# Biochar as a Forest Industry Co-product

# Is there space for new products in traditional manufacturing operations?

**Nate Anderson, Research Forester**
**U.S. Forest Service,**
**Rocky Mountain Research Station**

**Forest Biomass and the Bioeconomy**

April 25, 2019 ~ Vancouver, WA

# Overview

- What's the supply chain problem?
- Is biochar part of the solution?
  1. Small scale operations
  2. Medium & large scale operations
  3. Value added operations
- Summary
- Discussion

Unburned slash piles left behind after logging, Fraser National Forest.

# Acknowledgements


| Co-Authors | Industry Partners & Advisors |
|---|---|
| Nate Anderson, U.S. Forest Service (RMRS) | Jonah Levine, Biochar Solutions, Inc. |
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# Acknowledgements


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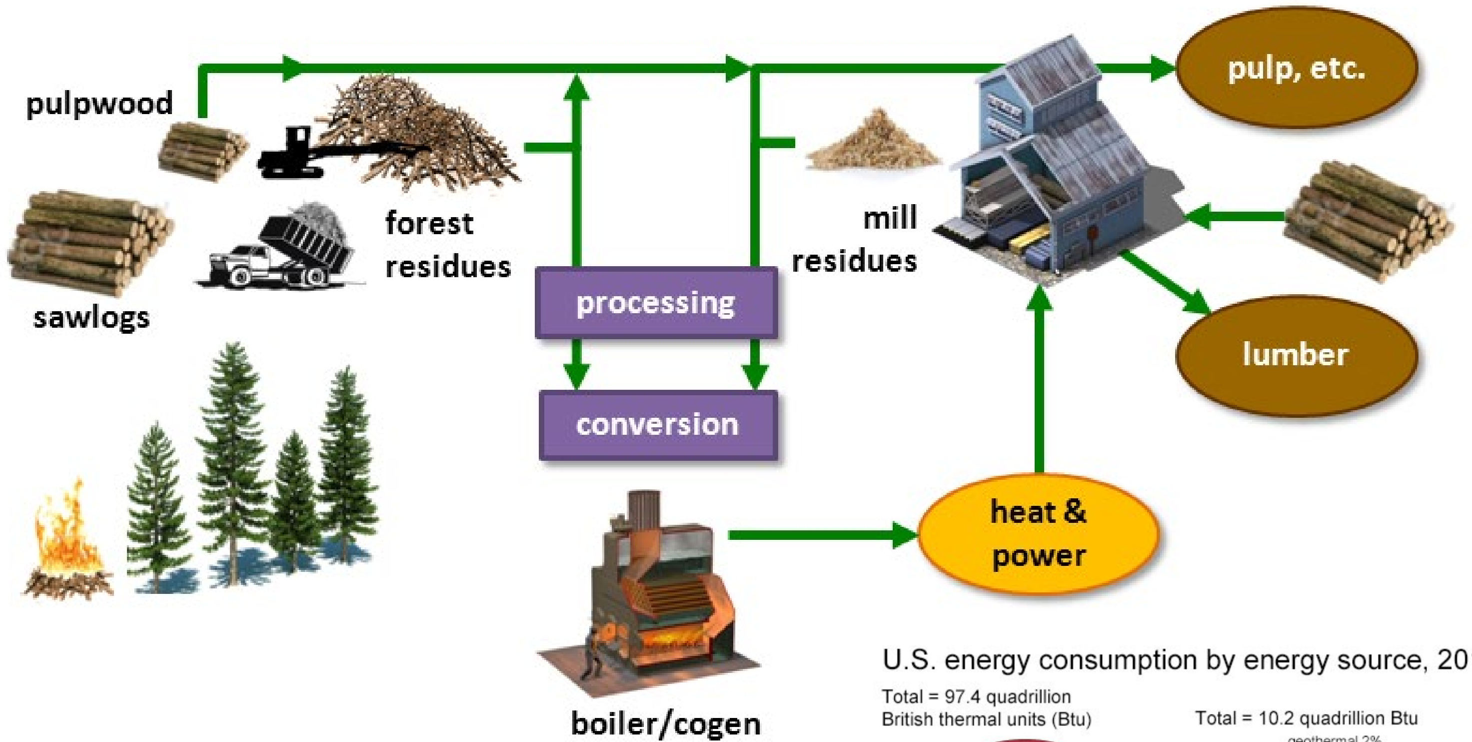
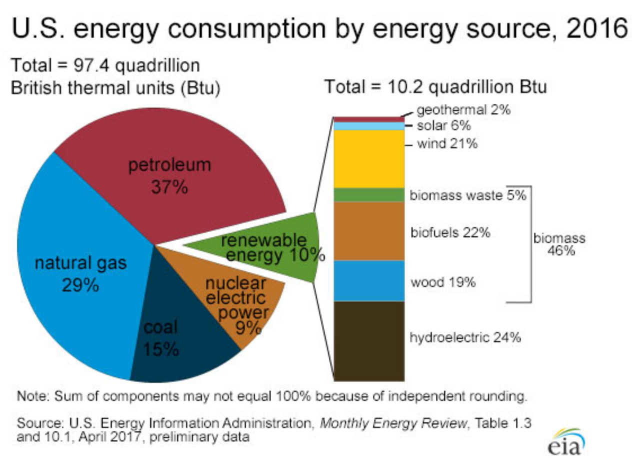
- Bioenergy Alliance Network of the Rockies (BANR, an AFRI-CAP)
- Biomass Research and Development Initiative (BRDI)

**USDA – U.S. Forest Service**

- Rocky Mountain Research Station
- National Fire Plan
- Woody Biomass, Bioenergy, and Bioproducts Competitive Grant

# What's the problem?




U.S. Forest Industry

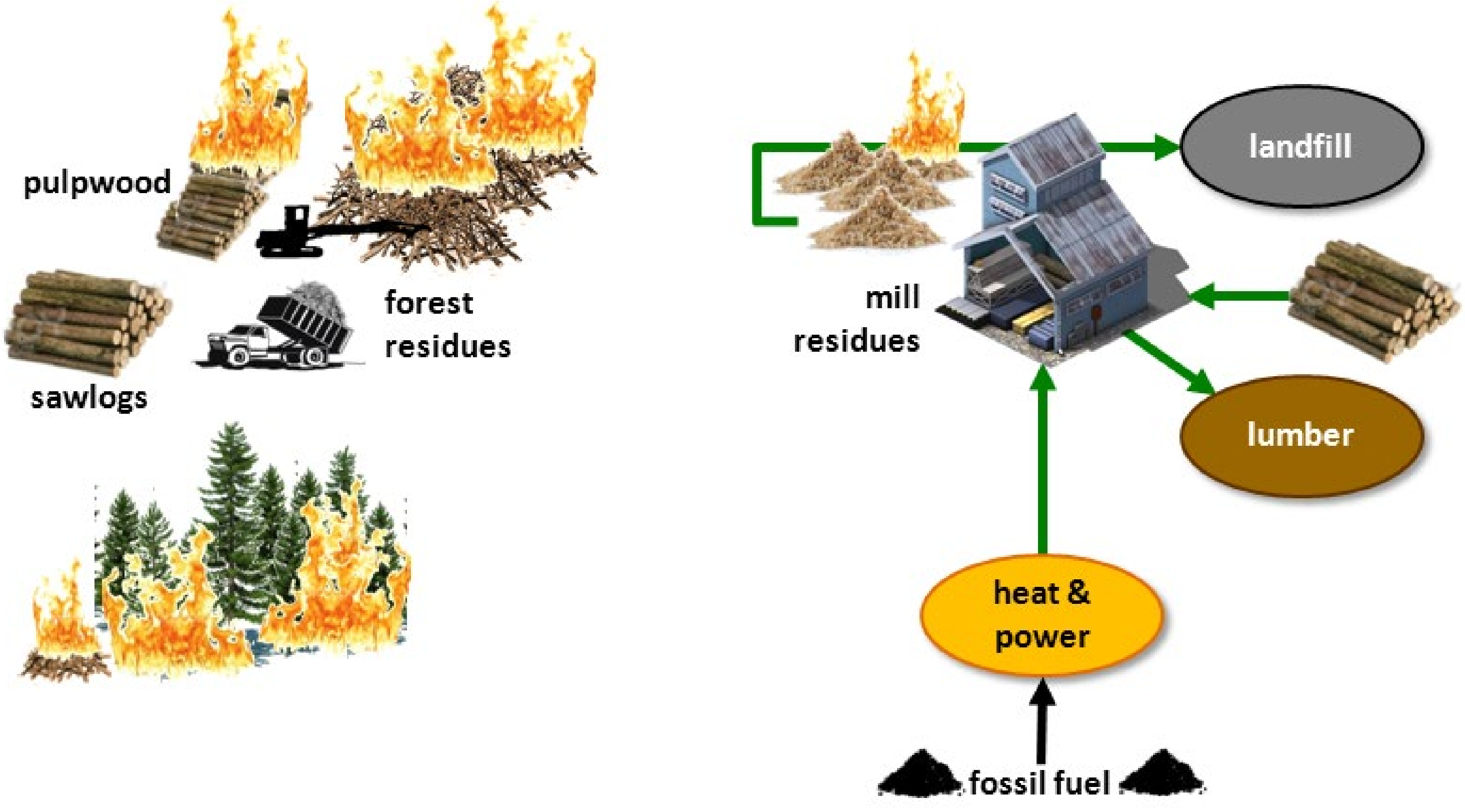
10% of energy consumption is renewables

46% of renewable energy is biomass

24% of renewable energy is from wood & waste

(EIA 2018, statistic for CY 2016)

