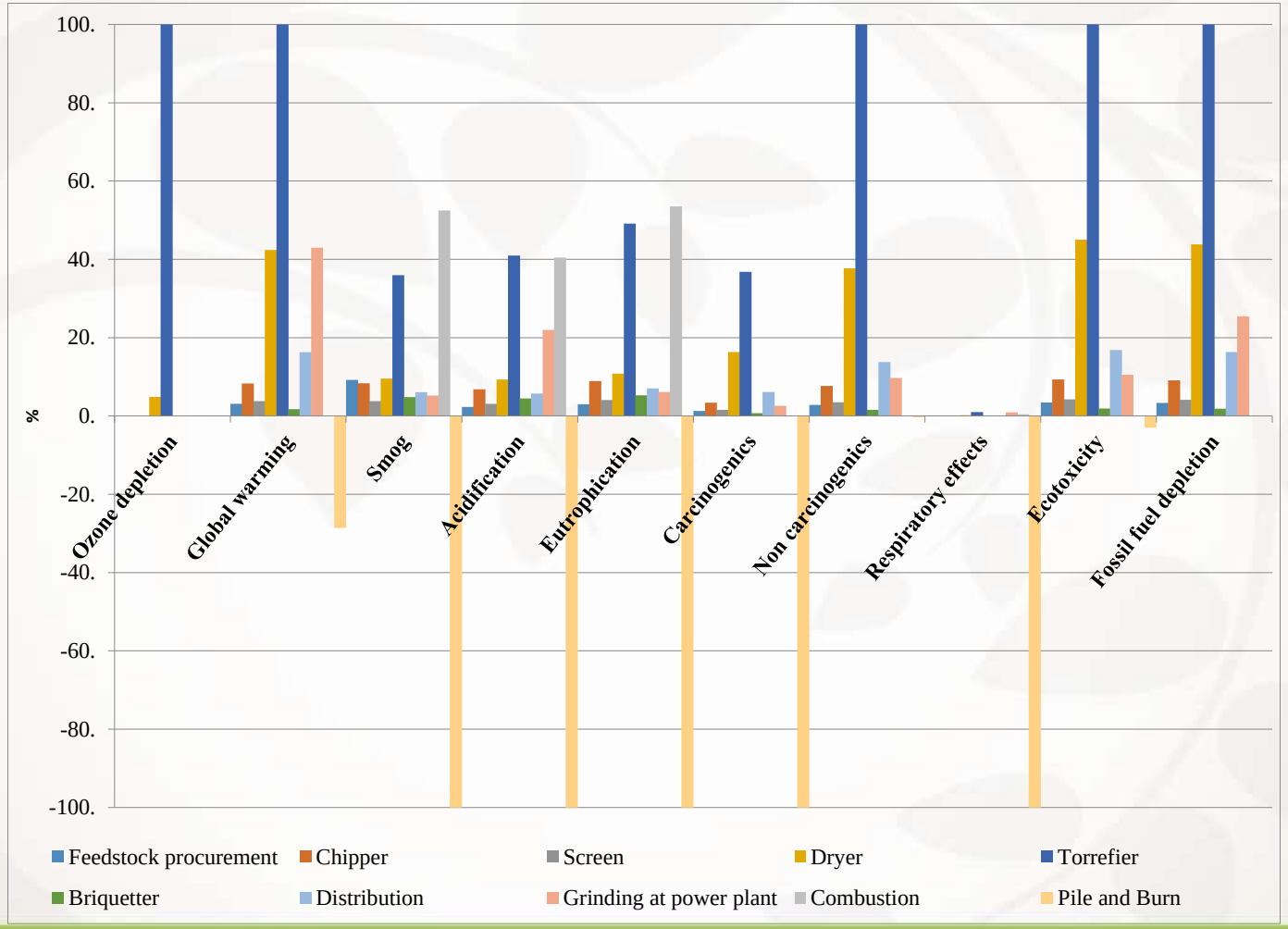
Global Warming Impact- scenarios



Resulting GHG-emissions when gasifier power is used is 66% lower than diesel power

Pile & burn credits account for 13% reduction in global warming impact

Process Contribution to Environmental Impact-TOB



Concluding Remarks

- ✓ Use of torrefied briquettes to substitute for coal at power plant has major effect on the resulting GHG emissions.
- ✓ Using wood gasifier instead of diesel for remote power generation decrease Global Warming impact by 66%.
- ✓ Efficient recovery of torgas is necessary to enhance environmental sustainability
- ✓ Avoiding pile & burn by utilization of forest residues notably lowers resulting environmental impact.

