Economics of Torrefaction Plants with Integrated Ethanol and Coal Power Plants

ICER13
Seoul, Korea
August 27, 2013
Douglas G. Tiffany
Assistant Extension Professor
ACKNOWLEDGEMENTS

• This research was supported by the Initiative for Renewable Energy and the Environment.
• Torrsys, a subsidiary of Bepex, was the source of most of our torrefaction costs of production.
• Nalladurai Kaliyan and Vance Morey of BBE worked on the engineering and life cycle analysis.
• This project utilizes business modeling designed by Carrie Johnson of ApEc. Doug Tiffany and Won Fy Lee performed additional business modeling.
Today’s Discussion:

• Torrefaction is just starting in N. America to serve European markets and uses to make biofuels.
• Focus on economics for torrefaction plants and the purchasers of their products, which are biocoal, off-gasses or steam from combustion of off-gasses
• Analytical Tools and Assumptions
• Regulations Facing Coal Power Plants
• Modeled Return on Equity (ROE) for Torrefaction Plants, Coal Power Plants and Ethanol Plants Buying Steam from Off-Gasses
• Presentation of Sensitivity Analysis of ROEs of Torref., Power Plants, Ethanol Plants due to Prices of Inputs, Products, Policy Incentives, Penalties
TORREFACTION FOR WOODY OR HERBACEOUS BIOMASS

• Like coffee roasting (in absence of oxygen)
• Roast biomass at (250-320º C) at near zero oxygen to drive off water and VOCs while degrading hemicelluloses to release the heat needed to drive the reaction
• Depending upon initial moisture of biomass, there may be steam available after pre-drying for other purposes or sales.
• Use of inert gases (like CO2), prevents combustion from occurring during roasting phase (15 to 20 minutes)
• Hydrophobic, will not rot or harbor pests like wood pellets, integrates with coal infrastructure, increases energy density
• Brittliness of densified torrefied biomass facilitates grinding at power plants.
• Torrefied biomass can replace coal in combustion or be used as a feedstock for further pyrolysis or gasification.
Mass & Energy Balance of Torrefied Corn Stover

Dry Matter

- 65.6

Energy Content

- 74.5

- 34.4

- 22.5

Lost as off-gas volatiles

biocoal
Schematic of Torrefaction Unit by Agri-Tech
Steps in the Analysis

• Develop spreadsheets to determine costs of converting biomass to biocoal, ethanol plants, coal-fired power plants
• Collect data on delivered biomass and coal costs
• Determine GHG emissions from pulverized coal power plants using various blends of “biocoal”
• Determine ROE of torrefaction plants and plants using products to comply with environmental regulations
• Determine if existing power plants will gradually reduce their GHG emissions by blending torrefied biomass in order to extend their economic lives
# Technical Worksheet for Torrefaction

**Torrefaction Process** by Douglas G. Tiffany 20-Nov-12

University of Minnesota

**Biomass with Sale of Steam**

| Return on Invested Capital | 16.07% |
| Return on Invested Capital (No Steam) | 6.03% |

## Installed Capital Cost

<table>
<thead>
<tr>
<th>Nameplate Annual Output</th>
<th>150,000</th>
<th>Finished Tons</th>
<th>93.2%</th>
<th>Capacity Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Capital Cost</td>
<td>$328.00</td>
<td>per T of Capacity</td>
<td>$34,200,000</td>
<td></td>
</tr>
</tbody>
</table>

## Percent Equity

| Percent Equity | 40% |
| Percent Debt   | 60% |

| Interest Rate Charged on Debt | 6% |

## Operational Parameters

### Dry Matter Remaining

| 70% | BDT/BTD | (60-75%) |

### BTUs used for drying at rate of

| 1200 | BTUs/lb. of Water Removed |

### BTUs Released by facility per hour

| 95,950,000 | from flow of 13,187 |

**Tons of 17% Biomass = 2,873,873 BTUs/T @ 17% Moist.**

### Feedstock Grinding

| 37.8 | kWh/ T Biomass | 166,601.12 | $ 0.07 |

### Torrefaction Reactor Electrical

| 56.25 | kWh/ T BioCoal | 139,800 | $ 0.07 |

### Roll Press Briquetting Electrical

| 8.05 | kWh/ T BioCoal | 139,800.00 | $ 0.07 |

### Natural Gas for Volatile Combustion

| 0.045 | MMBTUs of NG/T Biomass | $ 5.00 |

### Water pumping for BioCoal Quenching

| 0.064 | kWh/ T BioCoal | 139,800 | $ 0.07 |

### Fan Cooling of BioCoal Pellets

| 1.091 | kWh/ T BioCoal | 139,800 | $ 0.07 |

## Revenues

### Biocoal Production

| Biocoal Production | at moisture of 1.10% | 139,800 | K lb of ST/hr | $ 19,572,000 |

