Economics of Torrefaction Plants and Businesses Buying Their Products

Heating the Midwest
April 25, 2013
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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 ROEs 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
MAJOR FLOWS OF MATERIALS AND ENERGY

- **Torrefaction Plant**
  - **Wood**
  - **Corn Stover**

- **Ethanol Plant**
- **Biocoal to Power Plant**
  - **Volatile Off-Gasses**
  - **Steam**
- **Coal Power Plant**
TORREFACTION FOR WOODY OR HERBACEOUS BIOMASS

- Roast biomass at (250-320º C) at near zero oxygen to drive off water and VOCs while degrading hemicellulloses 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)
- Brittleness 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.
TORREFACTION REDUCES MASS MORE THAN ENERGY CONTENT

- Mass lost is 30%--------.70 remains
- Energy lost is 10%--------.90 remains
- Energy density per unit of mass is increased
  \[ \frac{.90}{.70} = 130\% \]

Source: Energy Research Centre, Netherlands

- Torrsys has developed equipment and tested biocoal.
- In South Carolina, Agri-Tech has designed equipment.
- ECN (Netherlands) has licensed production of their units
- Trade from Maine, Mississippi, Georgia, B.C selling biocoal to Great Britain, Netherlands, and Germany.
Schematic of Torrefaction Unit by Agri-Tech
1.0 Billion Tons of U.S. Biomass per Year
Projections for Biomass Supply
(U.S. Billion Ton Update, U.S. DOE, 2011)
1.0 Billion Tons of Coal Dominate Surface Transportation

Source: National Renewable Energy Lab

Source: Federal Highway Administration, 2002
Steps in the Analysis

- Develop spreadsheet 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
## Torrefaction Process

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

### Installed Capital Cost

<table>
<thead>
<tr>
<th>Nameplate Annual Output</th>
<th>150,000</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Capital Cost</td>
<td>$228.00</td>
<td>per T of Capacity</td>
</tr>
<tr>
<td>Percent Equity</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Percent Debt</td>
<td>60%</td>
<td></td>
</tr>
<tr>
<td>Interest Rate Charged on Debt</td>
<td>6%</td>
<td></td>
</tr>
</tbody>
</table>

### Operational Parameters

- **Dry Matter Remaining**: 70%
- **BDT/BDT**: (60-75%)
- **BTUs used for drying at rate of**: 1200 BTUs/lb. of Water Removed
- **BTUs Released by facility per hour**:
  - **from flow of**: 95,950,000
  - **13.37 Tons of 17% Biomass =** 2,873,873 BTUs/T @ 17% Moist.
- **BTUs to Dry a Ton As Received to 17%**:
  - **Feedstock Grinding**: 37.8 kWh/T Biomass
  - **Torrefaction Reactor Electrical**: 56.25 kWh/T BioCoal
  - **Roll Press Briquetting Electrical**: 8.05 kWh/T BioCoal
  - **Natural Gas for Volatile Combustion**: 0.045 MMBTU of NG/T Biomass
  - **Water pumping for BioCoal Quenching**: 0.064 kWh/T BioCoal
  - **Fan Cooling of BioCoal Pellets**: 1.091 kWh/T BioCoal

### Revenues

- **Sale of Biocoal (F.O.B.)**: $140.00 at moisture of 1.10%
  - **139,800 K lb of ST/hr**
  - **8164.32 Hours of Operation**
- **Steam Price (Per 1,000 lb.)**: $5.00
  - **84,080 lb. of Steam/hr**
- **Delivered Cost of Biomass**: $70.00 at moisture of 17.00%
  - **166,601.12 Tons of 17% Biomass**

### Operating Costs and Depreciation

<table>
<thead>
<tr>
<th>Description</th>
<th>Rate/Fin. Ton</th>
<th>Costs per Ton Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salaries and Benefits</td>
<td>$4.50</td>
<td>$629,100</td>
</tr>
<tr>
<td>General &amp; Administrative</td>
<td>$1.00</td>
<td>$139,800</td>
</tr>
<tr>
<td>Maintenance Expenses</td>
<td>$3.20</td>
<td>$447,360</td>
</tr>
<tr>
<td>Natural Gas Expense</td>
<td>$8.81</td>
<td>$1,231,200</td>
</tr>
<tr>
<td>Electrical Expense</td>
<td>$1,081,369</td>
<td>$5,846,314</td>
</tr>
<tr>
<td>Interest</td>
<td>$16.31</td>
<td>$2,280,000</td>
</tr>
<tr>
<td>Depreciation (SL) for asset life of 15 years</td>
<td>$16.31</td>
<td>$2,280,000</td>
</tr>
<tr>
<td>Total Operating Costs and Depreciation</td>
<td>$33.82</td>
<td>$5,846,314</td>
</tr>
</tbody>
</table>

