Transportable Fast-Pyrolysis Process for Distributed Conversion of Waste Biomass to Renewable Liquid Fuels

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Energy Manufacturing Workshop
Broomfield, CO

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Mainstream Engineering Corporation

- Small business incorporated in 1986
- 100+ employees
- Mechanical, chemical, electrical, materials and aerospace engineers
- 85,000 ft² facility in Rockledge, FL
- Laboratories: electric power, electronics, materials, nanotube, physical and analytical chemistry, thermal, fuels, internal combustion engine
- Manufacturing: 3- and 5- axis CNC and manual mills, CNC and manual lathes, grinders, sheet metal, plastic injection molding, welding and painting

**Capabilities**

- Basic Research, Applied Research & Product Development
- Transition from Research to Production (Systems Solution)
- Manufacture Advanced Products

**Mission Statement**

To research and develop emerging technologies. To engineer these technologies into superior quality, military and private sector products that provide a technological advantage.
Drivers for Change

• Numerous Regulations Driving Renewables
  • Energy Independence and Security Act of 2007
  • State Renewable Portfolio Standards

• Present Biofuels (Ethanol) Require Energy Crops
  • High water consumption
  • Potential impact on food prices

• Limited Lignocellulosic Biofuels Capacity
  • Multiple technologies in development/pilot stage
  • High CapEx and high transport costs
Deployed Military Applications

- Waste often disposed of in open pit burning
  - Bad for health of soldiers
- High cost for fuel delivery
  - Fully burdened cost of fuel is $15+/gallon
  - Every $1 increase in fuel cost the Pentagon $130M/yr
  - One solider casualty for every 24 fuel convoys

Smoking air curtain incinerator at U.S. camp in the Balkans

Fuel convoy heads north in Iraq
The Transportable Concept

Collection
Waste biomass feedstocks collected

Conversion
Converted to bio-oil on location

Transport
Bio-oil tankered to customer

End-Use
Power generation or upgrading
Military Manufacturing

- Multiple units can be delivered to accommodate changes in deployment strategies
- Tricon container used as packaging constraint
  - 8’ x 8’ x 6.5’
- Force Provider
  - 550 people
- Zero Footprint Camp
  - Recycling initiative
Military Manufacturing

- Concept includes two Tricon containers for deployed units
  - One for reactor skid (1 tpd) and one for waste pre-processing
  - Tricon containers can be linked together and shipped as 20’ units
Commercial Applications

- Pilot-scale built; debugging, testing and optimization underway
- Next milestone is a demonstration program to scale up to full-scale (10 tpd), address key technical risk elements, and prove out business model for distributed biomass conversion
- Focused on waste biomass, near-term offtake, and portability
## Feedstock Availability

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Tonnes/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagasse</td>
<td>2,591,680</td>
</tr>
<tr>
<td>Forest Residues</td>
<td>2,399,000</td>
</tr>
<tr>
<td>Primary Mill Residues</td>
<td>1,883,475</td>
</tr>
<tr>
<td>Urban Wood and Sec Mill Residues</td>
<td>1,795,503</td>
</tr>
<tr>
<td>Corn Stover</td>
<td>18,329</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8,687,989</strong></td>
</tr>
</tbody>
</table>

Generating 1.2B Gallons of Oil in Florida Alone
Scale-Up Progression

- Thermogravimetry
- Pyrolysis rxn kinetics

- Bench-scale reactor
  - Continuous, 1 kg/hr
  - Measured yields and product quality

- Pilot reactor
  - Continuous, 45 kg/hr
  - Measured product quality
1-TPD Fast Pyrolysis Pilot
Army Waste Surrogate

- A Force Provider unit produces approximately 1 tpd of waste
  - 40% moisture due to food/slop
  - Designer trash initiative to optimize entire waste management system
  - Packaging will be compatible with processing equipment

<table>
<thead>
<tr>
<th>Material</th>
<th>% Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardboard</td>
<td>15.4</td>
</tr>
<tr>
<td>Water</td>
<td>34.5</td>
</tr>
<tr>
<td>Paper</td>
<td>24.9</td>
</tr>
<tr>
<td>PS</td>
<td>15.3</td>
</tr>
<tr>
<td>PET</td>
<td>5.1</td>
</tr>
<tr>
<td>HDPE</td>
<td>5.1</td>
</tr>
</tbody>
</table>
Army Waste Surrogate