### Sale of Biocoal (F.O.B.)

| $140.00 | at moisture of 1.10% | 139,800 |

### BTUs Remaining After Drying

| 95,950,000 | 84,080 | lb. of Steam/hr |

### Steam Price (Per 1,000 lb.)

| $ 5.00 | 8164.32 Hours of Operation |

### Total Revenues

| $ 23,004,276 |

### Delivered Cost of Biomass

| $ 570.00 | at moisture of 17.00% | 166,601.12 |

### Gross Margin

| $ 11,342,197 |

## Operating Costs and Depreciation

### Salaries and Benefits

| Rate/Fin. Ton | $ 4.50 | $ 629,100 |

### General & Administrative

| Rate/Fin. Ton | $ 1.00 | $ 139,800 |

### Maintenance Expenses

| Rate/ Fin. Ton | $ 3.20 | $ 447,360 |

### Natural Gas Expense

| $ 37,485 |

### Electrical Expense

| $ 1,081,369 |

### Interest

| Rate/Fin. Ton | $ 8.81 | $ 1,231,200 |

### Depreciation (SL) for asset life of 15 years

| $ 16.31 | $ 2,280,000 |

### Total Operating Costs and Depreciation

| $ 33.82 | $ 41.82 |

### Net Margin

| $ 11,342,197 |

## Return on Invested Capital

| $ 39.31 | 16.07% |

| $ 14.76 | 6.03% |
Co-located Advantage for Torrefaction

• After cost of biomass, independent torrre. plant may have costs of production of $42 per finished ton.
• With sales of steam, costs of process, $17 per finished T. of biocoal, a $25/T. advantage.
  ▪ Co-located torrefaction plants can enjoy a 16% ROE vs. 6% ROE over independent plants.
• Require 1.7 tons of 17% biomass to yield 1.0 T. of biocoal D.M.
MAJOR FLOWS OF MATERIALS AND ENERGY

Torrefaction Plant

Corn Stover

Wood

Dryer

Biocoal to Power Plant

Volatile Off-Gasses

Steam

Flue Gases to Dry Wood

Coal Power Plant

Ethanol Plant
Life Cycle Assessment (LCA)

• Determination of GHG emissions associated with the production and use....

• Three Businesses:
  • 150,000 ton/year torrefaction plant
  • 100 MM gpy eth plant co-located w/torref. plant
  • Coal power plant co-firing biocoal

• Sources
  • Bepex
  • USDA, ERS model, Aspen Plus
  • Greet Model, Argonne National Lab
Life-Cycle GHG Emissions of Biocoal vs. Coal

Life-Cycle GHG emission of Biocoal compared to Coal

Coal: 110.6 g/MJ
Biocoal: 11.4 g/MJ
Torrefaction + Ethanol Plant Co-location

A 150,000 ton/year torrefaction plant can produce excess heat in the torrefaction off-gas volatiles, which can meet 42.8% of process energy needs in the ethanol plants.

GHG emission of gasoline

GHG emission of conventional ethanol plant relative to Gasoline(%)

GHG emission of ethanol plant with 42.8% energy from Torref.Plant relative to Gasoline(%)

GHG emission of ethanol plant with 100% energy from Torref.Plant relative to Gasoline(%)

100%

65.90%

60.00%

52.10%
GHG Reductions of Coal PP Co-firing Biocoal

- 8.50% at 10%
- 17.10% at 20%
- 25.60% at 30%
- 85.50% at 100%

Biocoal co-firing percentage
Policy Drivers in the U.S.

