Biomass Conversion to Heat, Power & Fuels

Rapid Thermal Processing (RTP™)
And Pyrolysis Oil Upgrading

USDA-ARSTeleseminar Series on Chemical Conversion Technologies, October 11th, 2011
Honeywell Corporate Overview

- 125,000 employees in more than 100 countries
- A Fortune 100 company – sales of $33.4 billion in 2010
- Global leader in advanced technology products, services and solutions

Honeywell

Technology Company, Financial Strong and Global
Since 2005, a Honeywell Company – part of Specialty Materials business unit

Leading supplier and licensor of processing technology, catalysts, adsorbents, process plants, and technical services to the petroleum refining, petrochemical, and gas processing industries.

UOP Technology Furnishes:
- 60% of the world’s gasoline
- 85% of the world’s biodegradable detergents
- 60% of the world’s para-xylene.

3400 employees worldwide.

2008 Financials: $1.9 billion in sales.

Strong relationships with leading refining and petrochemical customers worldwide.

2003 National Medal of Technology Recipient

Refining | Gas Processing | Petrochemicals | Renewable Energy

Bridging Feedstocks Today, but Focus on 2nd Generation
Honeywell/UOP Renewable Fuels Vision

- Building on 96 years of petrochemical industry technology and expertise
- Produce real “drop-in” fuels instead of fuel additives/blends
- Leverage existing refining, transportation, energy, biomass handling infrastructure to lower capital costs, minimize value chain disruptions, and reduce investment risk
- Focus on path toward second generation feed stocks and chemicals

**Oxygenated Biofuels**
- Ethanol
- Biodiesel

**Renewable Energy**
- Fuel & Power

**Hydrocarbon Biofuels**
- Diesel
- Jet
- Gasoline

**First Generation**
- Natural Oils From Vegetables and Greases

**Second Generation**
- “Other” Oils: Camelina, Jatropha
- Lignocellulosic Biomass, Algal Oils

*Bridging Feedstocks Today, but Focus on 2nd Generation*
UOP Renewable Fuel & Energy Technologies

Natural Oil/Fats → UOP/Eni Ecofining™ Process → Honeywell Green Diesel™

Natural Oil/Fats → Renewable Jet Process → Honeywell Green Jet™

Biomass → RTP® (Pyrolysis) → Rentech / UOP Alliance

- Gasification
- Separation
- FT Synthesis
- Conversion

→ Green Fuels

Green Power / Fuel Oil (now)

Upgrading Process

Green Fuels (future)

Envergent Technologies – UOP/Ensyn JV

Technologies for converting the whole plant – oil and biomass
Envergent Technologies LLC – UOP / Ensyn Joint Venture

• Formed in October 2008
• Provides pyrolysis oil technology for fuel oil substitution and electricity generation
• Channel for UOP R&D program to upgrade pyrolysis oil to transportation fuels

Second Generation Renewable Energy Company – Global Reach

- Leading process technology licensor
  ~$2 billion in sales, 3000 employees
- Co-inventor of FCC technology
- Modular process unit supplier
- Global reach via Honeywell & UOP sales channels

- Over 20 years of commercial fast pyrolysis operating experience
- Developers of innovative RTP™ fast pyrolysis process
- Seven commercial RTP units designed and operated
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
History and 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>

New Projects:

<table>
<thead>
<tr>
<th>Year of Project</th>
<th>Technology</th>
<th>Location</th>
<th>Customer</th>
<th>Size (TPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>RTP</td>
<td>Italy</td>
<td>INDI</td>
<td>150</td>
</tr>
<tr>
<td>2010</td>
<td>RTP</td>
<td>North America</td>
<td>High North</td>
<td>400</td>
</tr>
<tr>
<td>2010</td>
<td>RTP</td>
<td>Malaysia</td>
<td>Premium</td>
<td>400</td>
</tr>
<tr>
<td>2010</td>
<td>RTP</td>
<td>Sweden</td>
<td>--</td>
<td>2 x 400</td>
</tr>
<tr>
<td>2011</td>
<td>RTP</td>
<td>Canada</td>
<td>--</td>
<td>400</td>
</tr>
</tbody>
</table>
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, Switchgrass

• 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
RTP™ Product Yields

**400 BDMTPD of Hardwood Whitewood**

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

**Typical Product Yields, wt% Dry Feed**

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Yield</th>
</tr>
</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>

* Char is utilized as fuel for the re-heater section of the RTP™. No net char is generated. Ash is produced as by-product.

**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>
<tr>
<td>Light Fuel Oil (#2)</td>
<td>38.9</td>
<td>139,400</td>
</tr>
</tbody>
</table>

Suitable for Energy Applications
Pyrolysis Oil Energy Applications

- Replacement of fossil fuel for heat/steam generation
- Production of green electricity
- Future upgrading to transportation fuels

Multiple Applications for Pyrolysis Oil, a Renewable Fuel Available Today
Pyrolysis Oil to Energy & Fuels Vision

Phased Commercialization

Fuel Oil Substitution
Available for Sale
Commercially available in 2013

Fast Pyrolysis
Pyrolysis Oil

Biomass
Ag Residue

Energy/Fuels

Electricity Production

Transport Fuels (Gasoline, Jet, Diesel)
Pyrolysis Oil: Replacement of Fossil Fuels to Generate Heat

• Specialized burner tips improve flame/burning
• Low emissions (NOx, SOx)
• Fuel consistency - ASTM D7544
• Flexibility to decouple pyrolysis oil production from energy generation (location and time)
• GHG emission reduction of 70-90%
• 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 RTP Unit
    • Assumes 60 $US/bbl crude
    • Includes RTP operating cost and 15-yr straight line depreciation of CAPEX
    • 330 Days per Year

\[ \text{~} 8 \, \text{$US Million per Year Savings} \]
Applications for RTP Green Fuel

Replacement of fossil fuel to generate heat

- Low emissions (NOx, SOx)
- Fuel consistency - ASTM standard
- GHG emission reduction of 70-90%
- Favorable economics versus purchased fuel oil

Production of green electricity

- Stationary diesel engine operation with 100% RTP Green Fuel in final development
- The most efficient route for biomass conversion to electric power
  - Up to 40% energy conversion efficiency versus direct combustion at 16-26%
Pyrolysis Oil: Upgrading to Green Transportation Fuels

• Objectives
  - Remove oxygen
  - Reduce acidity and viscosity
  - Break up molecules to make gasoline and diesel/jet precursors

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

Achieved in Lab, Working on Scale-up
UOP received $25M DOE grant

Plant to be built at Tesoro/Hawaii refinery, operated by UOP

Will include RTP and RTP Green Fuel upgrading

2nd Generation feedstocks to include
- Corn Stover
- Cane Bagasse
- Switch Grass
- Guinea Grass
- Algae Biomass
- Forest Residue

Demonstration to be complete in three years
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 2013