The Economics of Near-Forest Woody Biomass Torrefaction

Waste to Wisdom Webinar
August 9, 2017

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The Economics of Near-Forest Woody Biomass Torrefaction

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Near-forest woody biomass torrefaction

Sort and Process

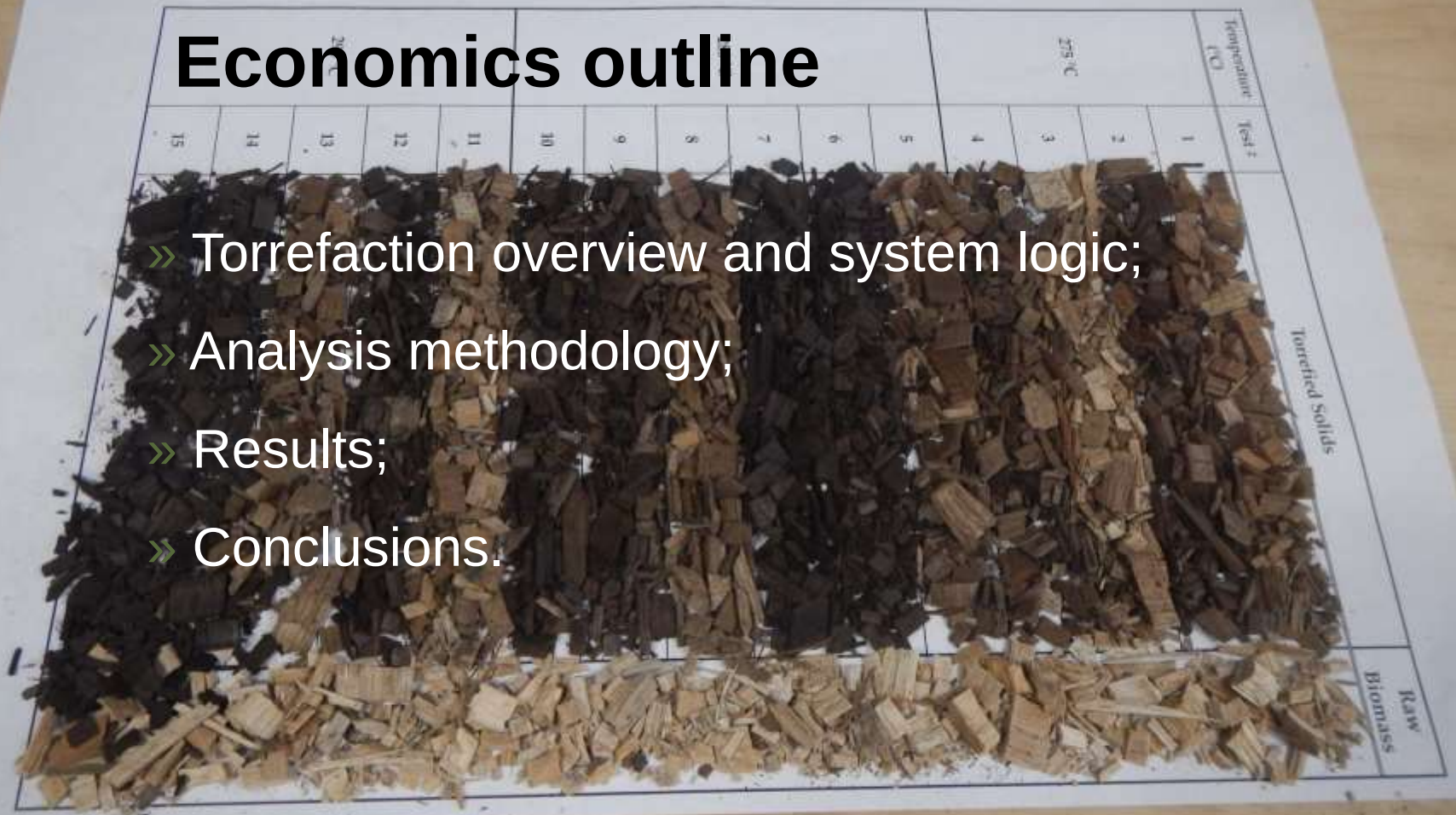
Comminute

Screen

Torrefy

Economics outline

- Torrefaction overview and system logic;
- Analysis methodology;
- Results;
- Conclusions.



Why torrify?

» Oxygen

» Moisture

» Calorific value

» Hydrophobicity

» Ease of comminution (“grindability”)

