GHG Impact of Using Fast Pyrolysis Oil for Electricity and Biofuel Generation

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UOP LLC, A Honeywell Company

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Presentation Overview

• Introduction
  – RTP™ Rapid Thermal Processing Technology
  – Heat, Power and Fuel Applications

• Life Cycle GHG Assessments
  – Pyrolysis Oil from Forest Biomass
  – Electricity via Pyrolysis Oil Combustion
  – Gasoline via Pyrolysis Oil Conversion

• Summary & Technology Benefits
Rapid Thermal Processing Technology

Pyrolysis Oil

- 510°C, <2 seconds
- Biomass converted to liquid pyrolysis oil
- Fast fluidized bed, sand as heat carrier

Solid Biomass

Commerially Proven Patented Technology
Feedstock Sources

• Forestry and Pulp and Paper
  • Wood chips, sawdust, bark
  • Forest & mill residues, short rotation crops

• 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
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><strong>Pyrolysis Oil</strong></td>
<td><strong>19.9</strong></td>
<td><strong>71,500</strong></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 to Energy & Fuels Vision

Phased Commercialization

Available for Sale

Commercially available in 2012

Fast Pyrolysis

Pyrolysis Oil

Substitution Fuel Oil

Production Electricity

Fuel Oil (Jet, Diesel, Gasoline, Fuels Transport)

Transport Fuels (Gasoline, Jet, Diesel)

Fuel Oil Substitution

Available for Sale Commercially available in 2012

Phased Commercialization

Biomass

Ag Residue

Forest Fiber

Pyrolysis Oil to Energy & Fuels Vision

A Honeywell Company
Pyrolysis Oil as a Fuel Oil Substitute

- Specialized burner tips improve flame/burning
- Low emissions (GHG, NOx, SOx)
- Fuel consistency - ASTM D7544
- Flexibility to decouple pyrolysis oil production from energy generation (location and time)
- 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

Comparison of Cost of Buying #2 Fuel Oil to Producing Pyrolysiss Oil

~ 8 $US Million per Year Savings
Pyrolysis Oil to Green Electricity

- Compatible with specialized turbines
- Green electricity production cost is ~0.12 $US/kWh
  - Includes RTP operating cost and 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 to Green Transportation Fuels

• Conversion Objectives
  – Remove oxygen atoms
  – Reduce acidity and viscosity
  – Shape molecules to match gasoline and diesel/jet fuel hydrocarbons
  – 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
LCA Study Overview

- Conducted to ISO 14040 standards
- LCA software employed SimaPro 7.1 Cumulative Energy Demand & IPCC GWP 100a methodologies
- Functional unit for power = 1 kWh electricity generated
- Functional unit for biofuel = 1 MJ of fuel energy
- System boundaries:
  Raw material extraction (cultivation) through either electricity production or fuel combustion (WTW for biofuel)
- Primary Focus: Emission of GHGs
- Several feedstocks considered
  - Logging residues
  - Hybrid poplar
  - Hybrid willow
  - Sawmill waste

LCA study team included:
Dr. David Shonnard, Professor MTU
Jiqing Fan, Ph.D. Candidate
Matthew Alward, Undergraduate Researcher
Jordan Klinger, Undergraduate Researcher
Adam Sadevandi, Undergraduate Researcher
# RTP™ Mass & Energy Balance

## 400 BDMTPD of Hardwood Whitewood

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

### Typical 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>

### 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**
- **High Yields of Pyrolysis Oil, Co-products provide Process Energy**
- **Minimal Net Utilities (primarily electrical power)**
Feedstock GHG Emissions

Cultivation and Harvesting

<table>
<thead>
<tr>
<th></th>
<th>Residue</th>
<th>SRF Crops</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Logging</td>
<td>Willow</td>
</tr>
<tr>
<td>Biomass Yield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>odt/ha/yr</td>
<td>0.62</td>
<td>11.95</td>
</tr>
<tr>
<td>GHG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>kg CO₂-eq/kg dry Biomass</td>
<td>0.027</td>
<td>0.035</td>
</tr>
</tbody>
</table>