# What's the problem?

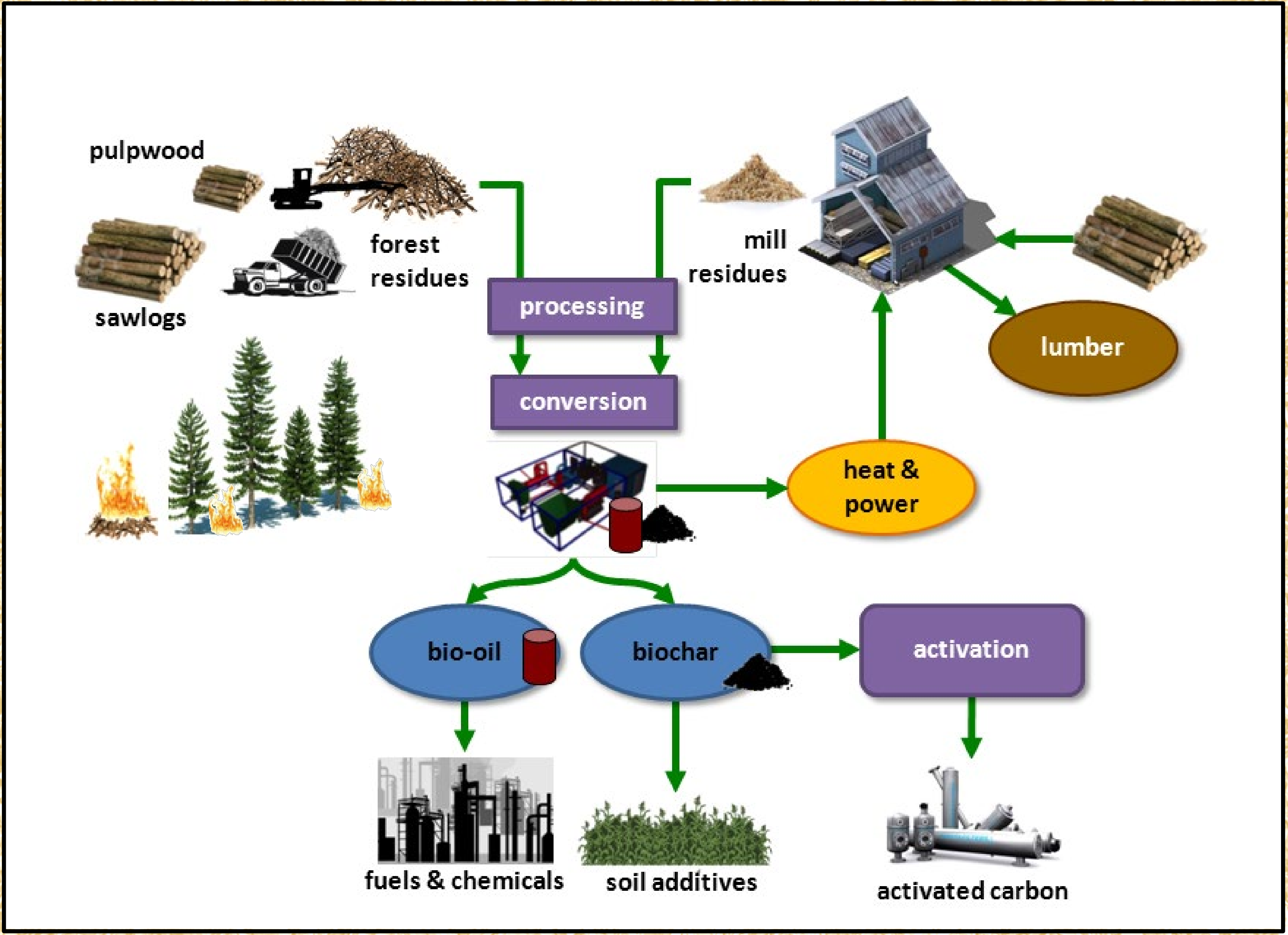


# What's the problem?

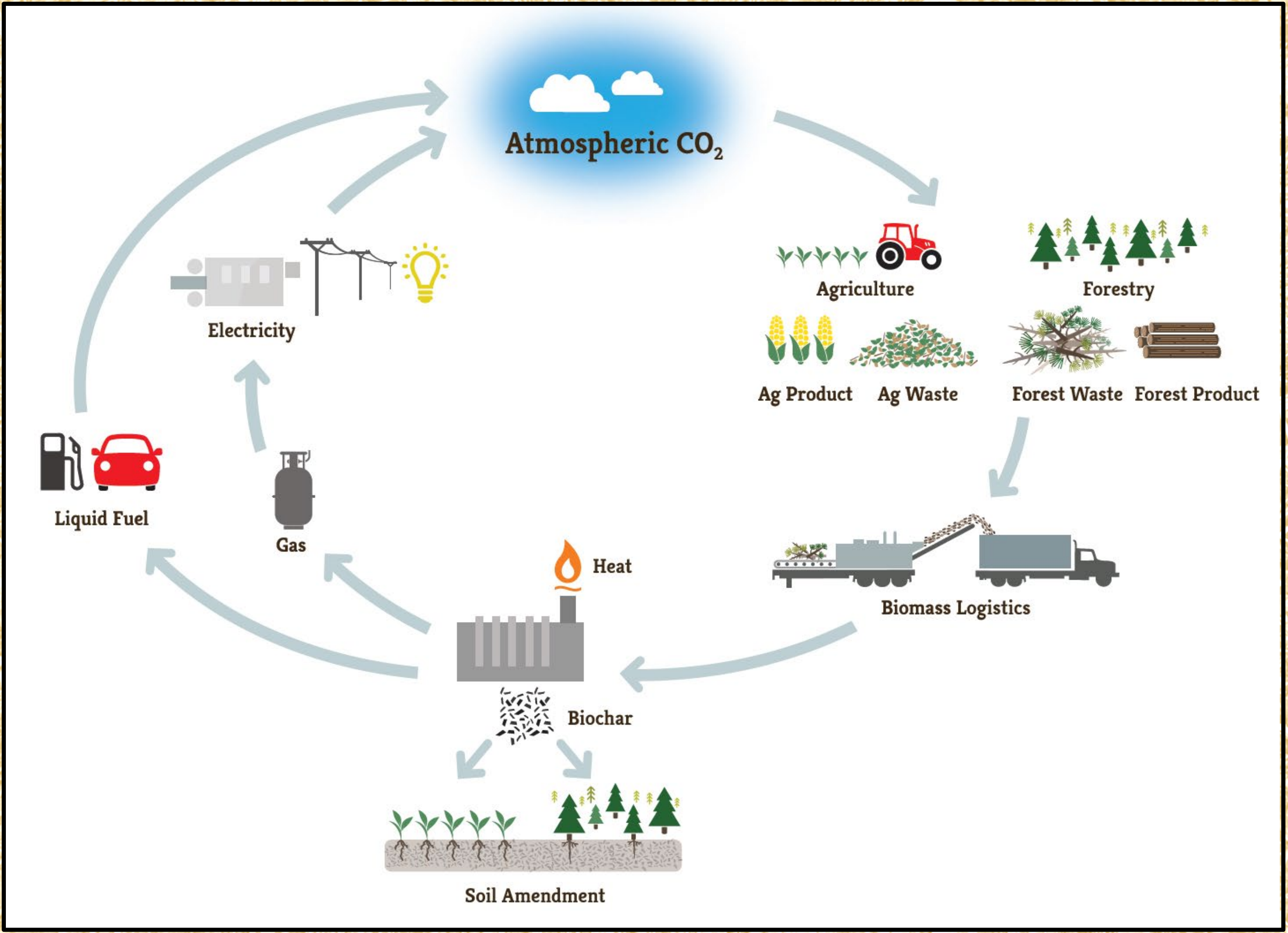
- Smurfit-Stone linerboard plant
  - > 1 million tonne pulpwood and hog fuel per year
  - Equal to 69 Nexterra gasifiers (@ 14,500 t $yr^{-1}$)
  - 1.0 to 1.5 million tonnes $CO_2$ (pile burning)
  - > 40,000 hectares of treatment

Smurfit-Stone statistics from Morgan 2009, University of Montana 2011, Jones et al. 2010

# What's the solution?



# What's the solution?



# 1. Small Scale Operations

**FEEDSTOCK** → **CONVERSION** → **PRODUCTS**

**Mill Residues**
Pueblo Wood Products
Coniferous live and dead
55 bdt of residues per day
Composting operation with local dairy farm

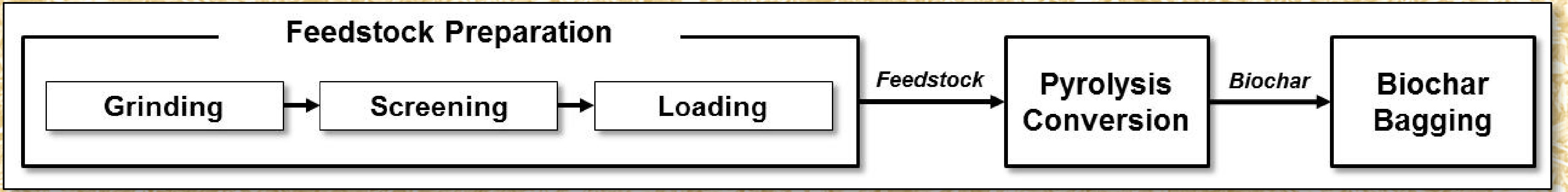
**Biochar Solutions, Inc.**
$200,000 system price
5.4 dry tons feedstock per day
Modular, low-cost biochar
Flexible feedstock
400-700ºC two-stage conversion

**Biochar**
Soil amendment
Mine reclamation
Forest, agriculture and greenhouse applications

# Methods

<u>Industrial Engineering Methods</u>

- Time study: 5 weeks, 25 work days
- Daily shift-level data and samples
- Financial analysis
- Net present value on a 10-yr project

