Life Cycle Assessment and Economics of Torrefied Biomass

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August 9, 2017

For more information please visit WasteToWisdom.com
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
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.

- 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
Torrefied biomass is produced by heating to 250 – 320°C 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

- 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

Torrefaction

Produce high quality solid biofuel
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

Diagram:
- Goal definition
- Scope definition
- Inventory analysis
- Impact Assessment
- Interpretation
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

Chipper
Screener
Dryer

Torrefier
Briquetter

Nontorrefied briquette (NTB)
Torrefied briquette (TOB)

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%

<table>
<thead>
<tr>
<th>Properties</th>
<th>TOB</th>
<th>NTB</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC, % wb</td>
<td>0.6</td>
<td>8.3</td>
</tr>
<tr>
<td>Ash Content %, db</td>
<td>2.5</td>
<td>3.4</td>
</tr>
<tr>
<td>VM %, db</td>
<td>71</td>
<td>81</td>
</tr>
<tr>
<td>HHV, MJ/kg wb</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>Durability %</td>
<td>93</td>
<td>85</td>
</tr>
</tbody>
</table>
0.16 MJ of fossil fuel consumed to generate 1 MJ of torrefied briquette
Process Contribution to Global Warming Impact—nontorrefied briquette (NTB)

1 kWh NTB

- Feedstock procurement: 1%
- Chipping: 3%
- Screening: 1%
- Drying: 20%
- Briquetter: 1%
- Distribution: 9%
- Grinding at power plant: 64%
- Combustion: 1%
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

- Feedstock procurement
- Chipper
- Screen
- Dryer
- Torrefier
- Briquetter
- Distribution
- Grinding at power plant
- Combustion
- Pile and Burn

Graph showing contributions to various environmental impacts from different processes.
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")

Ability to Co-fire with coal
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 = $25.68/BDT (with loader)
Productivity = 14.25 BDT/PMH

Star screen (Peterson Pacific)
Machine rate = $22.09/PMH (with loader)
Productivity = 28.50 BDT/PMH

Loader machine rate = $6.10/BDT
Chip cost = $11.10/BDT
» Deck screen (Peterson Pacific)
  Machine rate = $25.68/BDT (with loader)
  Productivity = 14.25 BDT/PMH

Star screen (Peterson Pacific)
  Machine rate = $22.09/PMH (with loader)
  Productivity = 28.50 BDT/PMH

Sawdust machine (Beaver Korea)
  Estimated machine rate = $22.66/BDT (w/loader)
  Productivity = 6.75 BDT/PMH (15 GT/hour w/no downtime)

Loader machine rate = $6.10/BDT
Chip cost = $11.10/BDT
Deck screen (Peterson Pacific)
  Machine rate = $25.68/BDT (with loader)
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Loader machine rate = $6.10/BDT
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Microchipper (Peterson 4300)
  Machine rate = $17.54/BDT (w/loader)
  Productivity = 37.21 BDT/PMH

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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Loader machine rate = $6.10/BDT
Chip cost = $11.10/BDT

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?

It depends...

Torrefied

Not torrefied
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

**Overall project assumptions**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project planning life</td>
<td>10 years</td>
</tr>
<tr>
<td>Standard operating days/year</td>
<td>250</td>
</tr>
<tr>
<td>Standard daily operating hours</td>
<td>8.0</td>
</tr>
<tr>
<td>Cost inflation rate</td>
<td>1.0%</td>
</tr>
<tr>
<td>Revenue inflation rate</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

**Project planning life**

- 10 years

**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  |

**Project financing**

| Required minimum 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 (years)                                               | 6.00   |
| Loan and deposit payments per year                              | 12     |
| Working capital required as a percentage of next year’s sales  | 2.0%   |

**Capital assets**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depreciation code</td>
<td>DB</td>
</tr>
<tr>
<td>Terminal asset value multiplier</td>
<td>100%</td>
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</table>

**Fixed operating costs**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>General administration ($/year)</td>
<td>$6,000</td>
</tr>
<tr>
<td>Administration staff (number)</td>
<td>0.25</td>
</tr>
<tr>
<td>Administration staff salaries ($/person/year)</td>
<td>$80,000</td>
</tr>
<tr>
<td>Site lease ($/year)</td>
<td>-</td>
</tr>
<tr>
<td>Equipment lease ($/year)</td>
<td>-</td>
</tr>
<tr>
<td>Annual insurance percent</td>
<td>1.6%</td>
</tr>
<tr>
<td>Other annual fixed costs ($/year)</td>
<td>-</td>
</tr>
</tbody>
</table>

**Conversion variables**

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

**Taxes**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income tax rate</td>
<td>40.0%</td>
</tr>
<tr>
<td>Tax losses or net tax credits are...</td>
<td></td>
</tr>
<tr>
<td>Biomass utilization tax credit</td>
<td>$ -</td>
</tr>
<tr>
<td>Ad valorem (property) tax mill rate</td>
<td>-</td>
</tr>
</tbody>
</table>
## Results

### Summary Financial Measures:

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

Product price assumption = $225/BDT, delivered
Cost breakdown: Before-finance & tax

- Capital assets (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 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?

Webinar Info at: http://www.wastetowisdom.com/webinars/
General Contact Info at: http://www.wastetowisdom.com/contact-us/

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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**

<table>
<thead>
<tr>
<th></th>
<th>Before-finance &amp; tax</th>
<th>Before-tax</th>
<th>After-tax</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NPV ($000)</strong></td>
<td>$ (807)</td>
<td>$ (805)</td>
<td>$ (490)</td>
</tr>
<tr>
<td><strong>Nominal IRR</strong></td>
<td>-24.6%</td>
<td>-29.3%</td>
<td>-19.2%</td>
</tr>
<tr>
<td><strong>Real IRR (adjusted by cost inflation at 1.0%)</strong></td>
<td>-25.4%</td>
<td>-30.0%</td>
<td>-20.0%</td>
</tr>
</tbody>
</table>

**NOTE:** Nominal discount rates used to calculate NPVs and B-E values (Assuming 1.0% cost inflation, 1.0% revenue inflation, and 40.0% gearing at 6.00%)

- **Break-even avg. torrefied product value ($/ton)**: $339
- **Break-even delivered yr. 1 feedstock cost ($/green ton)**: $341
- **Medium-term operating B-E avg. product value ($/ton)**: $257
- **Short-term operating B-E avg. product value ($/ton)**: $213

**IRR seed = -50%**