What to torrefy?

Preferably, a feedstock without much variation…

wood chips
(<3/4 inch)

micro-chips
(<1/4 inch)

sawdust
(<5/32 inch)

- Deck screen (Peterson Pacific)
  - Machine rate = $44.09/BDT
  - Productivity = 14.25 BDT/PMH
- Star screen (Peterson Pacific)
  - Machine rate = $14.60/PMH (w/out loader or labor)
  - Productivity = 28.50 BDT/PMH

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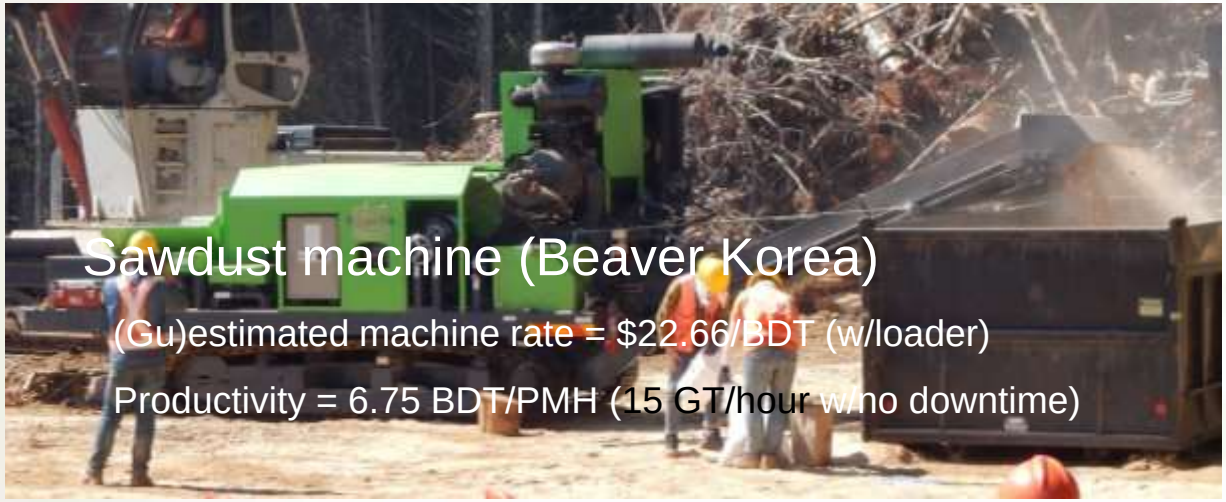

Sawdust machine (Beaver Korea)

- (Gu)estimated machine rate = $22.66/BDT (w/loader)
- Productivity = 6.75 BDT/PMH (15 GT/hour w/no downtime)