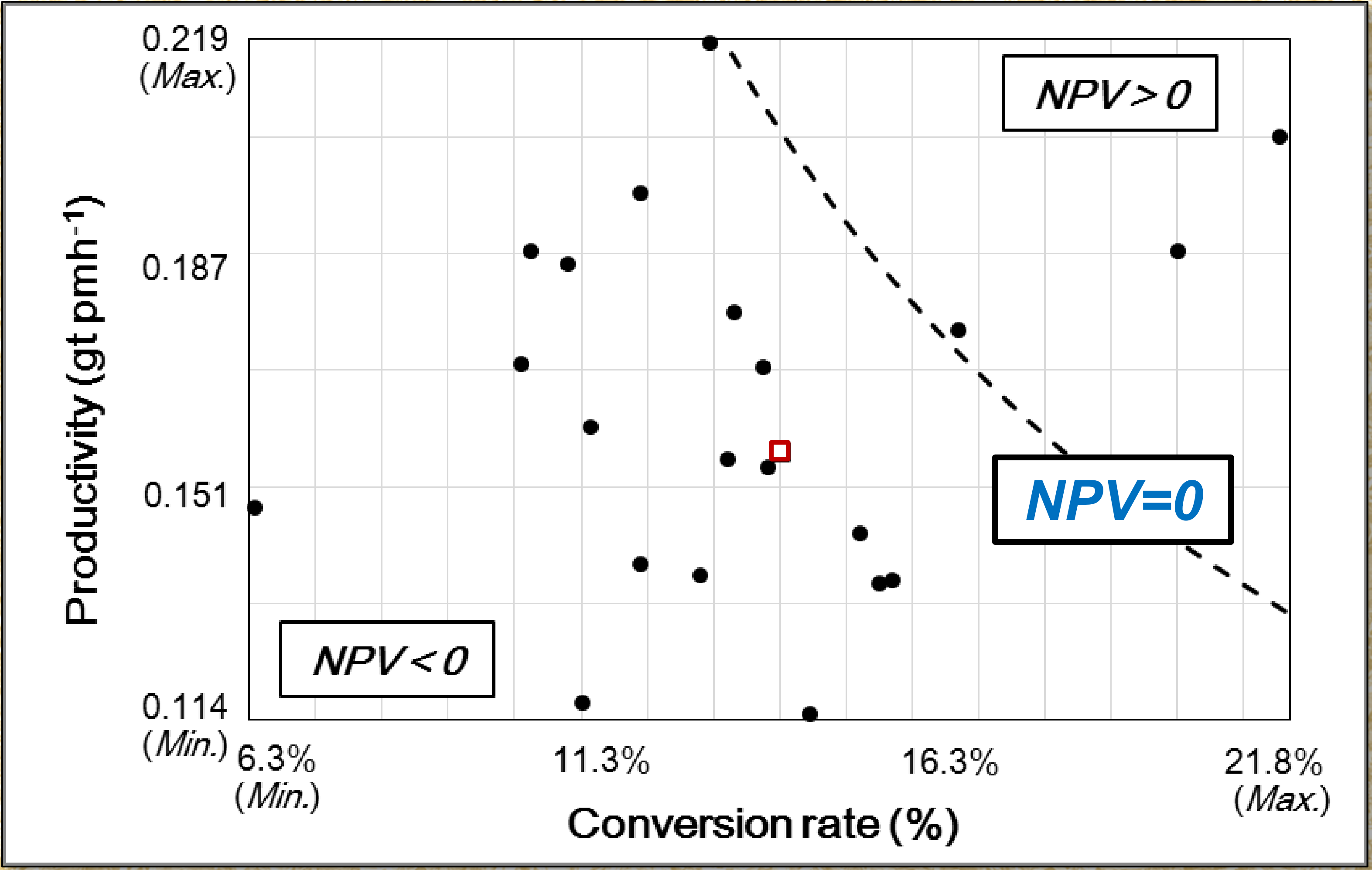



# Results

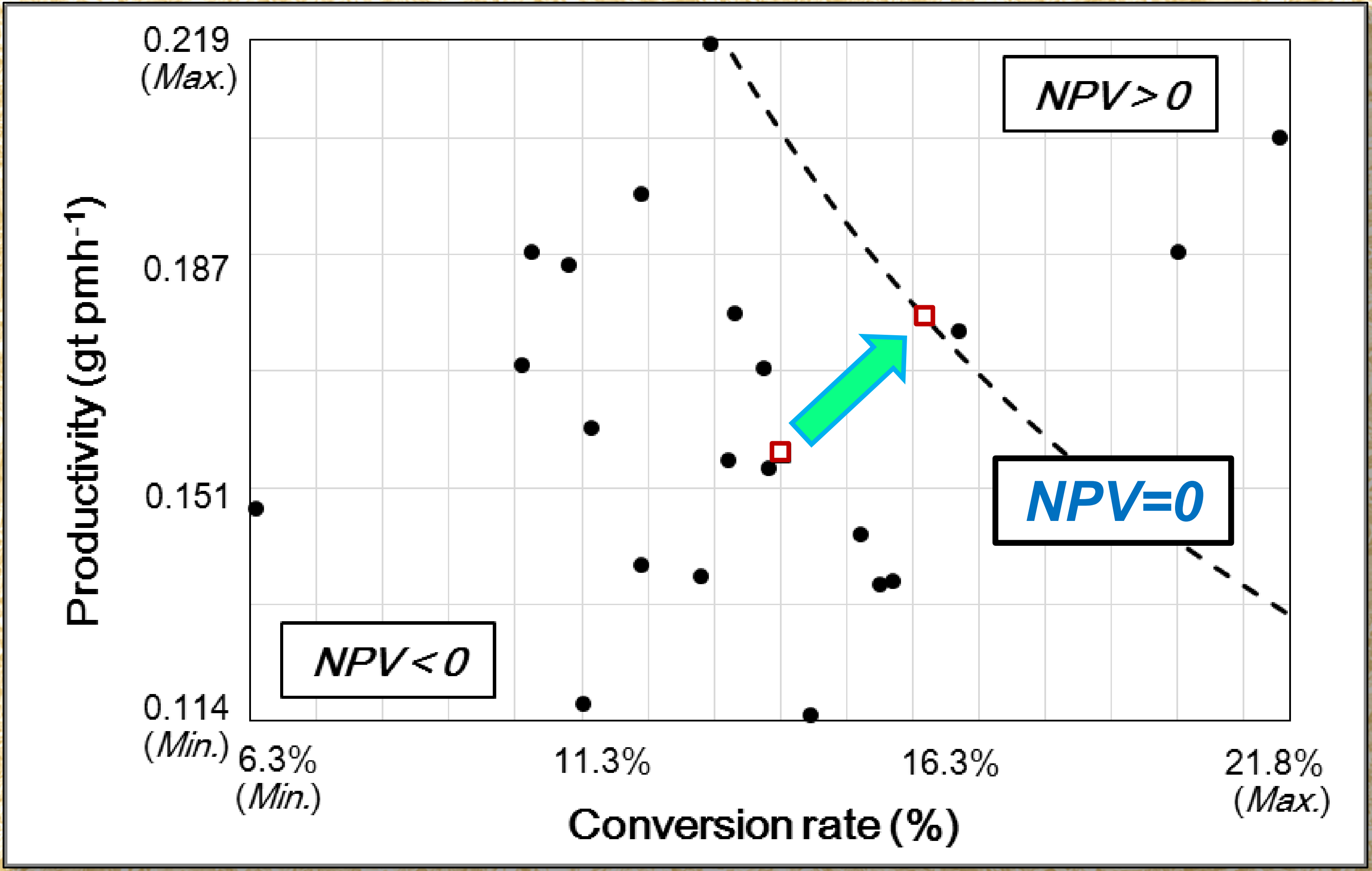
| Metric | Feedstock Preparation | | | Pyrolysis | Biochar bagging |
|---|---|---|---|---|---|
| | Grinding | Screening | Loading | | |
| **Machine rate ($ $hr^{-1}$)** | $163.81 | $39.78 | $78.86 | $48.07 | n/a |
| **Productivity (gt $hr^{-1}$)** | 13.61 | 13.61 | 54.43 | 0.156 | n/a |
| **Component cost ($ $gt^{-1}$)** | $12.04 | $2.92 | $1.45 | $308.14 | $65.99 |
| **Cumulative cost ($ $gt^{-1}$)** | $12.04 | →$14.96 | →$16.41 | →$324.55 | →$390.54 |

- Annual cost: $126,597
- Annual revenue from biochar: $101,013
- Annual net revenue: -$ 25,554
- NPV for a **10-year project period**: **-$168,955**

# Results

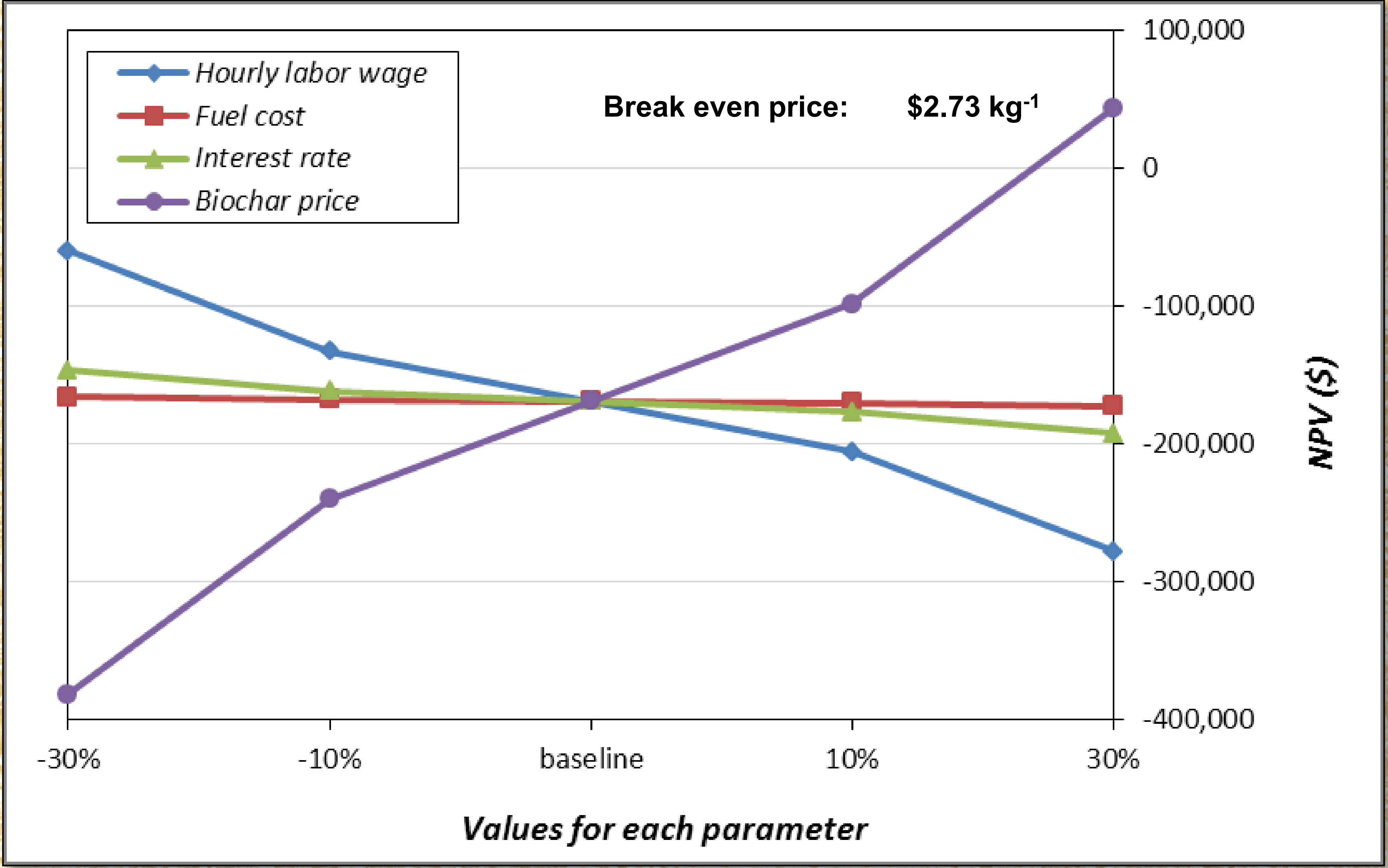

0.219
(Max.)
0.187
0.151
0.114
(Min.)
Productivity (gt pmh-1)
6.3%
(Min.)
11.3%
16.3%
21.8%
(Max.)
Conversion rate (%)
NPV > 0
NPV=0
NPV < 0

# Results



0.219
(Max.)
0.187
0.151
0.114
(Min.)
Productivity (gt pmh-1)
6.3%
(Min.)
11.3%
16.3%
21.8%
(Max.)
Conversion rate (%)
NPV > 0
NPV=0
NPV < 0

# Results



Hourly labor wage
Fuel cost
Interest rate
Biochar price
Break even price: $2.73 kg-1
100,000
0
-100,000
-200,000
-300,000
-400,000
NPV ($)
-30%
-10%
baseline
10%
30%
Values for each parameter

# 2. Larger Operations

**FEEDSTOCK** → **CONVERSION** → **PRODUCTS**

Photo: Colorado Public Radio

Photo: CPES

Photo: Pacific Biochar

Photo: CPES


**<u>Treatment Residues</u>**
Fuel treatment
Beetle salvage
Forest restoration

**<u>Thermochemical pathways</u>**
Combustion heat and power
Gasification and pyrolysis
Catalytic fuel production
Pellet mill

**<u>Mulitple products</u>**
Single outputs
Combinations of products:
Heat, Power, Biochar,
Pellets, Liquid fuel

# Methods

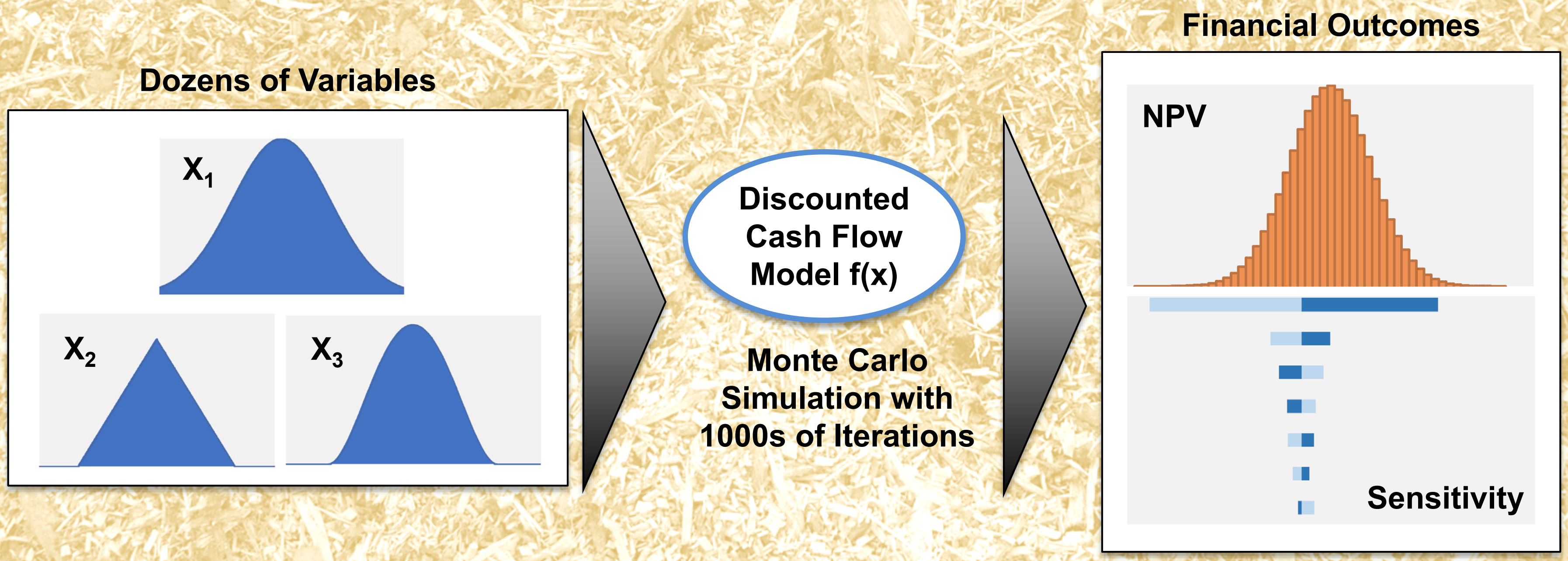
- Techno-Economic Analysis (TEA)
- Detailed technical specifications + financial analysis

