Integrated Biorefinery for the Direct Production of Synthetic Fuel from Waste Carbonaceous Feedstocks

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REI International

BETO IDL Workshop
Golden, CO

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General Overview
Project Description and Objectives

Stage 1
Syngas Production

Stage 3
Catalytic Conversion

Stage 4
Distribution of Synthetic Fuels

Biomass Residues
Biomass Crops
CO₂ Emissions
Natural Gas
Flared NG

Thermochemical Conversion

Direct “Drop-In Fuel Production (new PRF technology)

Wax Production (old technology - Sasol, Shell, etc.)

Premium, Synthetic Fuel

Refinery Processing
Hydro-Cracking Isomerization

Confidential
General Overview
Project Description and Objectives

<table>
<thead>
<tr>
<th>REII Headquarters:</th>
<th>Sacramento, CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Location:</td>
<td>Toledo, OH</td>
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<tr>
<td>Feedstock:</td>
<td>Wood (0.15”-2.00” chips) and Rice Hulls (whole)</td>
</tr>
<tr>
<td>Feedstock Input:</td>
<td>2.5 - 25 ton / day</td>
</tr>
<tr>
<td>Product Output:</td>
<td>56 gal/daft of transportation fuel</td>
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Thermochemical Conversion (TCC)  
Pyrolysis & Steam Reforming

Liquid Fuel Production (LFP)  
Direct Fuel Production

Rice Harvest Residues  
Wood Residues  
Syngas  
Diesel
Direct Production of “Drop-In” Synthetic Fuels from Carbonaceous Resources using Thermochemical Processes – Unit Processes
Project Description

25 tpd Integrated Biorefinery (IBR) Plant [Construction Completed (3/2012)]
Thermochemical Conversion (TCC) System
(Unit Processes #1-4A)
Liquid Fuel Production System
(Unit Processes #4b-#8)
Carbon Mass Conversion Efficiency (Wood)

- Ash (Average % C Conversion = 85%)
- Syngas (Average % C Conversion = 90%)

Wood Carbon Mass Conversion Efficiency
2- Technical Performance
Synthetic Diesel Fuel Tests on Heavy-Duty Diesel Engines
2 – Technical Performance
Results of Heavy Duty Diesel Engine Tests

The % Difference in Emissions between the 20%
Synthetic Diesel Fuel Blend and Certification Diesel Fuel

<table>
<thead>
<tr>
<th>% Difference (20% Blend vs. Certification Fuel)</th>
<th>Emission Species (grams/Kw-hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>THC</td>
</tr>
<tr>
<td>Engine Out Emissions</td>
<td>-10.0</td>
</tr>
<tr>
<td>Tail-Pipe Emissions (after control)</td>
<td>Near zero</td>
</tr>
</tbody>
</table>

The Difference in Fuel Economy, Work and Power at 1,200-1,600 rpm for the 20%
Synthetic Diesel Blend compared to the EPA/CARB Certification Fuel

<table>
<thead>
<tr>
<th>BSFC Fuel Economy (miles/gallon)</th>
<th>Work Output (KW-hr)</th>
<th>Power Output (KW-hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 0.7</td>
<td>+ 0.3</td>
<td>- 0.6</td>
</tr>
</tbody>
</table>
Emissions Relative to Typical CA Diesel Fuel for In-Use (2000-2008) Diesel Vehicles

- CO: -40 to 0
- HC's: -35 to -5
- NO\textsubscript{x}: -25 to -15
- Particulates: -20 to -10
## IBR Plant - Unit Processes

### Additional RD&D Needed for Successful Commercial Deployment

<table>
<thead>
<tr>
<th>Process Description</th>
<th>FEL Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>UP #1 – Upgrade and validate the current ram charge feeder to insure robustness and reliable operation over the life of the IBR plant</td>
<td>FEL-1</td>
</tr>
<tr>
<td>UP #2 – Increase the capacity of the ash removal system to handle high ash content feedstocks</td>
<td>FEL-1</td>
</tr>
<tr>
<td>UP #3 – Design, build and validate a less costly and more energy efficient gases steam reforming system</td>
<td>FEL-1</td>
</tr>
<tr>
<td>UP #9 – Select and validate an efficient and inexpensive fuel distillation process</td>
<td>FEL-1</td>
</tr>
</tbody>
</table>