GHG Contribution by Process

Logging Residue

- Total of all Processes
- Combustion of Diesel
- Diesel, Low-sulphur
- Building Machinery

Willow

- Total of all Processes
- N₂O Emissions from N Fertilizer Use
- CO₂ Emissions from Diesel Combustion
- Ammonium Sulfate, as N, at Regional Storehouse/RER S
- Diesel, Low-sulphur, at Regional storage/RER S
- CO₂ from Heavy Fuel Oil Combustion
- Others

Hybrid/Poplar

- Total of all Processes
- Ammonium Nitrate
- CO₂ Emissions from Diesel Combustion
- N₂O Emissions from N Fertilizer Use
- Single Superphosphate, as P2O5
- Diesel, Low-sulfur
- Others

UOP 5398A-30
## Pyrolysis Oil Production

### Life Cycle GHG Emissions

<table>
<thead>
<tr>
<th>gCO₂ eq /MJ</th>
<th>PyOil Logging Residue</th>
<th>PyOil Willow</th>
<th>PyOil Poplar</th>
<th>PyOil Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass Cultivation and Harvesting</td>
<td>2.1</td>
<td>2.4</td>
<td>4.0</td>
<td>0</td>
</tr>
<tr>
<td>Biomass Transportation</td>
<td>3.8</td>
<td>0.9</td>
<td>0.8</td>
<td>0</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Total</td>
<td>14.5</td>
<td>11.9</td>
<td>13.4</td>
<td>8.6</td>
</tr>
</tbody>
</table>

\[
r_{\text{circle}} = \frac{2}{3} \times T \times \sqrt{\frac{F}{\pi \times Y \times f}} \quad \text{(Wright et. al.)}
\]

- \( t \): the tortuosity factor of the road
- \( f \): fraction of land devoted to biomass crops
- \( F \): feedstock biomass required in (short ton / acre / year)
- \( Y \): yield of biomass (short tons / acre)
GHG Sensitivity to Transport & Energy Source

**Pyrolysis Oil**

**GHG Emissions vs f**

<table>
<thead>
<tr>
<th>r_{\text{circle}} (miles)</th>
<th>f=0.03</th>
<th>f=0.1</th>
<th>f=0.3</th>
<th>f=0.6</th>
<th>f=0.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poplar</td>
<td>20.05</td>
<td>10.98</td>
<td>6.34</td>
<td>4.48</td>
<td>3.66</td>
</tr>
<tr>
<td>Willow</td>
<td>21.34</td>
<td>11.69</td>
<td>6.75</td>
<td>4.77</td>
<td>3.90</td>
</tr>
<tr>
<td>Residue</td>
<td>93.74</td>
<td>51.34</td>
<td>29.64</td>
<td>20.96</td>
<td>17.11</td>
</tr>
</tbody>
</table>

Transportation Distance vs. f

In parasitic system, a portion of the electricity generated from pyrolysis oil is used to operate RTP and Biomass pretreat units.

**Pyrolysis Oil**

**GHG Emissions vs Power Source**

Imported Power (US Grid Mix) vs. Parasitic System

- Pyrolysis
- Feedstock Transportation
- Feedstock Cultivation/Harvesting

f Value = Fraction of Land in Cultivation
Pyrolysis Oil Production footprint similar to other energy alternatives

Assumed biomass transport distances
- 200 km for logging residues
- 25 km for short rotation forest crops
- 0 km for sawmill residues (waste)

Pyrolysis Oil Production Life Cycle footprint greener than other alternatives
- 70-90% lower GHG emission
- SO\textsubscript{x} emission similar to Natural Gas
Multiple Scenarios Evaluated

- Co-firing Cases *(lowest capital)*
  - Fuel Oil Power Plant
  - Coal Power Plant
  - Natural Gas Power Plant

- Advanced Power Facilities *(highest efficiency)*
  - Gas Turbine Combined Cycle (GTCC) with heat recovery
  - Distributed Diesel Generator located at site
  - Parasitic Electric Power Supply

