Unlocking Bioenergy Potential: Recent Advances in Sustainable Energy and Fuels Process Technology

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Vice President & General Manager
Honeywell’s UOP
Honeywell International

- $36 billion (2011) in revenues, 50% outside of U.S.
- Nearly 130,000 employees operating in 100 countries
- Morristown, NJ global corporate headquarters

Aerospace
- $10.8-11.2B

Automation & Control Solutions
- $14.7-15.1B*

Performance Materials & Technologies
- $5.0-5.2B*

Transportation Systems
- $4.3-4.5B*
UOP LLC, A Honeywell Company

- Founded in 1914
- A leading international supplier and licensor of processing technology, catalysts, adsorbents, process plants, and technical services.
- Largest process licensing organization in the world.
- 31 out of 36 refining technologies in use today were developed by UOP

**Markets**
- Petroleum refining
- Petrochemical production
- Gas processing
- Renewable fuels and chemicals

**Products/Services**
- Developing and licensing of process technology
- Equipment
- Catalysts
- Adsorbents
- Molecular sieves
Perspectives

• Current Context for Biofuels and Bioenergy
  - Issues of Politics v. Policy
  - Increasing Pressure, Decreasing Resources
  - Balancing Priorities in Apparent Conflict

• Delivering Economically Attractive Solutions
  - Advanced Bioenergy processes
  - Drop-in Fuels from Sustainable Resources
  - Perspectives on the Future of Bioenergy
Politics v. Policy – Who’s at the Wheel?

McCain attacks Navy biofuels spending, says it could become a "Solyndra situation"

Navy moves ahead on biofuels despite congressional ire

Green Strike Group or Green Hike Group? With small-scale advanced biofuels, who foots the bill?

• US Biofuels policy currently makes good politics
• Unfortunately, the debate neglects the fact that we need alternative sources of energy
  • Quickly, cheaply and in abundance

Let’s not mortgage the long-term for short-term political gain
Population, Consumption Grows

Global Population Growth 2008 to 2035

- Africa
- India
- China
- Other Asia
- OECD Europe
- Latin America
- OECD North America
- E. Europe/Eurasia
- Middle East
- OECD Pacific

Privately Owned Light-Duty Vehicles – 1980 to 2035

- China
- Other non-OECD
- United States
- Other OECD

Ownership rate: OECD (right axis)
Ownership rate: non-OECD (right axis)

Sources: UNPD and World Bank databases; IEA analysis.

Population, Consumption Growth March On Irrespective of Debate
Who will control our right to grow?

• Current product rates exhaust 2009 proven reserves in non-OPEC region before 2035
  - Does not factor in new discoveries

• Dramatic shift in supply, not only toward OPEC, but specifically the Middle East

Cumulative Production vs. Proven Reserves

- OPEC
- Non-OPEC
- World

Energy Security / Assured Access significant concern

Sources: BGR (2009); O&GJ (2009); USGS (2000 and 2008) and information provided by the USGS directly to the IEA; IEA estimates and analysis.
Conflicting Goals or Confluence of Benefits?

Three seemingly competing objectives – common resolution

- Environment
- Energy Security
- Rural Wealth Creation

Three seemingly competing objectives – common resolution
**Honeywell Renewable Fuels Vision**

- Building on 98 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 (lower capital costs, minimize value chain disruptions, reduced investment risk)
- Focus on path toward second generation feed stocks and chemicals

### Oxygenated Biofuels
- Ethanol
- Biodiesel

### Renewable Energy
- Fuel & Power
  - Biodiesel

### Hydrocarbon Biofuels
- Diesel
- Jet
- Gasoline

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

### “Other” Oils: Camelina, Jatropha

### Second Generation
- Lignocellulosic Biomass, Algal Oils
UOP Renewable Fuel Technologies

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

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

Gasification
Separation
FT Synthesis
Conversion

Rentech / UOP Alliance
Green Fuels

Biomass → RTP® (Pyrolysis) → Green Power / Fuel Oil (now)
Upgrading Process

Envergent Technologies – UOP/Ensyn JV

Green Fuels (2012)
New Additions to the UOP Portfolio

- Alcohols → UOP ATJ Process
  Alcohol to Jet (and Diesel) → Honeywell Green Jet™

  - Demonstrated under grant from US FAA
  - Project completed 2012 – ready for license 2014
  - Isoparaffinic kerosene – limited aromatics
  - Smooth boiling point curve – millions of paraffins, isoparaffins, naphthenes
  - Just like petroleum-derived jet fuel!