### Technologies Successfully Validated and Ready for Commercial Deployment

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<tr>
<th>Process Description</th>
<th>FEL Level</th>
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</thead>
<tbody>
<tr>
<td>UP #4a – The IBR syngas purification system is directly applicable to the commercial scale plants</td>
<td>FEL-2</td>
</tr>
<tr>
<td>UP #4b-#8 – The liquid fuel production system is robust and immediately applicable for the commercial scale application</td>
<td>FEL-3</td>
</tr>
<tr>
<td>The IBR control systems and plant safety systems are directly applicable to the commercial scale plants</td>
<td>FEL-3</td>
</tr>
</tbody>
</table>
### IBR Plant - Unit Processes

<table>
<thead>
<tr>
<th>Technologies Successfully Validated &amp; Additional RD&amp;D Needed for Successful Deployment of Commercial Scale IBR Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Additional RD&amp;D Needed for Successful Commercial Deployment</strong></td>
</tr>
<tr>
<td>Current syngas flow measurement systems are not reliable and more accurate and robust systems need to be developed and validated</td>
</tr>
<tr>
<td><strong>Technologies Successfully Validated and Ready for Commercial Deployment</strong></td>
</tr>
<tr>
<td>Several, suitable U.S. equipment suppliers have been identified for the design and manufacture of the modular unit processes, instrumentation, control systems and components (e.g. valves)</td>
</tr>
<tr>
<td>A catalyst manufacturing capability has been validated for multi-ton quantity production of high quality catalysts</td>
</tr>
<tr>
<td>IBR Plant - Environmental</td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td><strong>Additional RD&amp;D Needed for Successful Commercial Deployment</strong></td>
</tr>
<tr>
<td>Determine the potential of using the LFP water discharge for agriculture and other “gray water” uses</td>
</tr>
<tr>
<td><strong>Technologies Successfully Validated and Ready for Commercial Deployment</strong></td>
</tr>
<tr>
<td>Incorporate low emission gas burners for heating unit processes #2 &amp; #3</td>
</tr>
</tbody>
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1. Biomass Feed and Processing

Upgrade and Validate the Biomass Feed Introduction System
Upgrade and Validate the Biomass Feed Introduction System
Upgrade and Validate the Biomass Feed Introduction System
### Unit Process #1
**Biomass Feed & Processing**

<table>
<thead>
<tr>
<th></th>
<th>Technical Target</th>
<th>Results Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass input rate</td>
<td>25 dtpd</td>
<td>24 dtpd</td>
</tr>
<tr>
<td>Remove air (O(_2)) with CO(_2) purge</td>
<td>&lt; 500 ppm O(_2)</td>
<td>&lt; 500 ppm O(_2)</td>
</tr>
<tr>
<td>Biomass size input</td>
<td>1.25” Minus</td>
<td>0.15-2.50”</td>
</tr>
</tbody>
</table>

**Findings:**
- Very finely ground feedstock (<0.15”) can collect on the ram charge feeder seals causing leaks and become entrained into the gas stream and into unit process #3 which can adversely impacts carbon conversion and syngas purification efficiency.
- Feedstock greater than 1” in diameter is more difficult to convert.
- The introduction chamber needs to be emptied between runs.
- For commercial scale plants, the valves need to be re-designed and thoroughly tested to insure robust operation.
Biomass Feed Introduction System
Cause-Effect Diagram used for System Upgrading

Biomass Physico-Chemical Properties
- Type of biomass
- Moisture Content
- Compressibility
- Contaminants
  - Particle size
  - Size distribution
  - Bulk density

Operational Variables
- Start-up conditions
- Shut down conditions
- Carrier gas used
- Feeding rate
- High feeding line temperature
- Pressure
- Piston Frequency
- Feeding rate
- Distance between piston and cylinder
- Lubrication method
- Maximum design torque
- Type of feeder
- Shape and size of piston
- Contamination

Design Variables
- Type of feeder
- Shape and size of hopper and feeding line
- Instrumentation and control system
- Cooling system

Clogging and compaction in the feeding system
Recommended Upgraded Design for Biomass Feed Introduction System