- Comparison to Direct Biomass Combustion (BC)
  - Dedicated facility at 18% efficiency (existing BC1)
  - Dedicated facility at 25% efficiency (modern BC2)
Comparisons of LC-GHG Emissions with Direct Biomass Combustion (BC)

BC1 = existing combustion/steam turbine unit at 18% efficiency
BC2 = modern combustion/steam turbine at 25% efficiency

Typical Fossil Electricity GHG Values in g/CO₂ eq/kWh
Coal ~ 1000, Oil ~ 820, Natural Gas ~ 550
Pyrolysis Oil Pathway to Renewable Electricity Generation

- Pyrolysis Oil co-firing maximizes use of existing power plant infrastructure
  - No new solids storage or solids handling systems required
  - Avoids issues associated with co-firing solid biomass (e.g. NO$_x$ catalyst fouling, Use of ash as cement additive)

- Enables wider use of biomass in co-firing applications
  - Compatibility with existing NG, Oil, and Coal facilities demonstrated

- Reduces GHG produced during biomass transport
  - Up to 4 x higher energy density per unit volume shipped

- Future application to high efficiency power generation in distributed stand-alone facilities
  - GTCC or Stationary Diesel Power Generators
LC-GHG for Pyrolysis Oil Gasoline

Preliminary Configuration for Integrated Bio-Refinery (IBR) Complex

H₂ Generation Unit

Pyrolysis Oil Conversion Unit

Rapid Thermal Processing Unit

Air → H₂ Generation Unit

Water → H₂ Generation Unit

Fuel → H₂ Generation Unit

Utilities → H₂ Generation Unit

Biomass → H₂ Generation Unit

Spent Air → Gasoline

Wastewater → Kerosene (Jet Fuel)

Steam → Diesel

Air

Water

Fuel

Utilities

Biomass

(Py)Gasoline is Primary Product
Several Biomass Feeds Processed
- Mixed Wood
- Corn Stover
- Poplar

Liquid Product is a HC mixture of
- Gasoline
- Kerosene
- Diesel

Quality similar to Petroleum Fuel
- 99.5+% Hydrocarbon
- LHV ~43 MJ/kg
- 70% Naphthenes & Aromatics
- High Octane Value

* UOP experience in commercial hydroprocessing process scale-up and design
LC-GHG for Pyrolysis Oil Derived Gasoline

68-77% Lower WTW GHG Emissions

Energy Allocation for Co-products
Summary

- A variety of biomass feedstocks can be converted to pyrolysis bio-oil using RTP process technology
  - Cost competitive with petroleum fuels
  - GHG emissions are 70-90% lower than fossil alternatives
- Pyrolysis bio-oil can be utilized by a wider spectrum of power generation technologies compared to biomass combustion
  - Biomass combustion: limited to co-firing with coal
  - Pyrolysis bio-oil: compatible with NG, coal, and oil systems
- Greenhouse gas emissions of pyrolysis bio-oil electricity
  - Savings of GHG emissions between 77 – 99% possible for pyrolysis oil electricity compared to US Grid electricity
  - High efficiency applications for pyrolysis -oil electricity are more favorable compared to direct biomass combustion electricity
- Greenhouse gas emissions of pyrolysis bio-oil transportation fuel
  - Savings of GHG emissions between 68 – 77% is achieved for pyrolysis oil gasoline compared to petroleum baseline
  - Hydrocarbon based composition is compatible with existing fuel infrastructure. “Blend wall” hurdles not expected to be an issue.
RTP Technology Benefits

**Economics**
- Economic solution for renewable energy
- Competitive relative to fossil fuels
- Leverages existing assets
- Provides alternate revenue stream

**Environment & Social**
- Reduction of greenhouse gases and emissions
- Waste disposal
- Minimum environmental Impact
- Agriculture development
- Employment

**Technical**
- Proven application
- Feedstock flexibility
- Minimal net utilities
- Storable product allows decoupling from end user

**Energy Security**
- Energy diversification
- Reduction of fossil energy requirements

*Pyrolysis to Energy Now – Transport Fuels in 2012*