Rapid Thermal Processing (RTP™): A Proven Pathway to Renewable Liquid Fuel

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Business Development Director
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Agenda

• Introduction

• Rapid Thermal Processing (RTP™) Technology

• Applications

• Project Development

• Summary
Envergent Technologies LLC – UOP / Ensyn Joint Venture

- Formed in October 2008
- Provides pyrolysis oil technology for fuel oil substitution and electricity generation
- Development of technology for upgrading pyrolysis oil to transportation fuels

**UOP**
- Leading process technology licensor~$2 billion in sales, 3000 employees
- Nearly 100 years of refining technology development, scale-up and design
- Modular process unit supplier
- Global reach via Honeywell & UOP sales channels

**Ensyn**
- Over twenty years of commercial fast pyrolysis operating experience
- Developers of innovative RTP™ fast pyrolysis process
- Seven commercial RTP units designed and operated

*Second Generation Renewable Energy Company – Global Reach*
Pyrolysis Oil to Energy & Fuels Vision

Available for Sale
Commercially available in 2012

Biomass → Fast Pyrolysis → Pyrolysis Oil →

- Electricity Production

- Fuel Oil Substitution

- Transport Fuels (Gasoline, Jet, Diesel)

Phased Commercialization

Forest Fiber

Ag Residue
Rapid Thermal Processing (RTP™) Technology

- 510 °C, <2 seconds
- Biomass converted to liquid pyrolysis oil
- Fast fluidized bed, sand as heat carrier
- High yields; >70 wt% liquid on woody biomass

Pyrolysis Oil

Solid Biomass

Commercially Proven Patented Technology
Minimal net utilities
RTP is self-sustaining process
RTP™ Operating History & Commercial Experience

• Commercialized in the 1980’s
• 7 units designed and operated in the US & Canada
• Continuous process with >90% availability

<table>
<thead>
<tr>
<th>Plant</th>
<th>Year Built</th>
<th>Operating Capacity (Metric Tonnes Per Day)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manitowoc RTP™ – 1</td>
<td>1993</td>
<td>30</td>
<td>Manitowoc, WI, USA</td>
</tr>
<tr>
<td>Rhinelander RTP™ – 1</td>
<td>1995</td>
<td>35</td>
<td>Rhinelander, WI, USA</td>
</tr>
<tr>
<td>Rhinelander Chemical #2</td>
<td>1995</td>
<td>2</td>
<td>Rhinelander, WI, USA</td>
</tr>
<tr>
<td>Rhinelander RTP™ – 2</td>
<td>2001</td>
<td>45</td>
<td>Rhinelander, WI, USA</td>
</tr>
<tr>
<td>Rhinelander Chemical #3</td>
<td>2003</td>
<td>1</td>
<td>Rhinelander, WI, USA</td>
</tr>
<tr>
<td>Petroleum Demo # 1</td>
<td>2005</td>
<td>300 barrels per day</td>
<td>Bakersfield, CA, USA</td>
</tr>
<tr>
<td>Renfrew RTP™ – 1 (Owned and operated by Ensyn)</td>
<td>2007</td>
<td>100</td>
<td>Renfrew, Ontario, Canada</td>
</tr>
</tbody>
</table>

Note: design basis for wood based plants assumes feedstocks with 6 wt% moisture content.
Feedstock Sources

- **Forestry and Pulp and Paper**
  - Wood chips, sawdust, bark
  - Forestry residues

- **Agricultural**
  - Residues – corn stover, expended fruit bunches from palm (EFB), bagasse
  - Purpose-grown energy crops – miscanthus, elephant grass

- **Post-consumer**
  - Construction and Demolition Waste, Categories 1&2
  - Municipal solid waste (future)

- **DoE study 2005 - > 1 billion ton per year available in United States alone**

**Cellulosic Feedstocks Widely Available**
Feed Handling / Preparation

• Water is a heat sink
  • Dried to 5-6 wt% moisture content for efficient RTP™ reactor operation

• Size impacts heat transfer
  • Biomass sized to 0.125-0.25 inch (3-6 mm)