## Inputs

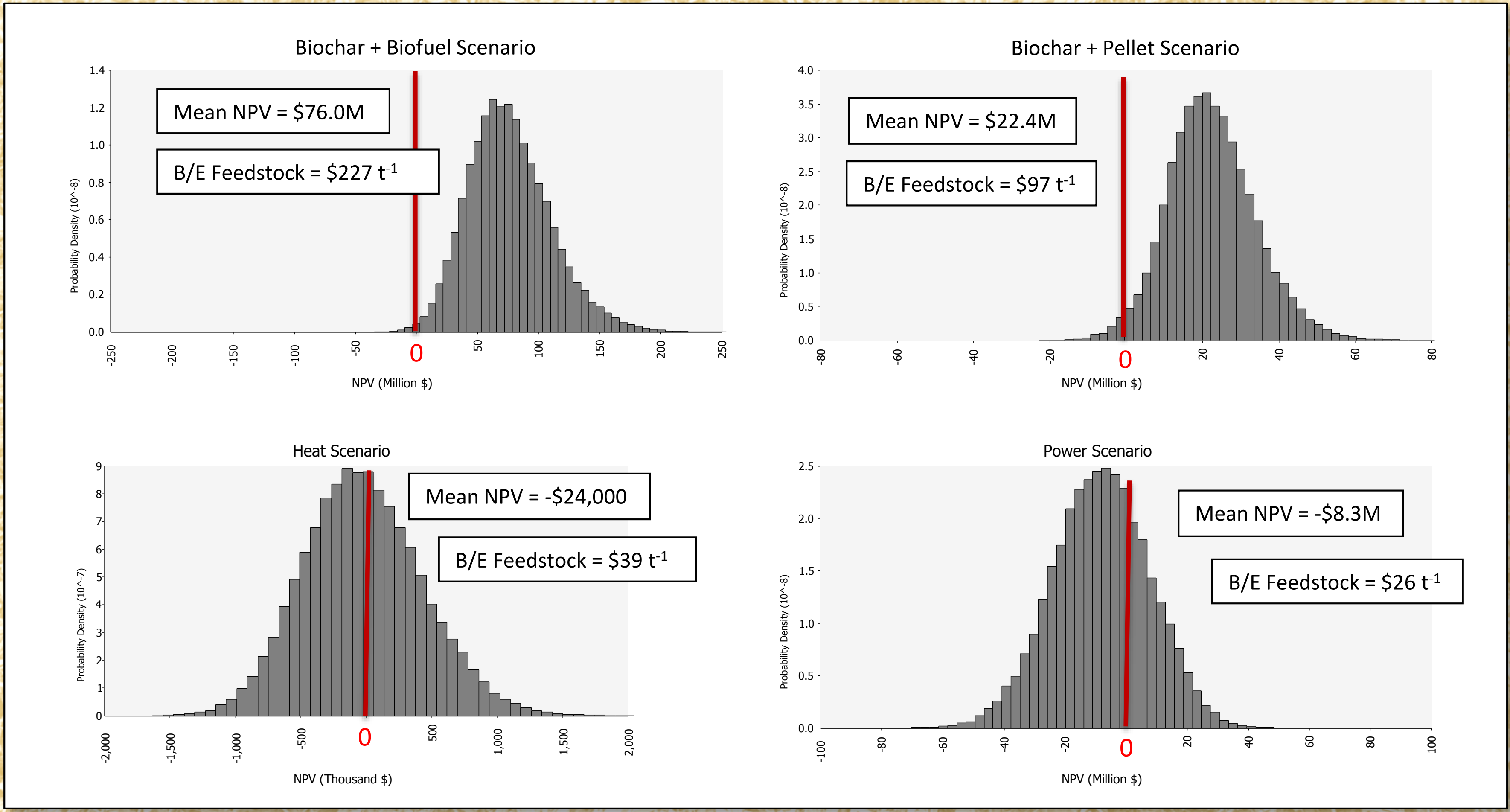
- Engineering specifications
- Production data
- Capital and operating costs
- Other economic variables

## Outputs

- Net Present Value (NPV)
- Breakeven Selling Price
- Max Feedstock Cost

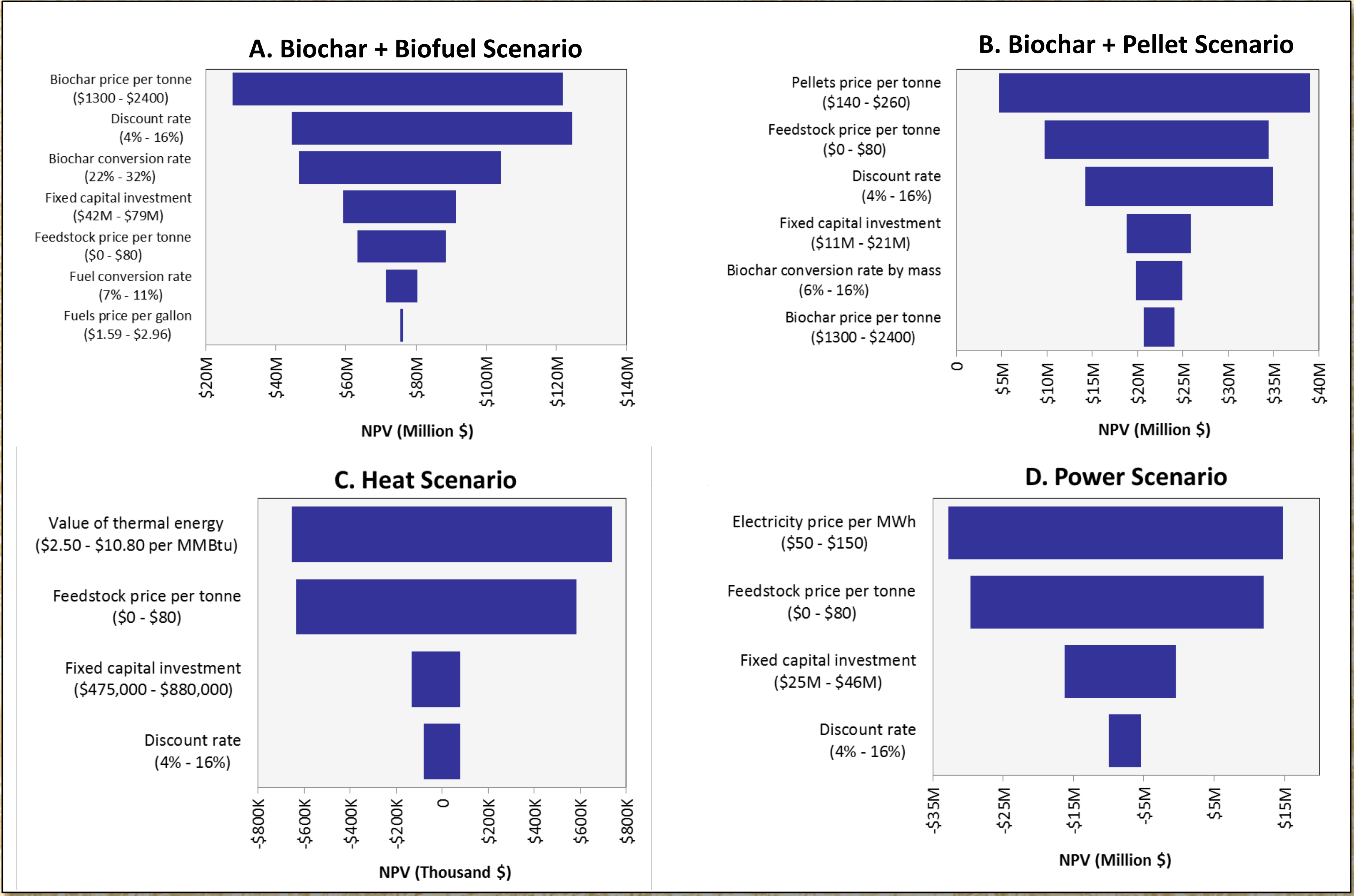


# Results

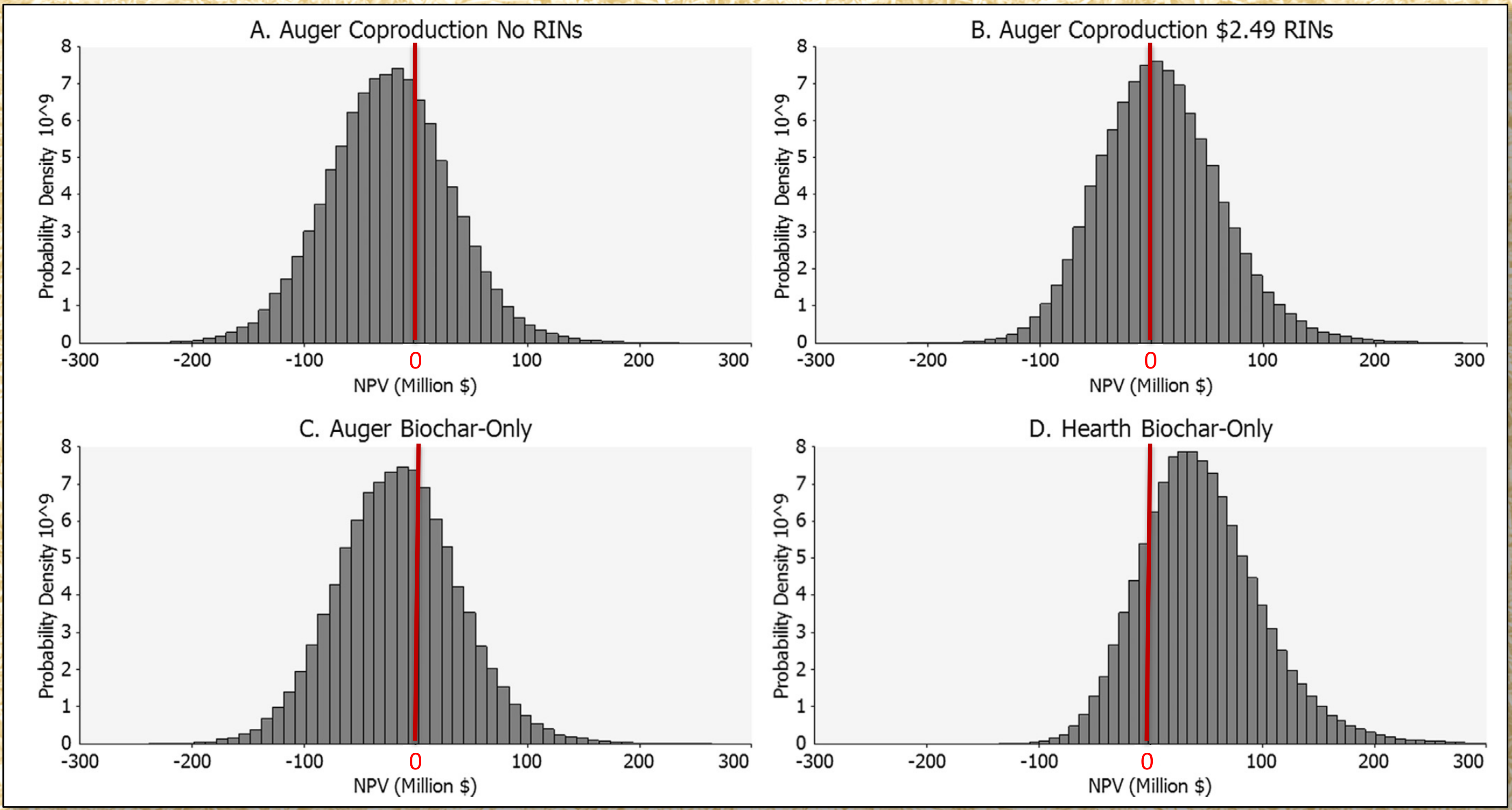


Biochar + Biofuel Scenario
Mean NPV = $76.0M
B/E Feedstock = $227 t-1
Probability Density (10^-8)
NPV (Million $)
0
Biochar + Pellet Scenario
Mean NPV = $22.4M
B/E Feedstock = $97 t-1
Probability Density (10^-8)
NPV (Million $)
0
Heat Scenario
Mean NPV = -$24,000
B/E Feedstock = $39 t-1
Probability Density (10^-7)
NPV (Thousand $)
0
Power Scenario
Mean NPV = -$8.3M
B/E Feedstock = $26 t-1
Probability Density (10^-8)
NPV (Million $)
0