### Gross Margin

- **$11,342,197**

### Net Margin

- **Margin Per Finished Ton**: $5,495,883

### Return on Invested Capital

- **16.07%**
- **Return on Invested Capital (No Steam)**: 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.
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
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 Reductions of Coal PP Co-firing Bioccoal

<table>
<thead>
<tr>
<th>Bioccoal co-firing percentage</th>
<th>Reduction (GHG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>8.50%</td>
</tr>
<tr>
<td>20%</td>
<td>17.10%</td>
</tr>
<tr>
<td>30%</td>
<td>25.60%</td>
</tr>
<tr>
<td>100%</td>
<td>85.50%</td>
</tr>
</tbody>
</table>
Policy Drivers in the U.S.

✦ EPA Regulations under Clean Air Act rules

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

• State policies designed to increase generation of electricity from renewable resources.
• Encourage electricity producers within a given jurisdiction to supply a certain minimum share of their electricity from designated renewable resources.
• No RPS program in place at the National level.
• 29 states and the District of Columbia had enforceable RPS as of Feb 2013.
Carbon Taxes around the World

Switzerland: $150
British Columbia, Canada: $30
Finland: $26
Ireland: $20
Denmark: $18
Australia: $15
California: $10
Quebec, Canada: $4
Japan: $3
India: $1
2009 Delivered Cost of Coal at Power Plants $/Ton
(Source: U.S. Dept. of Energy)
MAJOR FLOWS OF MATERIALS AND ENERGY

Torrefaction Plant

Corn Stover

Wood

Biocoal to Power Plant

Volatile Off-Gasses

Steam

Ethanol Plant

Coal Power Plant
<table>
<thead>
<tr>
<th>Assumptions Applied in Workbook</th>
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</thead>
<tbody>
<tr>
<td><strong>Ethanol Plants</strong></td>
</tr>
<tr>
<td>Name Plate Capacity</td>
</tr>
<tr>
<td>Factor of Equity</td>
</tr>
<tr>
<td>Factor of Debt</td>
</tr>
<tr>
<td>Interest Rate on Debt</td>
</tr>
<tr>
<td>Depreciation Method Chosen (SL or DDB)</td>
</tr>
<tr>
<td>Depreciation based on asset life (years)</td>
</tr>
<tr>
<td>Ethanol Price (denat. price at plant) $/gal</td>
</tr>
<tr>
<td>DDGS Price $/T</td>
</tr>
<tr>
<td>CO2 Price sold for Food and Industrial Uses</td>
</tr>
<tr>
<td>Corn Price ($ per bu.)</td>
</tr>
<tr>
<td>CO2 Tax</td>
</tr>
</tbody>
</table>
Baseline Returns on Equity

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: 14.47%
- Coal Power Plant + Cofiring: 13.28%
ROE of Torrefaction Comparison: By Delivered Cost of Corn Stover

Baseline at $70

Torrefaction Plant

Torrefaction Plant + Steam
ROE of Torrefaction Comparison: By Percentage of Moisture Content

Baseline at 17%
ROE Comparisons of Torrefaction & Power Plants By Sale Price of Biocoal
ROE at Torrefaction Plants Selling Steam and Ethanol Plants Buying Steam as Steam Prices Vary with NG price fixed at $5 per Decatherm
ROEs of Ethanol & Coal-fired Plants: By Price of Carbon Tax

Baseline at $0

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

-30.00% -25.00% -20.00% -15.00% -10.00% -5.00% 0.00% 5.00% 10.00% 15.00%

Ethanol Plant Ethanol Plant + Torr. Steam Coal Power Plant Coal Power Plant+Cofiring
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 favorable attributes for integration with coal infrastructure.
- GREET model predicts greater GHG reduction is possible by generating electricity from biomass than from trying to make biofuels. (also see Campbell, et al., 2009)
- Further analysis is planned for co-located torrefaction plant using wood at coal power plant.
THANK YOU!

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

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