• Capacity of unit expressed on bone dry feed basis
  • BDMTPD
  • Zero water content

RTP is Self-Sustaining – Excess Heat Dries Raw Biomass
RTP™ Product Yields

400 BDMTPD of Hardwood Whitewood

<table>
<thead>
<tr>
<th>Feed, wt%</th>
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<tbody>
<tr>
<td>Hardwood Whitewood</td>
<td>100</td>
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Typical Product Yields, wt% Dry Feed

<p>| | |</p>
<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>Pyrolysis Oil</td>
<td>70</td>
</tr>
<tr>
<td>By-Product Vapor</td>
<td>15</td>
</tr>
<tr>
<td>Char</td>
<td>15</td>
</tr>
</tbody>
</table>

Yields For Various Feeds

<table>
<thead>
<tr>
<th>Biomass Feedstock Type</th>
<th>Typical Pyrolysis Oil Yield, wt% of Dry Feedstock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardwood</td>
<td>70 – 75</td>
</tr>
<tr>
<td>Softwood</td>
<td>70 – 80</td>
</tr>
<tr>
<td>Hardwood Bark</td>
<td>60 – 65</td>
</tr>
<tr>
<td>Softwood Bark</td>
<td>55 – 65</td>
</tr>
<tr>
<td>Corn Fiber</td>
<td>65 – 75</td>
</tr>
<tr>
<td>Bagasse</td>
<td>70 – 75</td>
</tr>
<tr>
<td>Waste Paper</td>
<td>60 – 80</td>
</tr>
</tbody>
</table>

Cellulosic Feedstock Flexible With High Yields of Pyrolysis Oil
**RTP™ Pyrolysis Oil Properties**

- Pourable, storable and transportable liquid fuel
- Energy densification relative to biomass
- Contains approximately 50-55% energy content of fossil fuel
- Stainless steel piping, tankage and equipment required due to acidity
- Requires separate storage from fossil fuels

**Comparison of Heating Value of Pyrolysis Oil and Typical Fuels**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>MJ / Litre</th>
<th>BTU / US Gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol</td>
<td>17.5</td>
<td>62,500</td>
</tr>
<tr>
<td>Pyrolysis Oil</td>
<td>19.9</td>
<td>71,500</td>
</tr>
<tr>
<td>Ethanol</td>
<td>23.5</td>
<td>84,000</td>
</tr>
</tbody>
</table>
| Light Fuel Oil (#2) | 38.9       | 139,400         

**Suitable for Energy Applications**
Multiple Applications for Pyrolysis Oil, a Renewable Fuel Available Today

- Compatible with specialized turbines
- Specialized burner tips improve flame/burning
- Convert to steam to use existing infrastructure
- Use as a blend in diesel engines
- Upgradable to hydrocarbon fuels
Benefits and Uses of Pyrolysis Oil

• **Benefits**
  - Energy densification relative to biomass (i.e. forest residue)
  - Fuel consistency – ASTM D7544
  - Flexibility to process biomass in one location and economically ship/store pyrolysis oil for use at other place/time
  - GHG emission reduction of 70-90% relative to fossil fuels

• **Uses**
  - Internal replacement of fossil fuel for heat/steam generation
  - Production of electricity for internal use
  - Alternate revenue stream from external sale
  - Future upgrading to green transportation fuels

*RTP™ Plays a Key Role in the Biorefinery*
Pyrolysis Oil: Replacement of Fossil Fuels to Generate Heat

- **Consistent quality/improved operations**
  - ASTM D7544, Standard Specification for Pyrolysis Liquid Biofuel, established last month

- **Low cost liquid biofuel**
  - ~40% cheaper to make and use pyrolysis oil than to purchase #2 fuel oil on an equivalent energy basis
    - 400 BDMTPD unit
    - Assumes 60 $US/bbl crude
    - Includes RTP operating cost and 15-yr straight line depreciation of CAPEX
    - 330 Days per Year