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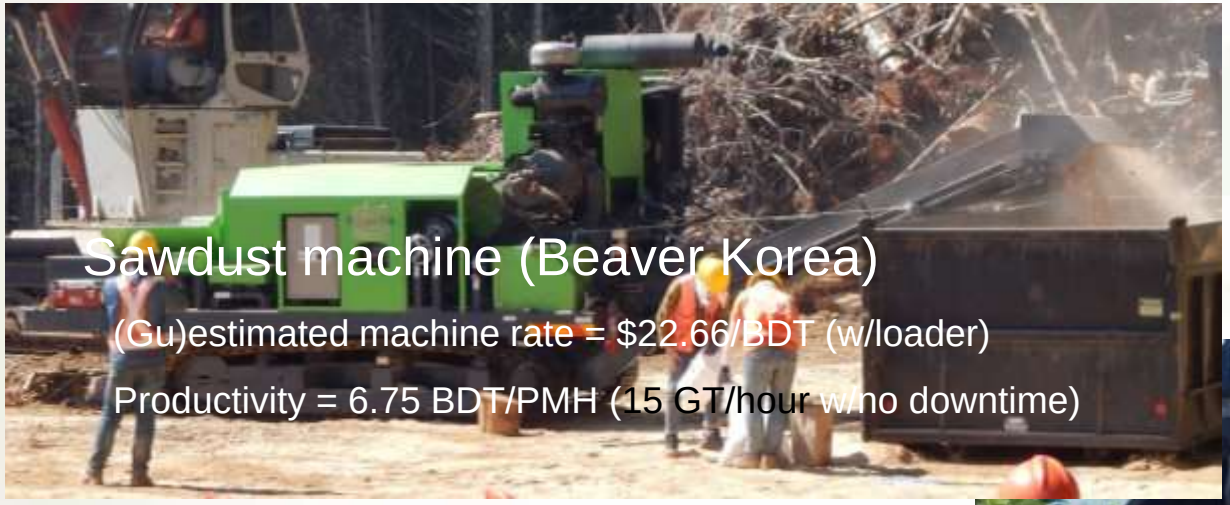

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Microchipper (Peterson 4300):

- Machine rate = $17.54/BDT (w/loader)
- Productivity = 37.21 BDT/PMH

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Torrefier feedstock input is 0.716 BDT/PMH

Why briquette?

» Torrefaction increases the energy content by weight, but decreases it by volume;

» In transporting chips, trailers usually reach their volume limits before they reach their weight limits; so torrefaction alone may make your transport economics worse;

» Briquettes can be made economically at a relatively-small scale

- » RUF-400 cost: $105,000
- » Design life: 100,000 hours (about 25 years)
- » Torrefied output: 0.406 BDT/hour
- » Machine rate: $25.34/BDT (w/out labor or feedstock)

What is a torrefied briquette?

What is a torrefied briquette?

Torrefaction Economics

Basic torrefaction assumptions:

- Torrefaction unit: Norris Thermal Technologies CM 600 @ $600,000
- Dryer: Norris Thermal Technologies Belt-o-matic 123B @ $45,000
- Economic life: 10 years
- Salvage value: 20%
- Avg. electric consumption: **108 kW (electrically-heated screw)**
- Feedstock throughput: 0.644 BDT/PMH
- Operation = 2,500 SMH @ 86% productivity
- Torrefied system mass conversion = 70%
- Feedstock = Microchips @ $17.54/BDT (including loader)
  - = $23.82/green ton

Other important assumptions:

- Electricity supply…
  - Gasifier genset @ $0.4236/kWh
  - Diesel genset @ $0.3999/kWh
  - Mains power @ $0.1546 (EIA "all-sector" for California, May 2017)
- Discount rate: 10% (pre-tax nominal w/inflation @ 1.5%)
- Product value: $225/BDT, delivered
- Delivery cost: $40/BDT
- Tax losses are: recognized immediately (not carried forward or lost)
- Loan = 40% of $852,500 in initial capital costs
- 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

Project planning life	10 years
Standard operating days/year	250
Standard daily operating hours	8.0
Cost inflation rate	1.0%
Revenue inflation rate	0.0%

Project financing

Required mininum nominal pre-tax risk premium on invested capital	8.5%
Deposit interest rate (APR)	1.50%
Initial gearing (% of total start-up cost that is financed)	40.0%
Loan interest rate (APR)	6.00%
Loan term	6.00 years
Loan and deposit payments per year	12
Working capital required as a percentage of next year's sales	2.0%