# Results

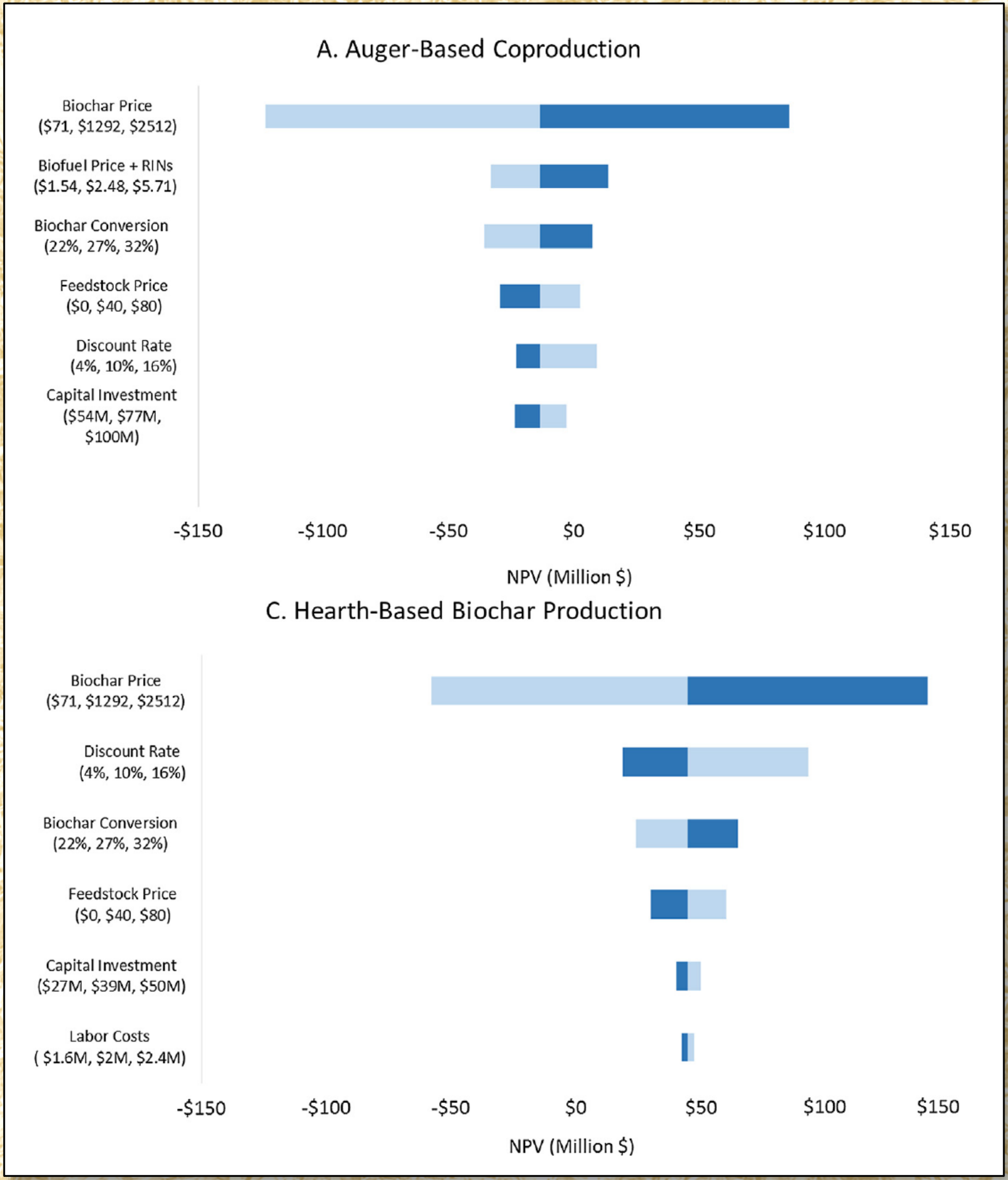

A. Biochar + Biofuel Scenario
Biochar price per tonne ($1300 - $2400)
Discount rate (4% - 16%)
Biochar conversion rate (22% - 32%)
Fixed capital investment ($42M - $79M)
Feedstock price per tonne ($0 - $80)
Fuel conversion rate (7% - 11%)
Fuels price per gallon ($1.59 - $2.96)
$20M $40M $60M $80M $100M $120M $140M
NPV (Million $)
B. Biochar + Pellet Scenario
Pellets price per tonne ($140 - $260)
Feedstock price per tonne ($0 - $80)
Discount rate (4% - 16%)
Fixed capital investment ($11M - $21M)
Biochar conversion rate by mass (6% - 16%)
Biochar price per tonne ($1300 - $2400)
0 $5M $10M $15M $20M $25M $30M $35M $40M
NPV (Million $)
C. Heat Scenario
Value of thermal energy ($2.50 - $10.80 per MMBtu)
Feedstock price per tonne ($0 - $80)
Fixed capital investment ($475,000 - $880,000)
Discount rate (4% - 16%)
-$800K -$600K -$400K -$200K 0 $200K $400K $600K $800K
NPV (Thousand $)
D. Power Scenario
Electricity price per MWh ($50 - $150)
Feedstock price per tonne ($0 - $80)
Fixed capital investment ($25M - $46M)
Discount rate (4% - 16%)
-$35M -$25M -$15M -$5M $5M $15M
NPV (Million $)

# Results



A. Auger Coproduction No RINs
B. Auger Coproduction $2.49 RINs
C. Auger Biochar-Only
D. Hearth Biochar-Only
Probability Density 10^9
NPV (Million $)
0
8
7
6
5
4
3
2
1
-300
-200
-100
100
200
300

# Results


A. Auger-Based Coproduction
Biochar Price
($71, $1292, $2512)
Biofuel Price + RINs
($1.54, $2.48, $5.71)
Biochar Conversion
(22%, 27%, 32%)
Feedstock Price
($0, $40, $80)
Discount Rate
(4%, 10%, 16%)
Capital Investment
($54M, $77M, $100M)
-$150
-$100
-$50
$0
$50
$100
$150
NPV (Million $)
C. Hearth-Based Biochar Production
Biochar Price
($71, $1292, $2512)
Discount Rate
(4%, 10%, 16%)
Biochar Conversion
(22%, 27%, 32%)
Feedstock Price
($0, $40, $80)
Capital Investment
($27M, $39M, $50M)
Labor Costs
( $1.6M, $2M, $2.4M)
-$150
-$100
-$50
$0
$50
$100
$150
NPV (Million $)