Raw process input:
1,500 lb/day mixed waste (40-50% moisture)
LHV 19 MJ/kg dry basis

- Dryer / Grinder
  - 8.3 kW
  - Grinding
  - Milled (1-2 mm),
    dried (10% water),
    29.6 kg/h (65 lb/h)
    preprocessed feed

- Fast Pyrolysis
  - 1.5 kW
  - Pumps, blowers,
    screw feeder,
    control system
  - Fluidizing gas
  - Hot products
    500°C
  - Reactor duty
    24.6 kWth

- Preheater
  - Preheater duty
    10.6 kWth

- Cool and Collect
  - Air-cooled condenser
    Duty -28.7 kWth
  - Bio-oil 42wt%
    12.4 kg/h
  - Char 15 wt%
    4.4 kg/h

- Burner 85% Efficiency
  - 59.8 kWth produced
  - Heat loss
    2.0 kWth
  - Gases 20wt%
    5.9 kg/h

- Bio-oil required for process heat
  6.8 kg/h

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<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM D7544 Bio-Oil Std</th>
<th>Bench-Scale / Pine Sawdust</th>
<th>Pilot-Scale / Pine Sawdust</th>
<th>Pilot-Scale / Mixed Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher Heating Value (MJ/kg)</td>
<td>15 min</td>
<td>19.0</td>
<td>14.1</td>
<td>28.6</td>
</tr>
<tr>
<td>Water Content (mass %)</td>
<td>30 max</td>
<td>30.0</td>
<td>33.1</td>
<td>14.5</td>
</tr>
<tr>
<td>Kin. Viscosity at 40°C (mm²/s)</td>
<td>125 max</td>
<td>76</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Density (g/mL)</td>
<td>1.1–1.3</td>
<td>1.2</td>
<td>1.07</td>
<td>1.10</td>
</tr>
<tr>
<td>Sulfur Content (mass %)</td>
<td>0.05 max</td>
<td>0.013</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Solids Content (mass %)</td>
<td>2.5 max</td>
<td>0.5</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Ash Content (mass %)</td>
<td>0.25 max</td>
<td>0.30</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Flash Point (°C)</td>
<td>45 min</td>
<td>57</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Pour Point (°C)</td>
<td>–9 max</td>
<td>&lt;–10</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>pH</td>
<td>report</td>
<td>3.0</td>
<td>3.8</td>
<td>—</td>
</tr>
<tr>
<td>TAN (mg KOH/g)</td>
<td>—</td>
<td>161</td>
<td>76.1</td>
<td>86.0</td>
</tr>
<tr>
<td>Elemental Analysis, wet basis (mass %)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>—</td>
<td>41.2</td>
<td>38.2</td>
<td>64.1</td>
</tr>
<tr>
<td>H</td>
<td>—</td>
<td>7.3</td>
<td>8.5</td>
<td>6.7</td>
</tr>
<tr>
<td>O</td>
<td>—</td>
<td>51.6</td>
<td>53.3</td>
<td>29.2</td>
</tr>
<tr>
<td>Elemental Analysis, dry basis (mass %)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>—</td>
<td>58.9</td>
<td>57.0</td>
<td>75.0</td>
</tr>
<tr>
<td>H</td>
<td>—</td>
<td>5.6</td>
<td>7.2</td>
<td>6.0</td>
</tr>
<tr>
<td>O</td>
<td>—</td>
<td>35.6</td>
<td>35.8</td>
<td>19.0</td>
</tr>
</tbody>
</table>
Conclusions/Next Steps

- Continue refining pilot plant into a continuous, fully integrated process from raw waste to fuel
  - Heat integration
  - Oil collection
  - Preprocessing/Feeding
- Leverage military design in transition to commercial applications
  - What are the biggest differences?
  - Who are the most promising customers?
- Optimize scale of process
  - Balance between capital expense, operating costs and feedstock availability