Capital assets

Deperciation code	DB
Terminal asset value multiplier	100%

Fixed operating costs

General administration ($/year)	$	6,000
Administration staff (number)		0.25
Administration staff salaries ($/person/year)	$	80,000
Site lease ($/year)	$	-
Equipment lease ($/year)	$	-
Annual insurance percent		1.6%
Other annual fixed costs ($/year)	$	-

Variable operating costs

	Plant operators		1.00
Variable labor cost ($/worker/scheduled hour)		$	40.00
	Electricity cost ($/kWh)	$	0.424
Standardized repairs & maintenance percentage			5.9%
	Repairs & maintenance function		Uniform
	Liquid propane ($/gallon)	$	2.39
	Periodic consumables cost	$	6,000
	Periodic consumables life		2,000 hours
Periodic consumables installation factor			0%
Additional periodic consumables	*cost*	$	3,000
Additional periodic consumables	*life*		2,000 hours
Misc. variable operating costs	*$/scheduled hr.)*	$	-
Other variable consumables cost	*($/ton torrefied*	$	-
	Finished goods transport cost ($/ton)	$	40.00

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	-

Conversion variables

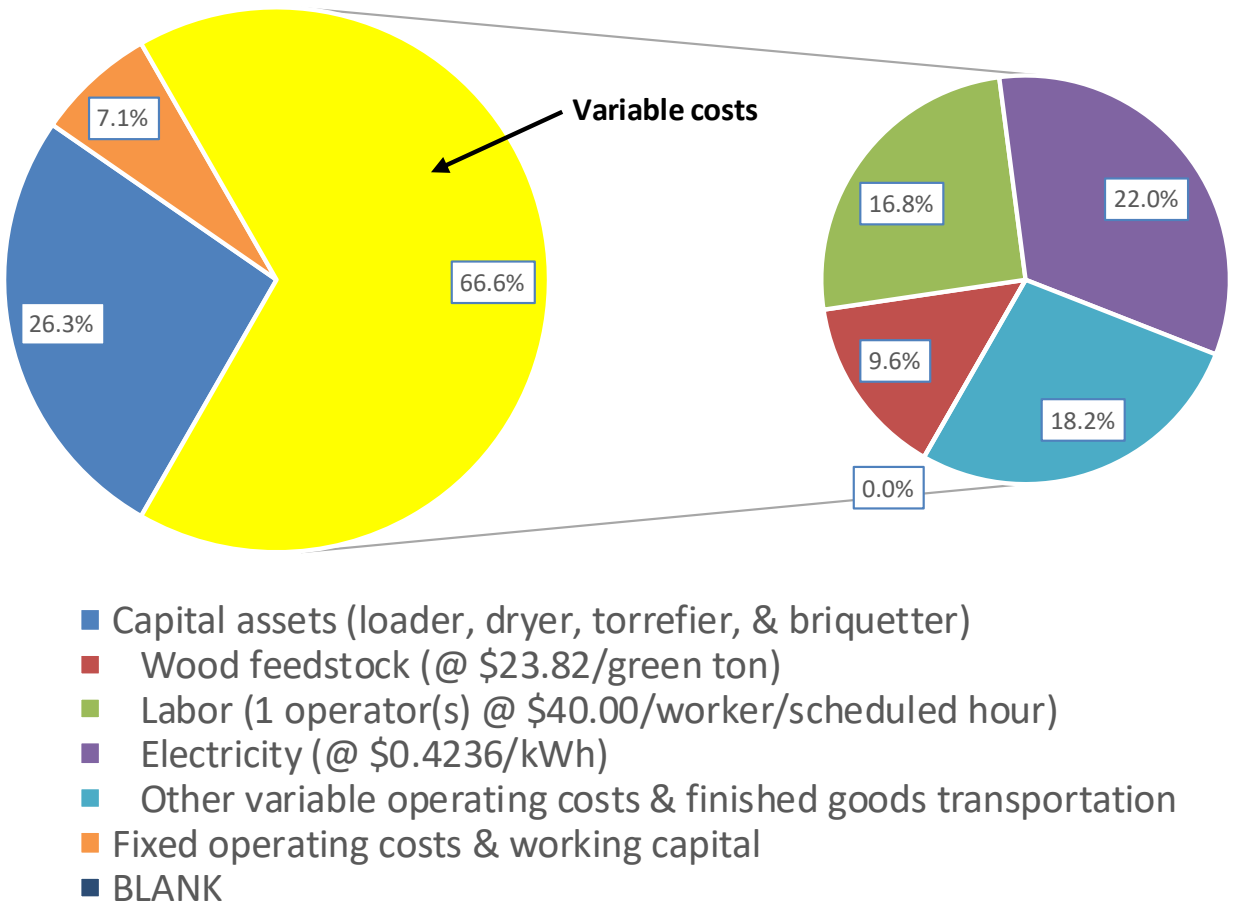
Torrefied system feedstock throughput (bone-dry tons/hour)	0.64
Torrefied system mass conversion/bone-dry ton of feedstock (%)	70.00%
Feedstock removal (bone-dry tons/acre)	18.00
Electrical energy required	130 kW
Liquid propane (gallons/productive hour)	7.64
Thermal production (million Btu/Bone-dry ton feedstock throughput)	1.76
Feedstock moisture content	35.8%