# 3. Value Added Operations

**FEEDSTOCK** → **CONVERSION** → **PRODUCTS**

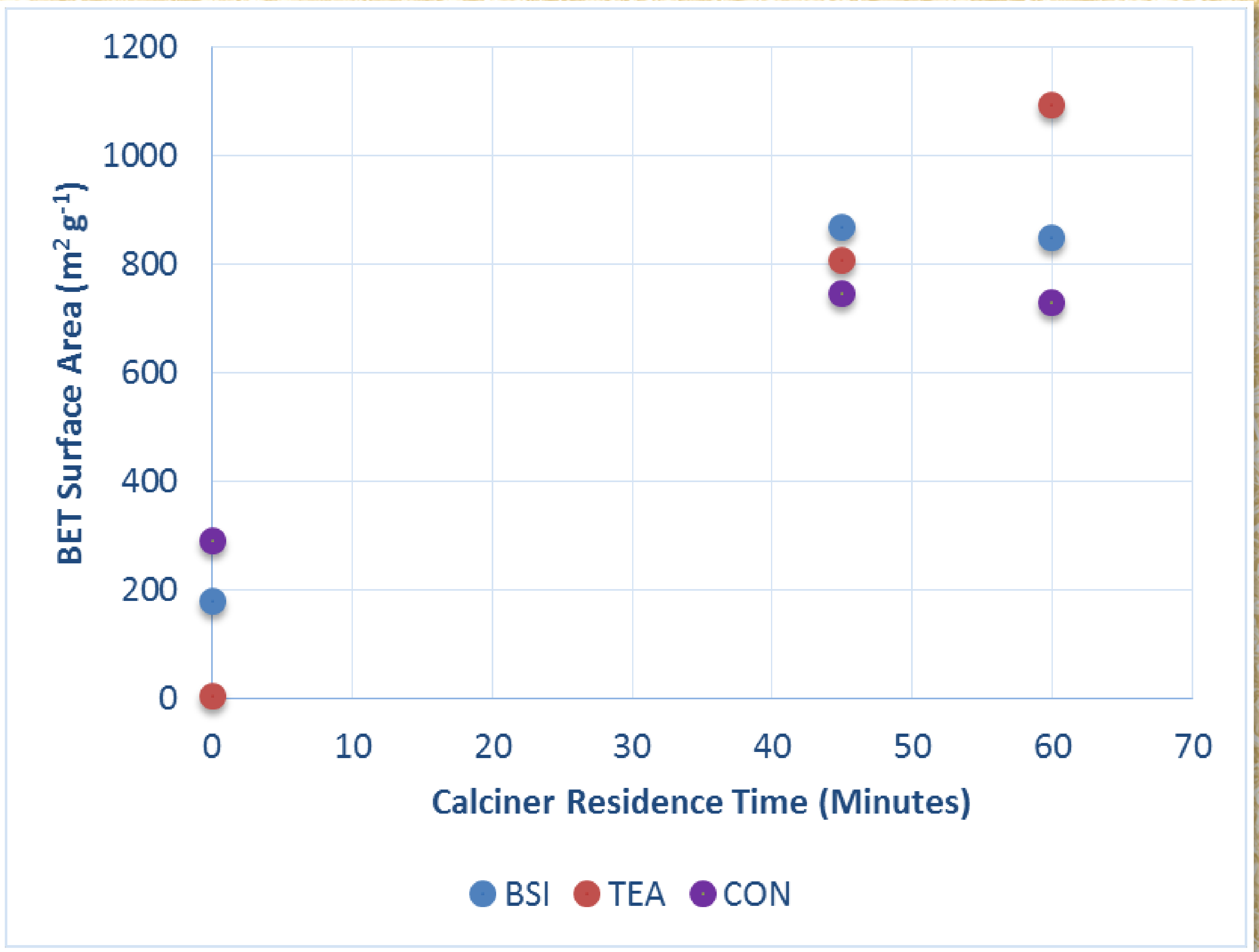


**<u>Logging & Mill Residues</u>**
Mixed western conifer
Screened

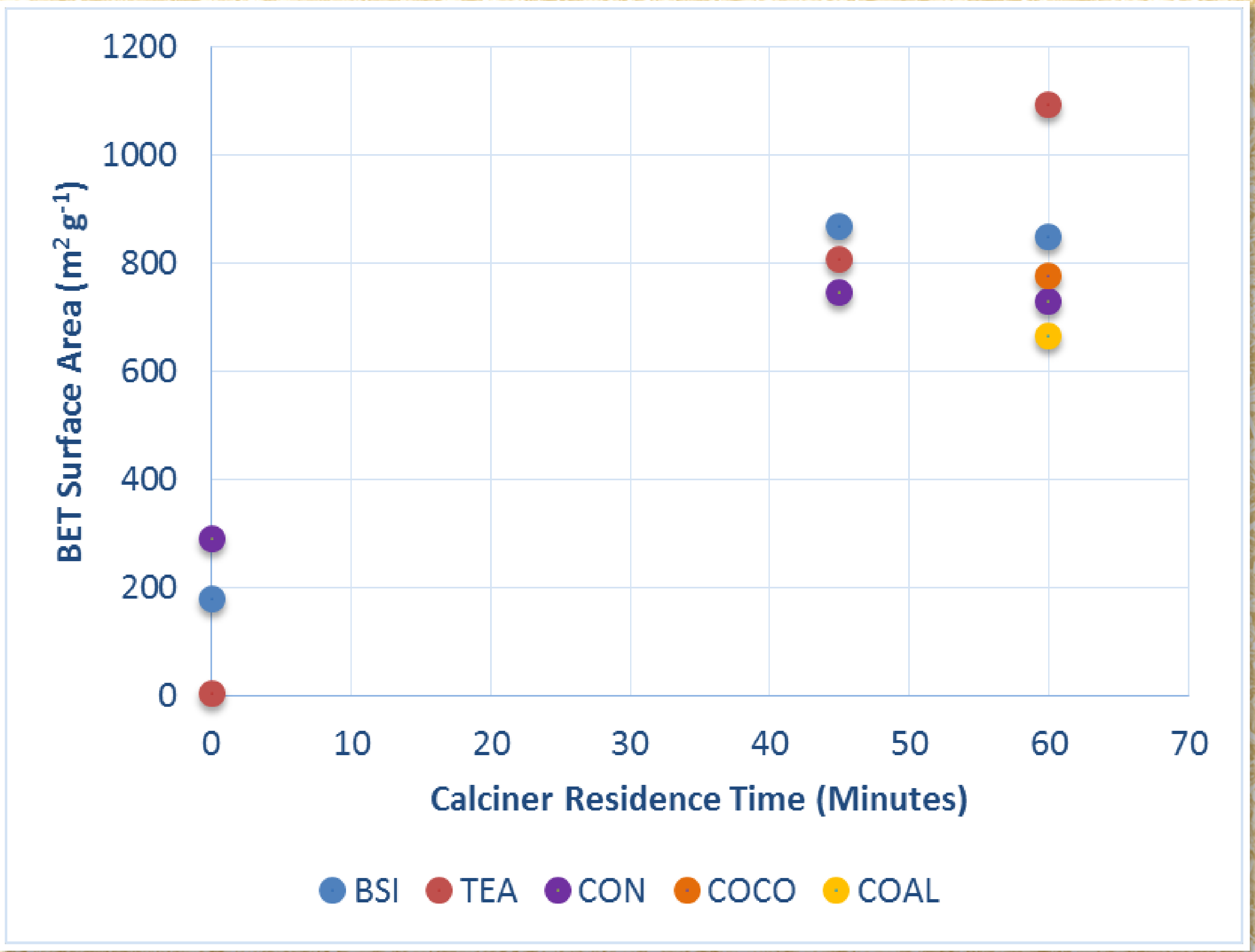
**<u>Thermochemical Conversion</u>**
3 different systems:
Confluence Energy (CON)
Biochar Solutions, Inc. (BSI)
Tucker Engineering Associates (TEA)

**<u>Activated Carbon</u>**
RBS industrial rotary calciner
3 biochar precursors
Steam injection with N purge
Temperature: 927 °C
45 min and 65 min trials