EPA Regulations under Clean Air Act rules

- Cross-State Air Pollution Rule (CSAPR), July 2011
- Mercury and Air Toxics Standards (MATS), Dec 2011
- Carbon Pollution Standard, March 2012

State Renewable Portfolio Standard (RPS)

- 29 States have policies designed to increase generation of electricity from renewable resources.
- Require supplying minimum shares of electricity from designated renewable resources
Carbon Taxes around the World

<table>
<thead>
<tr>
<th>Country</th>
<th>Carbon Tax (USD/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>$150</td>
</tr>
<tr>
<td>British Columbia, Canada</td>
<td>$30</td>
</tr>
<tr>
<td>Finland</td>
<td>$26</td>
</tr>
<tr>
<td>Ireland</td>
<td>$20</td>
</tr>
<tr>
<td>Denmark</td>
<td>$18</td>
</tr>
<tr>
<td>Australia</td>
<td>$15</td>
</tr>
<tr>
<td>California</td>
<td>$10</td>
</tr>
<tr>
<td>Quebec, Canada</td>
<td>$4</td>
</tr>
<tr>
<td>Japan</td>
<td>$3</td>
</tr>
<tr>
<td>India</td>
<td>$1</td>
</tr>
</tbody>
</table>
2009 Delivered Cost of Coal at Power Plants
$/Ton
(Source: U.S. Dept. of Energy)
## Assumptions Applied in Workbook

<table>
<thead>
<tr>
<th>Ethanol Plants</th>
<th>Torrefaction Plants</th>
<th>Coal Power Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name Plate Capacity</strong></td>
<td><strong>Number of Torrefaction Trains</strong></td>
<td><strong>Name Plate Capacity (MW)</strong></td>
</tr>
<tr>
<td>100 MM gal/yr. Steam Purch. fr. Torr. plant per 1,000 lb.</td>
<td>2</td>
<td>550 MW</td>
</tr>
<tr>
<td><strong>Factor of Equity</strong></td>
<td><strong>Capacity of Torref. Train (T / Yr.)</strong></td>
<td><strong>Capacity factor</strong></td>
</tr>
<tr>
<td>80% Natural Gas Price Purchased MM BTU</td>
<td>150,000 T</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Factor of Debt</strong></td>
<td><strong>Capacity Factor</strong></td>
<td><strong>RPS requirement</strong></td>
</tr>
<tr>
<td>20% Elec. Purchase from Grid per kWh</td>
<td>93.20%</td>
<td>30%</td>
</tr>
<tr>
<td><strong>Interest Rate on Debt</strong></td>
<td><strong>Factor of Equity</strong></td>
<td><strong>REC price ($ per MWh)</strong></td>
</tr>
<tr>
<td>6% Propane Purchase ($ per gallon)</td>
<td>40%</td>
<td>$0</td>
</tr>
<tr>
<td><strong>Depreciation Method Chosen (SL or DDB)</strong></td>
<td><strong>Factor of Debt</strong></td>
<td><strong>Loan Duration</strong></td>
</tr>
<tr>
<td>SL Denaturant Price /gal</td>
<td>60%</td>
<td>30</td>
</tr>
<tr>
<td><strong>Depreciation based on asset life (years)</strong></td>
<td><strong>Interest Rate Charged on Debt</strong></td>
<td><strong>Deprec based on asset life for SL (years)</strong></td>
</tr>
<tr>
<td>15 Denat /100 gal Anhyd.</td>
<td>6%</td>
<td>35</td>
</tr>
<tr>
<td><strong>Ethanol Price (denat. price at plant) $/gal.</strong></td>
<td><strong>Del. Cost of Bioccoal (per ton)</strong></td>
<td><strong>Income Tax Rate</strong></td>
</tr>
<tr>
<td>$2.25 Ethanol Yield (anhydrous gal per bushel)</td>
<td>2.75</td>
<td>38%</td>
</tr>
<tr>
<td><strong>DDGS Price $/T</strong></td>
<td><strong>Deprec. Method Chosen (SL or DDB)</strong></td>
<td><strong>SO₂ Allowance Market Cost (per ton)</strong></td>
</tr>
<tr>
<td>$290.00</td>
<td>SL</td>
<td>$0</td>
</tr>
<tr>
<td><strong>CO₂ Price sold for Food and Industrial Uses</strong></td>
<td><strong>Price of Bioccoal ($ per Ton)</strong></td>
<td><strong>Price of Electricity (Cents per kWh)</strong></td>
</tr>
<tr>
<td>$10.00</td>
<td>$140.00</td>
<td>7 Cents</td>
</tr>
<tr>
<td><strong>Corn Price ($ per bu.)</strong></td>
<td><strong>Delivered Cost of Biomass</strong></td>
<td><strong>Prod Tax Credit (PTC) per kWh Of Renewable Electricity</strong></td>
</tr>
<tr>
<td>$7.00</td>
<td>$70.00</td>
<td>$0.01</td>
</tr>
<tr>
<td><strong>CO₂ Tax</strong></td>
<td><strong>Moisture of Biomass to be Torrefied</strong></td>
<td><strong>CO₂ Tax(per ton)</strong></td>
</tr>
<tr>
<td>$0</td>
<td>17.00%</td>
<td>$0</td>
</tr>
</tbody>
</table>
BASELINE RETURNS ON EQUITY (ROE) OF BUSINESS ENTITIES ANALYZED