Results

Summary Financial Measures: Semi-mobile Torrefied Conversion System from Norris Thermal Systems	Before-finance & tax	Before-tax	After-tax
NPV ($000)	$ (1,866)	$ (1,907)	$ (1,279)
Real IRR (adjusted by cost inflation at 1.0%)	#NUM!	#NUM!	#NUM!
Nominal IRR	#NUM!	#NUM!	#NUM!
NOTE: Nominal discount rates used to calculate NPVs and B-E values	10.00%	8.40%	5.04%
(Assuming 1.0% cost inflation, 0.0% revenue inflation, and 40.0% gearing at 6.00%)		*IRR seed =*	-50%
Break-even avg. torrefied product value ($/ton)	$ 576	$ 559	$ 542
Break-even delivered yr. 1 feedstock cost ($/green ton)	$ (128)	$ (120)	$ (113)
Medium-term operating B-E avg. product value ($/ton)		$ 434	
Short-term operating B-E avg. product value ($/ton)	$ 383		

Product price assumption = $225/BDT, delivered

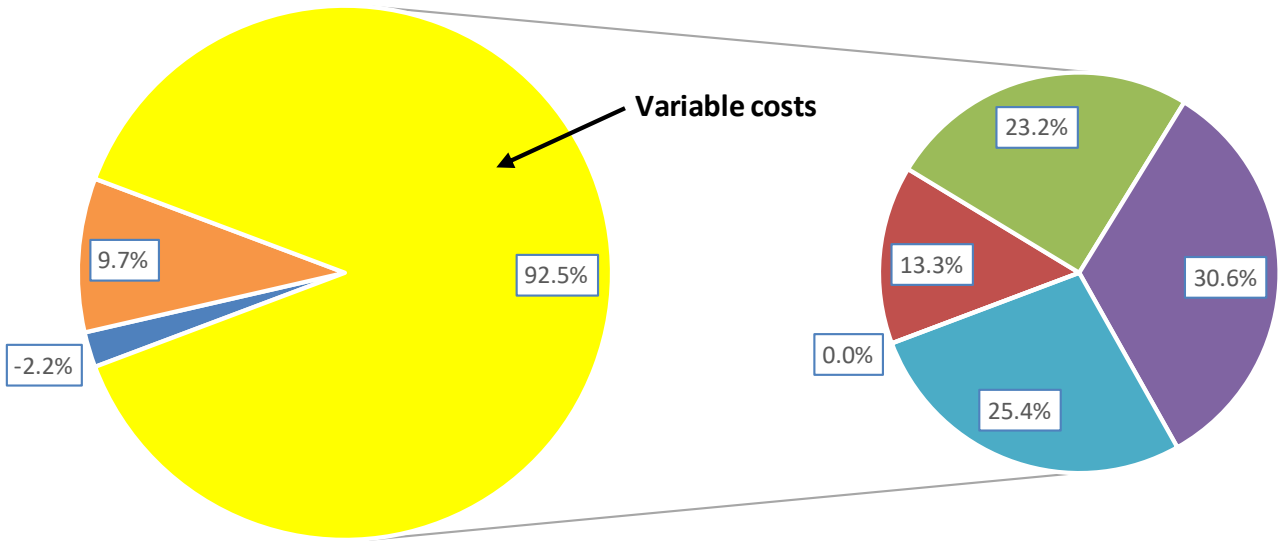
Cost breakdown: Before-finance & tax



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

NOTE: Total annualized costs = $498,619

Cost breakdown: After-finance & tax



- Capital assets, including financing costs and tax credits (loader, dryer, torrefier, & briquetter)
- Wood feedstock (@ $23.82/green ton)
- Labor (1 operator(s) @ $40.00/worker/scheduled hour)
- Electricity (@ $0.4236/kWh)
- Other variable operating costs & finished goods transportation
- Fixed operating costs & working capital
- BLANK

Total costs discounted at 5.04% nominal after-tax over 10 years with variable costs highlighted

NOTE: Total annualized costs = $362,472

Sensitivity analyses are all negative…

» Capital costs

» Fixed operating costs

» Variable operating costs

» Product revenue

» Feedstock conversion

» Required pre-tax risk premium on invested capital

» Financial gearing (i.e. initial debt/equity)

» Electricity cost

Markets

- Market for torrefied briquettes is yet undeveloped
  - Competitive advantage would come with farther shipping distances and uncovered storage for energy markets, especially where there are carbon taxes or incentives not to burn coal.
- Cannot compete with coal on a BTU basis