# Results: BET Surface Area

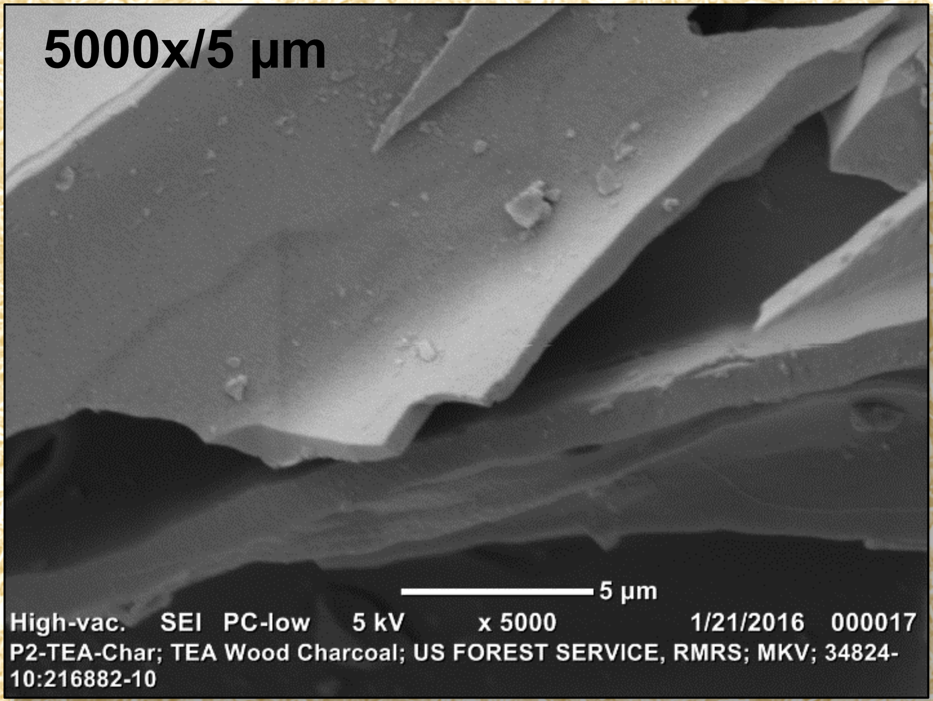


# Results: BET Surface Area

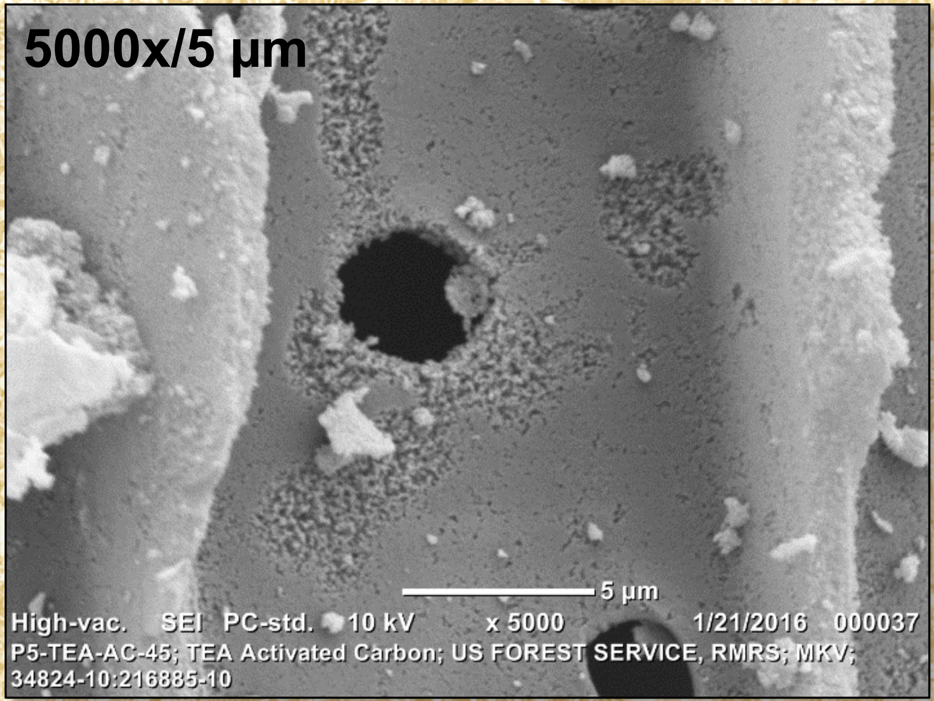


# Results

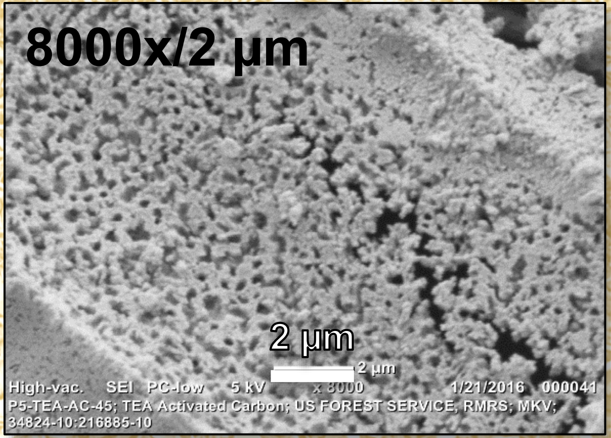
## Biochar



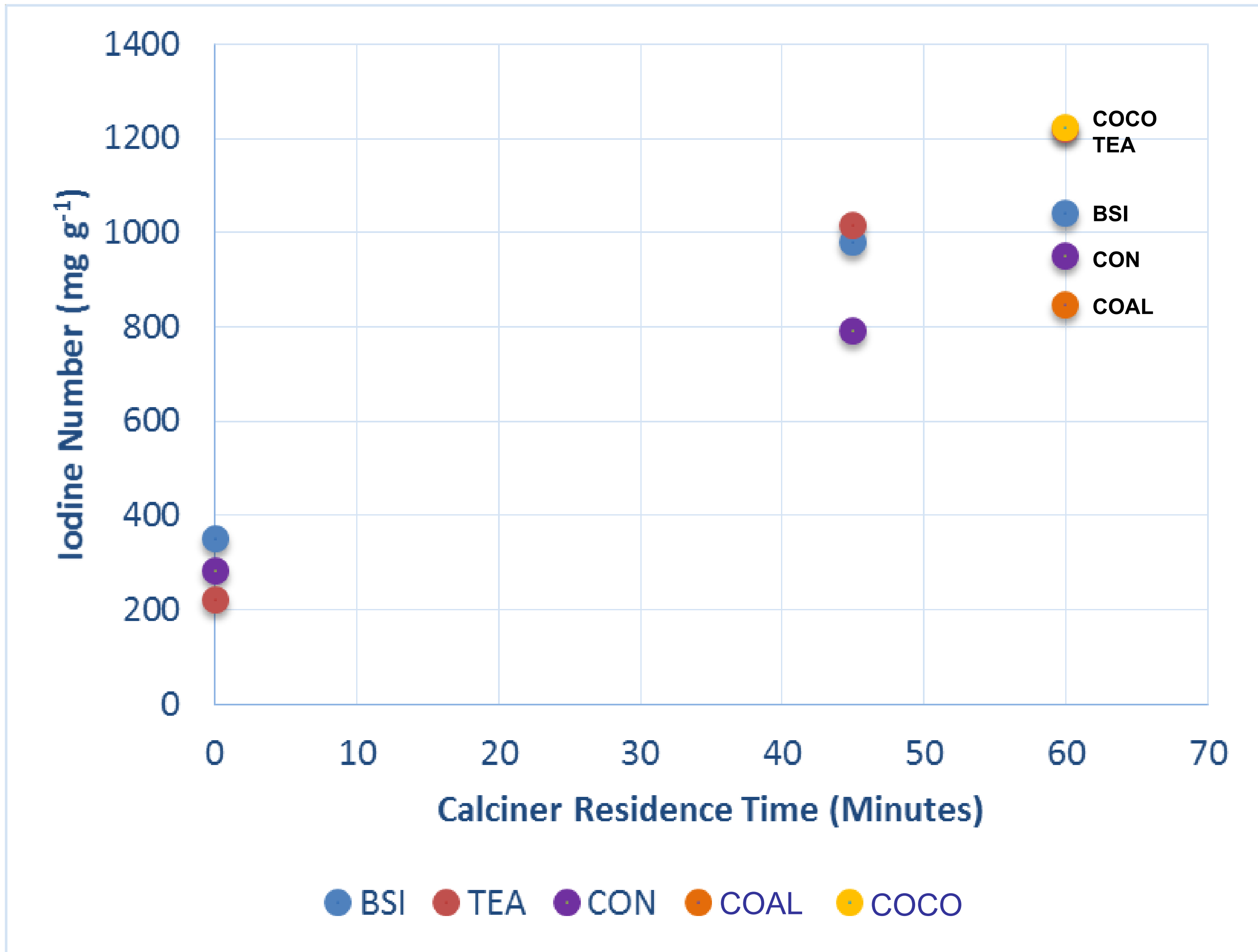

## Activated Carbon



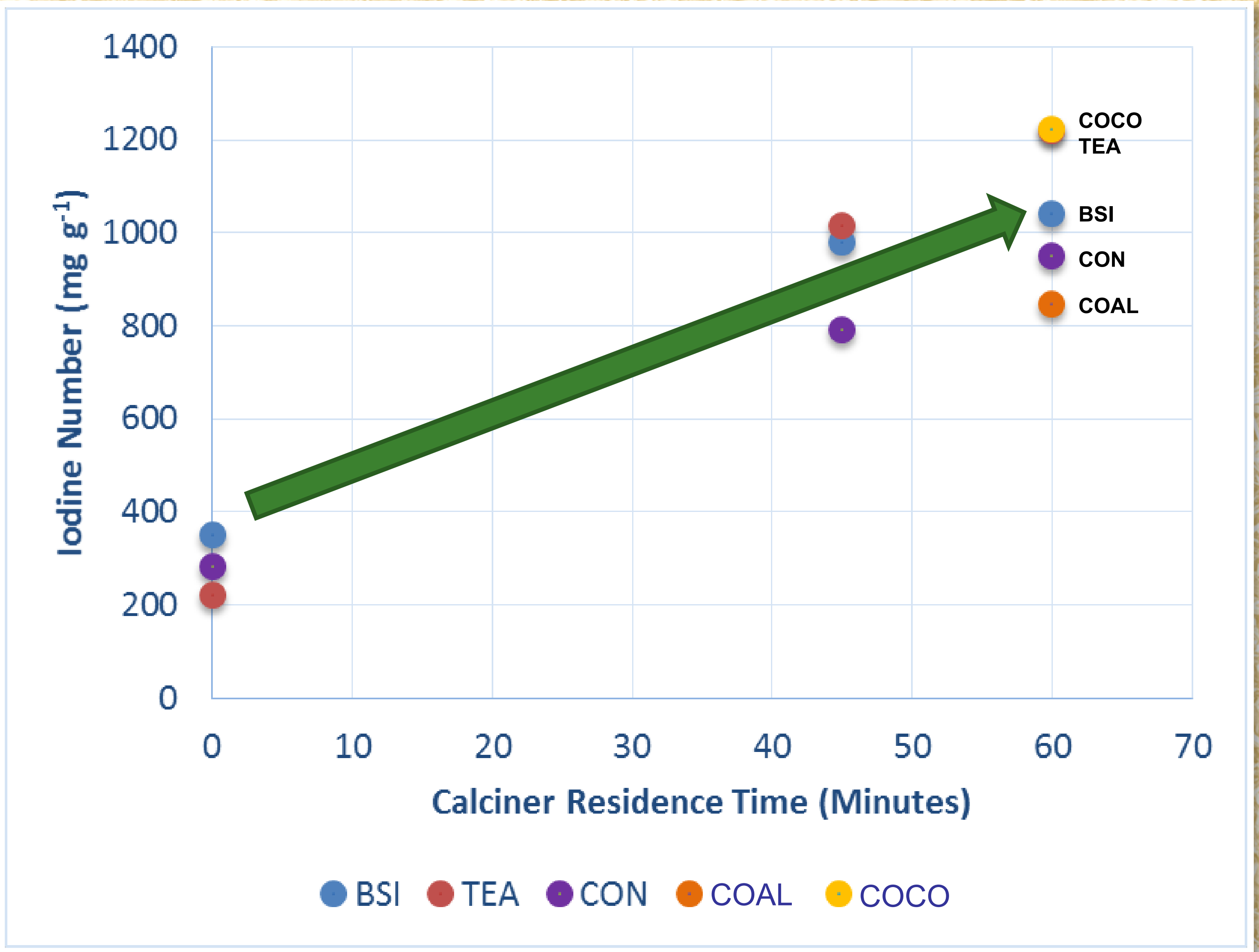

| TEA AC-60m | |
|---|---|
| BET SA: | 1093 $m^2g^{-1}$ |
| C/FC: | 92%/90% |
| I #: | 1218 mg $g^{-1}$ |



# Results: Iodine Number



# Results: Iodine Number



# Take Home Messages

More profitable operations

- High conversion efficiency
  - Increased productivity and conversion rate
  - Appropriate scale and system balance
  - Better quality feedstock (e.g. moisture, ash, etc.)
- Multi-product supply chains
- Higher and more stable prices for outputs
  - Heat and gas value
  - Biochar product and market development
  - High fuel prices
  - Public policy (e.g. RINs)

# For More Information


**Economics and Manufacturing**

Anderson, N.; Bergman, R.; Page-Dumroese, D. 2017. A supply chain approach to biochar systems. Chapter 2 in: *Biochar: A Regional Supply Chain Approach in View of Climate Change Mitigation.* Cambridge, UK: Cambridge University Press. p. 25-45.

Campbell, R.; Anderson, N. In review. Comprehensive economic evaluation of woody biomass energy from silvicultural fuel treatments. *Journal of Environmental Management*.

Campbell, R.; Anderson, N.; Daugaard, D.; Naughton, H. 2018. Technoeconomic and policy drivers of project performance for bioenergy alternatives using biomass from beetle-killed trees. *Energies* 11(2): 293, 20 pp.

Campbell, R.; Anderson, N.; Daugaard, D.; Naughton, H. 2018. Financial viability of biofuel and biochar production from forest biomass in the face of market price volatility and uncertainty. *Applied Energy* 230, pp.330-343.

Kim, D.; Anderson, N.; Chung, W. 2015. Financial performance of a mobile pyrolysis system used to produce biochar from sawmill residues. *Forest Products Journal* 65(5/6): 189-197.

# For More Information

**Products and Life Cycle Assessment**

Bergman, R.; Gu, H.; Page-Dumroese, D.; Anderson, N. 2017. Life cycle analysis of biochar. Chapter 3 in: *Biochar: A Regional Supply Chain Approach in View of Climate Change Mitigation.* Cambridge, UK: Cambridge University Press. p. 25-45.

Gu, H.; Bergman, R.; Anderson, N.; Alanya-Rosenbaum, S. 2018. Life cycle assessment of activated carbon from woody biomass. *Wood and Fiber Science* 50(3): 229-243.

Jarvis, J.; Page-Dumroese, D.; Anderson, N.; Corilo, Y.; Rodgers, R. 2014. Characterization of fast pyrolysis products generated from several western USA woody species. *Energy & Fuels* 28(10): 6438-6446.

Anderson, N.; Jones, J.G.; Page-Dumroese, D.; McCollum, D.; Baker, S.; Loeffler, D.; Chung, W. 2013. A comparison of producer gas, biochar, and activated carbon from two distributed scale thermochemical conversion systems used to process forest biomass. *Energies* 6: 164-183.

# Contact Information

Nate Anderson, Research Forester
Rocky Mountain Research Station
Missoula, MT, USA
nathaniel.m.anderson@usda.gov
(406) 329-2122

QUESTIONS?

# Additional slides for questions if needed.

# Methods

- Standard machine rate calculations
- Cost($ gt$^{-1}$)=Machine rate($ pmh$^{-1}$)/Productivity(gt pmh$^{-1}$)
- Feedstock cost: $0, Biochar revenue: $2.20 per kilogram
- Other Assumptions: 8 hrs per day, 260 days per year

| | Grinding | Screening | Loading | Pyrolysis |
|---|---|---|---|---|
| Parameter | Tub grinder | Rotary screener | Wheel loader | BSI mobile U5 beta |
| Purchased price ($) | $350,000 | $50,000 | $205,000 | $350,000 |
| PMH (hr yr$^{-1}$) | 1,664 | 1,664 | 1,664 | 2,080 |
| SMH (hr yr$^{-1}$) | 2,080 | 2,080 | 2,080 | N/A |
| Utilization rate (%) | 80 | 80 | 80 | N/A |
| Machine life (yr) | 7 | 7 | 7 | 10 |
| Salvage (% of price) | 20 | 20 | 20 | 10 |
| Interest (%) | 7 | 7 | 7 | 7 |
| Fuel cost ($ gal$^{-1}$) | $3.21 | $3.21 | $3.21 | N/A |
| Electricity cost ($ kWh$^{-1}$) | N/A | N/A | N/A | $0.0677 |
| Hourly labor wage | $17.89 | $17.89 | $17.89 | $17.89 |
| Labor benefits (%) | 35 | 35 | 35 | 35 |

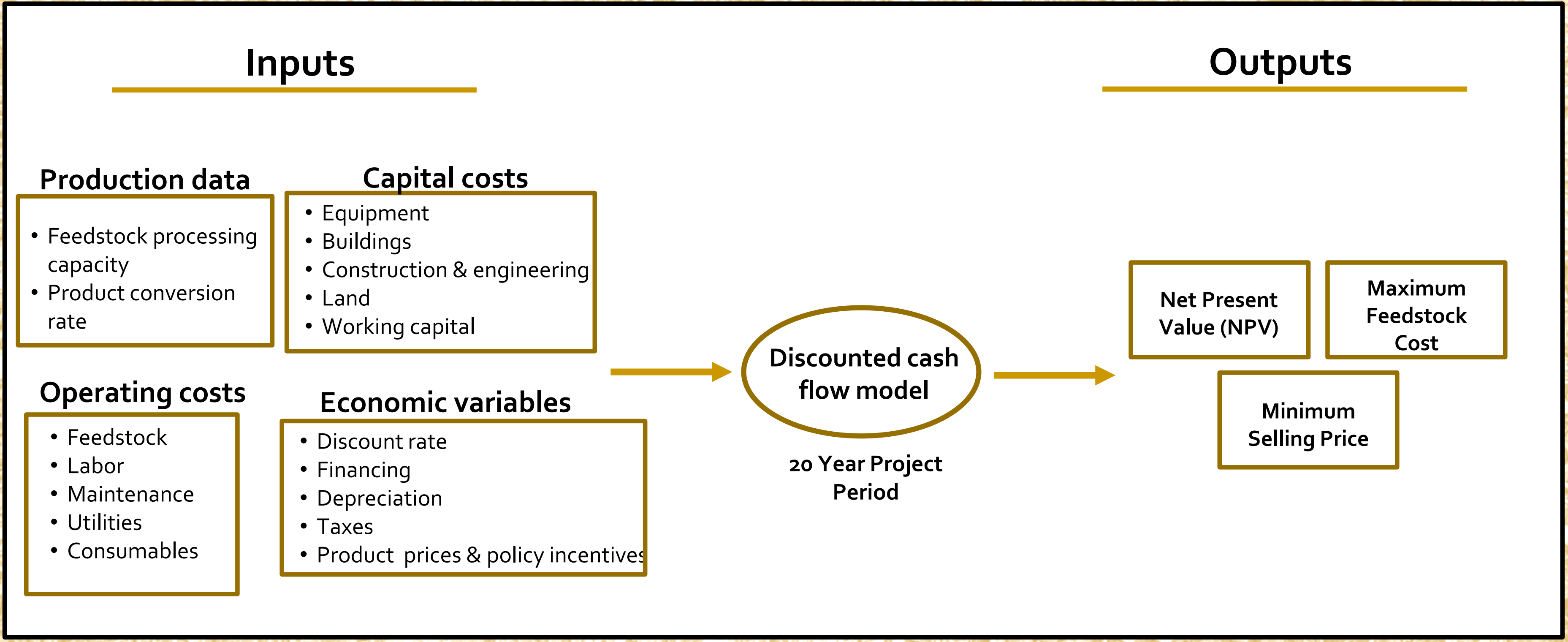
# Results

- Shift-level production

| Metrics | | Work hours (h) | Delay (h) | Productive hours (h) | Feedstock consumption (gt) | Biochar production (t) |
|---|---|---|---|---|---|---|
| **Total** | | **167.03** | **31.35** | **135.68** | **21.183** | **2.993** |
| Shift-level | Mean | 7.59 | 1.43 | 6.17 | 0.963 | 0.136 |
| | Min. | 3.75 | 0.00 | 2.23 | 0.219 | 0.041 |
| | Max | 10.23 | 5.30 | 9.20 | 1.433 | 0.285 |