Return on Equity (ROE) 5 Year Average

- Ethanol Plant: 7.64%
- Ethanol Plant + Torr. Steam: 7.79%
- Torrefaction Plant: 4.22%
- Torrefaction Plant + Steam: 11.73%
- Coal Power Plant: 12.37%
- Coal Power Plant + Cofiring: 10.68%
ROE of Torrefaction Comparison: By Delivered Cost of Corn Stover

![Bar chart showing ROE comparison between Torrefaction Plant and Torrefaction Plant + Steam. The chart is labeled with cost levels ranging from $30 to $90 and ROE percentages ranging from -15.00% to 20.00%. Baseline at $70.](chart.png)
ROE Comparisons of Torrefaction & Power Plants By Sale Price of Biocoal

Baseline at $140

- Torrefaction Plant
- Torrefaction Plant + Steam
- Coal Power Plant+Cofiring

© 2012 Regents of the University of Minnesota. All rights reserved.
ROE at Torrefaction Plants Selling Steam and Ethanol Plants Buying Steam as Steam Prices Vary with NG price fixed at $5 per Decatherm

-15.00%  -10.00%  -5.00%  0.00%  5.00%  10.00%  15.00%  20.00%  25.00%

$2  $3  $4  $5  $6  $7  $8  $9  $10  $15  $20

Baseline at $5

-15.00%

-10.00%

-5.00%

0.00%

5.00%

10.00%

15.00%

20.00%

25.00%

Ethanol Plant + Torr. Steam  Torrefaction Plant + Steam
ROEs of Ethanol & Coal-fired PPlants: By Price of Carbon Tax

- $0
- $5
- $10
- $15
- $20
- $25
- $30

Baseline at $0

Ethanol Plant
Ethanol Plant + Torr. Steam
Coal Power Plant
Coal Power Plant+Cofiring
CO-LOCATED WOOD TORREFACTION PLANT AND COAL POWER PLANT COMPARED TO BASELINE ROE OF CORN STOVER TORREFACTION AND BIOCOAL USING COAL POWER PLANTS

ROEs of Corn Stover Torrefaction Cases, Wood Co-located Torrefaction, and Coal Power Plants Using Coal, Coal + BioCoal and Coal + BioCoal + VOC

- Torref.P (Corn Stover): 4.22%
- Torref.P (Corn.S+Eth._co-location): 11.73%
- Torref.P (Wood+CPP_co-location): 13.25%
- CPP: 12.37%
- CPP+Cofiring: 10.68%
- CPP+Torref.P Co-location: 9.45%
Conclusions

- Torrefaction economics favor use of dry biomass so that more energy from the volatiles can be put to beneficial use.
- Although biocoal can improve emissions of coal-fired power plants, biocoal will not be used unless price of bituminous coal is higher than the U.S. average price of $68 per delivered ton. NG offers a cheaper alternative than coal for environmental compliance at current NG price.
- High CO2 fees & coal prices > ($100/T.) favor torrefaction adoption.
- Power utilities may try to extend the lives of some of their plants by using biocoal to comply with new laws and state renewable stds.
- Biocoal has more favorable attributes for integration with coal infrastructure than wood pellets because it saves freight and is hydrophobic
- Use of torrefaction on wood and use of flue gases for wood drying represent a favorable co-location scenario.
THANK YOU!

Photo by Andritz, (http://www.andritz.com/se-torrefaction)