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Heat of Combustion, MJ/kg, °C</td>
<td>15 min</td>
<td>ASTM D240</td>
</tr>
<tr>
<td>Pyrolysis Solids Content, wt%</td>
<td>2.5 max</td>
<td>ASTM D7544, Annex I</td>
</tr>
<tr>
<td>Water Content, wt%</td>
<td>30 max</td>
<td>ASTM E203</td>
</tr>
<tr>
<td>pH</td>
<td>report</td>
<td>ASTM E70</td>
</tr>
<tr>
<td>Kinematic Viscosity, cSt @ 40 °C</td>
<td>125 max</td>
<td>ASTM D445</td>
</tr>
<tr>
<td>Density, kg/dm³ @ 20 °C</td>
<td>1.1 – 1.3</td>
<td>ASTM D4052</td>
</tr>
<tr>
<td>Sulfur Content, wt%</td>
<td>0.05 max</td>
<td>ASTM 4294</td>
</tr>
<tr>
<td>Ash Content, wt%</td>
<td>0.25 max</td>
<td>ASTM 482</td>
</tr>
<tr>
<td>Flash Point, °C</td>
<td>45 min</td>
<td>ASTM D93, Procedure B</td>
</tr>
<tr>
<td>Pour Point, °C</td>
<td>-9 max</td>
<td>ASTM D97</td>
</tr>
</tbody>
</table>
Pyrolysis Oil: Production of Green Electricity

- Compatible with specialized turbines
- Green electricity production cost is 0.10 $US/kW-h
  - Includes RTP operating cost and 15-yr straight line depreciation of CAPEX (including gas turbine)
- Experience in stationary diesel engine as blend with fossil fuel
  - Operation with 100% pyrolysis oil under development
Pyrolysis Oil: Upgrading to Green Transportation Fuels

• **Objectives**
  - Remove oxygen molecules
  - Reduce acidity and viscosity
  - Break up molecules to make gasoline and diesel/jet precursors
  - Commercialization expected in 2012

• **Solution**
  - Thermochemical upgrading; leverage UOP’s extensive hydroprocessing experience
  - Continuous, reliable guaranteed process, per current refinery standards

**Achieved in Lab, Working on Scale-up**
Delivery & Scope of Supply

- **Standard sized modular units offered**
  - 100, 200, 400 and 1000 Bone Dry Metric Tons per Day (BDMTPD)
  - Design adjusted to meet site specific requirements

- **Design based on hardwood whitewood**
  - If alternate feedstock being processed, unit performance to be re-rated
  - Unit performance is *guaranteed*

- **Broad modular experience in refining, petrochemical and oil & gas industries**

*Modular Delivery Provides Faster Execution and Higher Reliability*
RTP™ Project Execution – Envergent Scope

• Three-phase work process
  • Develops project specific scope
  • Enhances capital figures to reduce uncertainty

<table>
<thead>
<tr>
<th>Project Scoping</th>
<th>Detailed RTP Development</th>
<th>RTP Project Execution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Goals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+/- 40% project specific RTP estimate</td>
<td>Project-specific RTP design and implementation plan</td>
<td>Detailed RTP engineering</td>
</tr>
<tr>
<td>Define project – Inside Battery Limits (ISBL)</td>
<td>Feedstock verification testing</td>
<td>Build RTP modules / pre-fab</td>
</tr>
<tr>
<td>Understand likely delivery model</td>
<td>Outside Battery Limits (OSBL) duty specifications</td>
<td>Procure equipment</td>
</tr>
<tr>
<td>Duration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-12 weeks</td>
<td>6 months</td>
<td>12-18 months</td>
</tr>
</tbody>
</table>

**Equipment Delivery – Guaranteed Performance**
RTP™ Summary

• Commercially proven technology: 7 units designed and operated
• Reliable operation with 90% on-line availability
• Designed to maximize pyrolysis oil yield, 70 wt% based on hardwood whitewood feed
• Performance guaranteed
• Cost-competitive with fossil fuels
• GHG emission reduction of 70-90%
• Engineering and modular delivery by world-renowned industry leader
• Technology for upgrading to transportation fuels expected to be available in 2012