# Methods

- Detailed Inputs



# Text

- Random variables

**Table 4**
Summary of inputs with uncertainty distributions.

| Variable | Minimum | Base-case | Maximum | Distribution | Source |
|---|---|---|---|---|---|
| Discount rate | 4% | 10% | 16% | Triangular | Petter and Tyner [12] |
| Biofuel price | $1.54 gal$^{-1}$ | $2.48 gal$^{-1}$ | $3.22 gal$^{-1}$ | Triangular | Table 5 |
| Biochar price | $ 71 t$^{-1}$ | $1292 t$^{-1}$ | $2,512 t$^{-1}$ | Pert | Table 1 |
| Feedstock price | $0 t$^{-1}$ | $40 t$^{-1}$ | $80 t$^{-1}$ | Triangular | U.S. DOE [5] |
| Capital investment | −30% | Scenario-specific | +30% | Triangular | Peters et al. [40] |
| Biochar conversion rate | 22% | 27.4% | 32% | Triangular | Industry Partners |
| Biofuel conversion rate | 7% | 9.3% | 11% | Triangular | Industry Partners |
| Natural gas costs | −54% | Scenario-specific | +54% | Triangular | Described in text |
| Labor costs | −17.5% | Scenario-specific | +17.5% | Triangular | Described in text |
| Loan financing | 0% | 50% | 100% | Triangular | Described in text |

# Results

- TEA Input Pricing

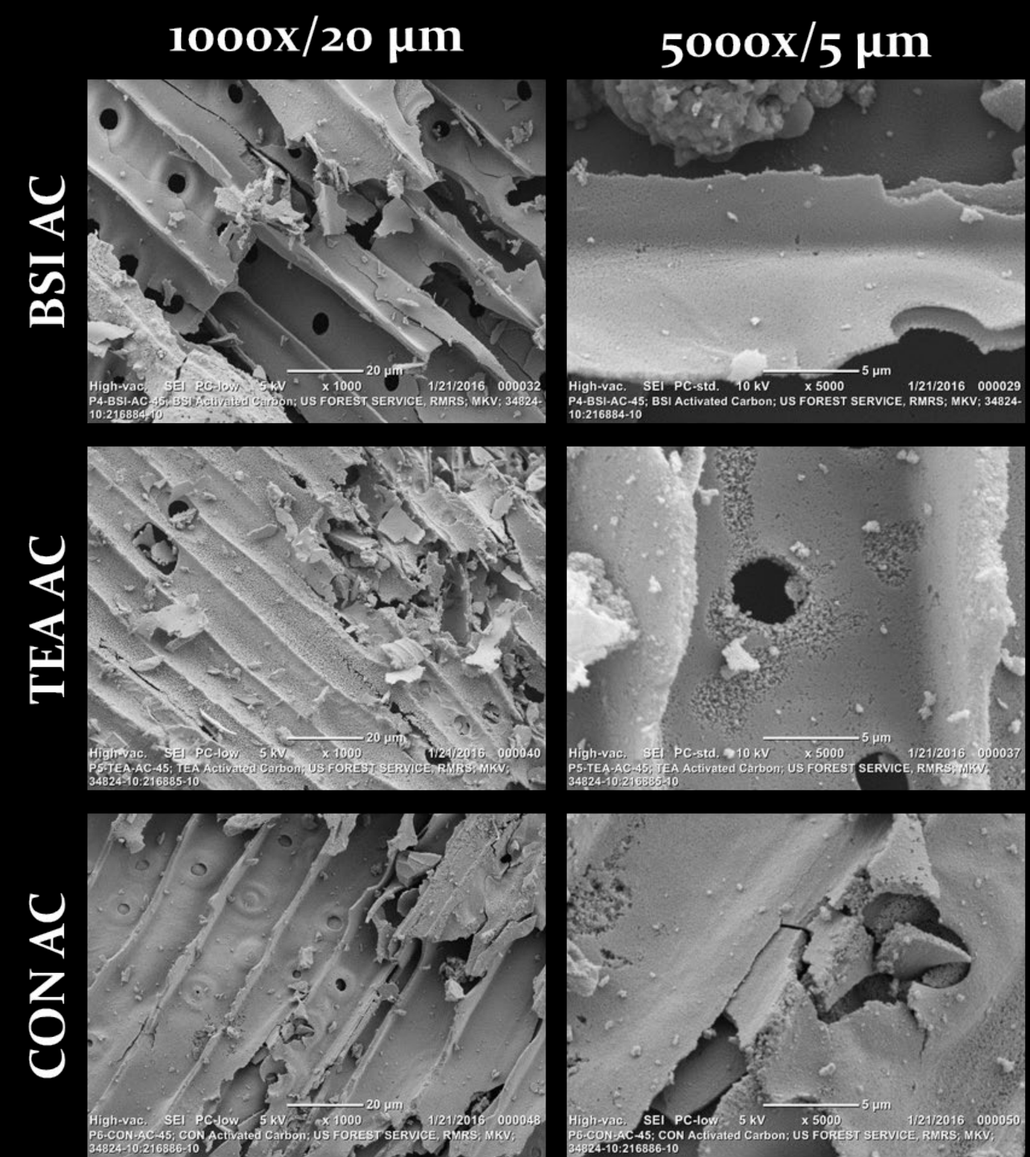
| Variable | Minimum | Base-Case | Maximum |
|---|---|---|---|
| **Pellets price** | $178 $t^{-1}$ | **$200 $t^{-1}$** | $222 $t^{-1}$ |
| **Biochar price** | $899 $t^{-1}$ | **$1,834 $t^{-1}$** | $2,778 $t^{-1}$ |
| **Electricity price** | $50 $MWh^{-1}$ | **$100 $MWh^{-1}$** | $150 $MWh^{-1}$ |
| **Biofuel price** | $1.59 $gal^{-1}$ | **$2.36 $gal^{-1}$** | $2.96 $gal^{-1}$ |
| **Heat price** | $2.52 $MMBtu^{-1}$ | **$5.35 $MMBtu^{-1}$** | $10.83 $MMBtu^{-1}$ |
| **Feedstock price** | $0 $t^{-1}$ | **$40 $t^{-1}$** | $80 $t^{-1}$ |

# Assumptions

Financial accounting assumptions.

| Parameter | Input Value | Source |
|---|---|---|
| Nominal discount rate | 7.5% | Petter and Tyner [12] |
| Inflation rate | 2.5% | Petter and Tyner [12] |
| Loan interest rate | 8% APR | Zhao et al. [10] |
| Loan term | 10 years | Zhao et al. [10] |
| Federal income tax rate | 21% | United States Congress [56] |
| Plant life | 20 years | Wright et al. [57] |
| Depreciation | Variable declining balance (MACRS)<br>7 year period | Peters et al. [40] |
| Construction spending | | Zhao et al. [10] |
| Year 1 | 8% of FCI and land | |
| Year 2 | 60% of FCI | |
| Year 3 | 32% of FCI and working capital | |

# Results




| BSI AC-60m | |
|---|---|
| BET SA: | 847 $m^2g^{-1}$ |
| C/FC: | 89%/86% |
| I #: | 1040 mg $g^{-1}$ |

| TEA AC-60m | |
|---|---|
| BET SA: | 1093 $m^2g^{-1}$ |
| C/FC: | 92%/90% |
| I #: | 1218 mg $g^{-1}$ |

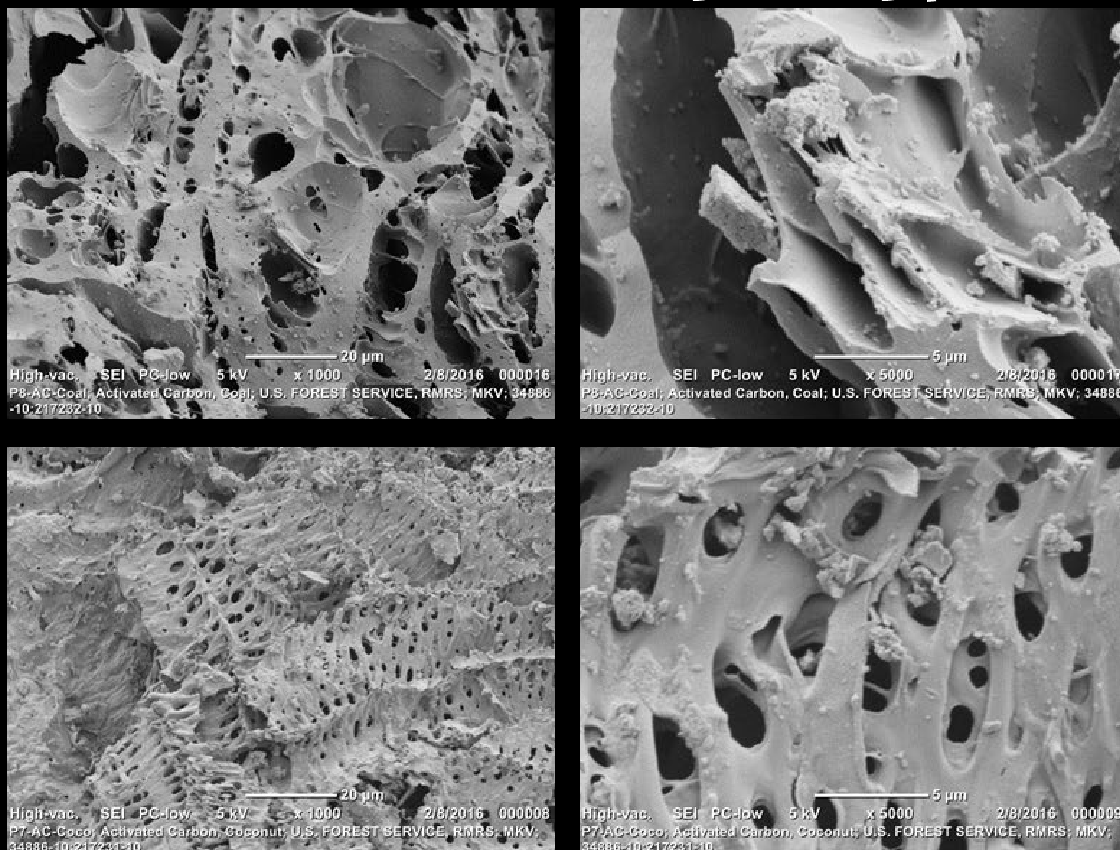
| CON AC-60m | |
|---|---|
| BET SA: | 730 $m^2g^{-1}$ |
| C/FC: | 94%/85% |
| I #: | 951 mg $g^{-1}$ |

# Results

1000x/20 µm | 5000x/5 µm

Coal AC

Coconut AC




| Coal AC | |
|---|---|
| BET SA: | 666 $m^2g^{-1}$ |
| C/FC: | 86%/87% |
| I #: | 847 mg $g^{-1}$ |

| Coconut AC | |
|---|---|
| BET SA: | 776 $m^2g^{-1}$ |
| C/FC: | 96%/97% |
| I #: | 1223 mg $g^{-1}$ |

**Two commercially available activated carbons marketed for water filtering applications.**