  - PRB is $11.65/ton (8,800 BTU/lb)
- Boardman (550 MW) – 8,000 tons/day

Conclusions

» Small-scale near-woods electrically-fired biomass torrefaction does not make much economic sense

- » Costs are relatively high;
- » Main market is industrial (which limits prices);
- » There would be challenges matching machine scales.

» However, the costs as presented could be lowered

- » Torrefaction could be done with waste heat;
- » Propane could be eliminated;
- » A larger-scale operation would probably not require additional labor, reducing per-unit labor costs;
- » It is possible that a client could require a less-torrefied product, allowing higher product recoveries.

Thank You

Questions?

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But what if…

- Torrefier capital cost was reduced from $600,000 to $450,000
- Torrefied conversion increased from 70% to 80%
- Torrefied system throughput increased from 0.64 to 1.00 BDT/PMH
- Electrical energy required decreased from 130 kW to 65 kW
- Electricity cost decreased from $0.4236/kWh to $0.3000/kWh
- Revenue increased at the same rate as costs (1%/year)
- The plant could avoid burning propane to combust torgas
- Feedstock was delivered at $5.00/green ton
- The nominal before-finance & tax discount rate was lowered to 5%

…then the NPVs would still be negative.

Summary Financial Measures: Semi-mobile Torrefied Conversion System from Norris Thermal Systems	Before-finance & tax	Before-tax	After-tax
NPV ($000)	$ (807)	$ (805)	$ (490)
Real IRR (adjusted by cost inflation at 1.0%)	-25.4%	-30.0%	-20.0%
Nominal IRR	-24.6%	-29.3%	-19.2%
NOTE: Nominal discount rates used to calculate NPVs and B-E values	5.00%	5.40%	3.24%
(Assuming 1.0% cost inflation, 1.0% revenue inflation, and 40.0% gearing at 6.00%)		*IRR seed =*	-50%
Break-even avg. torrefied product value ($/ton)	$ 339	$ 341	$ 330
Break-even delivered yr. 1 feedstock cost ($/green ton)	$ (49)	$ (50)	$ (44)
Medium-term operating B-E avg. product value ($/ton)		$ 257	
Short-term operating B-E avg. product value ($/ton)	$ 213		