Biomass → RTP® (Pyrolysis) → Upgrading Process → Green Fuels

  - Gasoline
  - Diesel
UOP/ENI Ecofining™ Green Diesel

- Technology that produces a fully fungible hydrocarbon product
- Uses existing refining infrastructure, can be transported via pipeline, and can be used in existing automotive fleet
- Two units licensed in Europe with first commercial start-up in 2010
- Excellent blending component, allowing refiners to expand diesel pool by mixing in “bottoms”
- Can be used as an approach to increase refinery diesel output

Process Comparison vs. Biodiesel

<table>
<thead>
<tr>
<th></th>
<th>Petrodiesel</th>
<th>Biodiesel</th>
<th>Green Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>Baseline</td>
<td>+10</td>
<td>Baseline or better</td>
</tr>
<tr>
<td>Cetane</td>
<td>40-55</td>
<td>50-65</td>
<td>75-90</td>
</tr>
<tr>
<td>Cold Flow Properties</td>
<td>Baseline</td>
<td>Needs Additives</td>
<td>Baseline or better</td>
</tr>
<tr>
<td>Oxidative Stability</td>
<td>Baseline</td>
<td>Needs Additives</td>
<td>Baseline or better</td>
</tr>
</tbody>
</table>

Ecofining Process Chemistry and Flow Scheme

1. Vegetable Oil
2. Acid Gas Removal
3. Make-up Hydrogen
4. CO₂
5. Propane & Light Ends
6. Naphtha or Jet
7. Diesel Product
8. Carbon Dioxide
9. Water
10. UOP Catalyst
11. Hydrogen
12. Vegetable Oil
13. Acid Gas Removal
14. Make-up Hydrogen
15. Carbon Dioxide
16. Water
17. UOP Catalyst
18. Hydrogen

Process Comparison vs. Biodiesel

Natural Oil/Grease + Methanol → Biodiesel (FAME) + Glycerol

Natural Oil/Grease + Hydrogen → Green Diesel + nC3 & Naphtha

Performance Comparison
UOP Renewable Jet Process

- Initially a DARPA-funded project to develop process technology to produce military jet fuel (JP-8) from renewable sources
- Targets maximum Green Jet production
- Green Jet Fuel can meet all the key properties of petroleum derived aviation fuel, flash point, cold temperature performance, stability
- Certification of Green Jet as a 50% blending component in progress
Upgrading to Green Transportation Fuels

Objectives:
• Remove oxygen as water and CO$_2$ by hydrogen & catalyst
• pH neutral fuel with viscosity equivalent to refined fuels
• Produce high octane gasoline, or diesel/jet precursors

Two Stage Hydrodeoxygneration

Biomass → RTP → 1$^{\text{st}}$ Stage HDO → Full HDO → Hydrocarbons

- RTP: $\text{H}_2\text{O} = 10-40\%$
- 1$^{\text{st}}$ Stage HDO: $\text{H}_2\text{O} = 10-30\%$, $\text{O} = 35-55\%$, TAN = 100-200
- Full HDO: $\text{H}_2\text{O} = 300-1000$ ppm, $\text{O} = <0.2\%$, TAN < 2

Mixed Woods
Corn Stover
IBR – Biomass to Transportation Fuel Pilot

- Pilot-scale conversion of biomass into liquid transportation fuels
- Located at the Tesoro Refinery in Kapolei, HI
- Backed by a $25 million award from the U.S. Department of Energy
- Utilizes a wide range of locally available biomass (switchgrass, algae, forest and agricultural residuals)
- Commercial units could create up to 800 construction jobs and 1,000 new jobs in biomass production and refinery operations
- Greater than 60% reduction in greenhouse gas emissions
- Phase 1 Start-up Underway 4/2/2012
- Fully Operation 1Q 2013

Making Cellulosic Biofuels a Reality
### Product Yield & Quality

#### RFO to Fuels Feed/Product Analysis

<table>
<thead>
<tr>
<th></th>
<th>Renewable Fuel Oil (RFO)</th>
<th>Stage 2 Product (Pilot Plant)</th>
<th>Gasoline Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{H}_2\text{O},%$</td>
<td>~25</td>
<td>0.03</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>$\text{O},%$</td>
<td>51</td>
<td>0.25</td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>$\text{TAN, meq/g}$</td>
<td>91</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
</tbody>
</table>

#### RFO to Liquid Hydrocarbon Yields

<table>
<thead>
<tr>
<th></th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Overall from RFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Yield %</td>
<td>53</td>
<td>78</td>
<td>41</td>
</tr>
<tr>
<td>Volume Yield %</td>
<td>65</td>
<td>93</td>
<td>60$^2$</td>
</tr>
</tbody>
</table>

1. Demonstrated yields at multiple equipment scales
2. Equals >90 gallons per dry MT for woody biomass

- ~50% of material in gasoline boiling range (IBP-200°C)
  - RON of gasoline ~ 80-89
  - Passes all tests (color, corrosion, etc) needed as gasoline blend stock

- ~40% of material in distillate (jet and diesel) boiling range
  - Contains paraffins, isoparaffins, naphthenes and aromatics
  - Full Range

*Drop-in Fuels at >90 gallons per MT of Dry Biomass*
Drop-in Biofuels Summary

- Our portfolio of offerings has grown!
  - Ecofining and Renewable Jet – renewable fuels from fats, greases, oils
  - Gas separation, purification and paraffin dewaxing – gasification / FT fuels
  - RTP for Renewable Fuel Oil – an energy dense substitute for fuel oil
  - Alcohol-to-Distillate Process – jet and diesel from renewable alcohols
  - RFO Upgrading to Transportation Fuels – true drop-in cellulosic biofuels

- We provide cost-effective options to meet biofuel and bioenergy needs:
  - Most efficient, cost effective and reliable renewable diesel and renewable jet fuel processes
  - Renewable fuel oil which competes with petroleum fuel oil without subsidy
  - Cellulosic biofuels from RFO Upgrading at parity with petroleum-derived gasoline and distillates