Liquid Catalytic Conversion of
Biomass to Jet Fuel

BIO Pacific Rim Conference

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turning biomass into value...
Biofuels Categories

Lower left quadrant:

*Liquid phase* = smaller equipment.

*Catalytic* = faster = smaller equipment.

= Lower capital costs.
REACH Technology

**Renewable Acid-hydrolysis**

- Acid-hydrolysis – breaks down biomass to non-sugar intermediates.

**Condensation**

- Condensation – combines molecules to customize carbon chain length.

**Hydrotreating**

- Hydrotreating – deoxygenates to drop-in hydrocarbon fuel.
REACH Block Flow

- **Acid-hydrolysis**
  - Feed
  - LA
  - Furfural
  - Lignin
  - Char
  - CMF

- **Condensation Feed Prep**
  - Ethanol

- **Condensation Reaction**

- **Mild Hydrotreat**

- **Severe Hydrotreat**

- **Jet Fuel**

- **H2**
Time is Money

- Liquid Phase
- Catalytic
- Short Residence Time
- Feedstock Flexible

- $0.90 /Gal ($38/bbl) OpEx
- $3-5 /GPY CapEx
Cellulosic Jet Fuel / Diesel
• Remove all oxygen for hydrocarbon fuel product.
• Total number of carbons will range from 8 to 15.
• Iso, cyclic, and normal alkanes for freeze point control.
Jet Fuel Composition

Freeze Point = -48.4°C
JP-8 (Mil.) spec < -47°C
# Main Components in Jet Fuel (Jet A)

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>FORMULA</th>
<th>CHEMISTRY</th>
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<tr>
<td>n-Octane</td>
<td>C\textsubscript{8}H\textsubscript{18}</td>
<td>n-Paraffin</td>
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<tr>
<td>2-Methylheptane</td>
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<td>Naphthene</td>
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<tr>
<td>Ethylcyclohexane</td>
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<tr>
<td>o-Xylene</td>
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<tr>
<td>p-Xylene</td>
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<tr>
<td>Cis-Decalin</td>
<td>C\textsubscript{10}H\textsubscript{18}</td>
<td>Naphthene</td>
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<td>Tetralin</td>
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<td>Naphthalene</td>
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<td>1-Ethynaphthalene</td>
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<td>n-Hexylbenzene</td>
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<td>n-Hexadecane</td>
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<td>n-Decylbenzene</td>
<td>C\textsubscript{16}H\textsubscript{26}</td>
<td>Aromatic</td>
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</table>
Byproducts

Ethyl Formate –or- Formic Acid

- Food safe fumigant/animal feed supplement
- Environmentally friendly de-icer
- Fuel cell feed

Char

- Solid Fuel
- Fertilizer / Soil Enhancer
- Potential On-site Hydrogen Production
Optional Chemical Products

**Ethyl Levulinate (EL)**
- Many chemical uses: e.g. plasticizer production.
- Renewable home heating oil.

**Furfural**
- Solvent for diene extraction
- Resin manufacturing
Processing Advantages

- Lower Capital and Operating Expenses.
- Feedstock / product flexibility.
- Fuels match performance of petroleum products.

Does not:
- Depend on sugar intermediates.
- Depend on enzymes or fermentation.
- Directly produce a CO2 byproduct.
• U.S. Liquid fuels sales in 2011 was estimated at over 200 Billion gallons where just under 22 Billion was Jet and just under 45 Billion was Diesel (Source: US Energy Information Association)

• RFS2 mandates biofuels must ramp up to a minimum of 21 Billion gallons annually by 2022 (@$4.00 per gallon) or $84 Billion market for 2nd generation biofuels

• A 2% market share would translate to revenue of nearly $2 Billion for Mercurius in 2022, with an $84 Billion market assuming $4/gallon
Customers

- Prompted by the Navy and Air Force, the DOD is committed to supply 50% of fuel needs with non-petroleum fuels by 2020.
- Many airlines, including Alaska, Delta and Virgin Australia have committed to using increasing amounts of biofuels.
- Diesel vehicle fleets are potential high volume customers.
- Customers for Optional Chemicals and By-Products include not only fuel customers but also agricultural and specialty chemical companies.
Scale-up Strategy

REACH™ Pilot Plant

- 10 MTPD (dry metric tons per day)
- Target 2014 start-up
- Hydrotreating - Existing facilities available

REACH™ Commercial scale-up ~ 50:1

- 500 MTPD
- Target 2016 start-up
- US Department of Defense, DPA grant for military fuel
- Other grants and loan/bond guarantees available
- Plan to have in place off-take agreements with customers
Build and operate in Michigan.

4.6 mil$ grant from the US DOE.

10 Dry Metric Tons/day Hydrolysis/Condensation.

Hydrotreating - existing small scale units.

Initial feedstock – local corn stover.
Key Partners

- CSIRO (Australia) – process optimization research
- Purdue University – scientific/engineering/aviation expertise
- UC Davis – Hydrolysis technology and IP
- Pacific Northwest National Laboratory (PNNL) – past hydrotreating and catalyst development
- Haldor Topsoe - catalyst / hydrotreating technology
- Michigan State University Bioeconomy Institute
Purdue Overview

- Purdue Team Members supporting Mercurius
- Overall Project Approach & Integration
- Feedstock: Type, Supply, Logistics & Economics
- Conversion: Hydrolysis Optimization Support
- Primary Pilot Plant Location & Regional Support Facilities
- **Fuel Validation: Chemical characterization, testing and emissions**
- Synthesis:
  - GHG and LCA modeling using GREET
  - Techno-economic modeling
- Estimated Budget & Cost-share
Support & Testing Facilities

- **AirTIES**, Air Transport Institute for Environmental Sustainability is co-located at the Purdue airport
  - A unique advantage for accessibility to fuels, components and aircraft

- AirTIES provides the coordinating link between:
  - Academic researchers
  - Industry partners (upstream & downstream)
  - End-users
  - DoD and regulating bodies

- **Expertise includes:**
  - Fuel requirements,
  - Major market and policy drivers,
  - FAA regulations,
  - Techno-economic analyses
  - Technological testing
Fuel Validation

- Renewable jet fuels will be analyzed and validated in real-time
  - Chemical characteristics of key intermediates and finished fuels
  - Validation of Fuels “Fit-for-purpose”
  - Engine and component level testing
  - Gaseous and Particulate Emissions
- Strategic expertise, certification & support from Purdue, Air Force Research Lab (AFRL) and Baere Aerospace
- Candidate fuels will be tested in accordance with ASTM D4054
- High-impact, critical specifications will be prioritized to reduce technical risk and ensure efficient use of capital
- Potential to provide feedback to inform upstream chemical/engineering/design and processing steps
ASTM Alternative Fuel Evaluation,
ASTM D4054, MIL-HDBK-510

SOURCE: FAA, CRC Emerging Fuels Group, May 2010
Characterization & Certification

• Focus on ‘Priority’ Attributes

• “Fuel Specification” Properties:
  • Composition
  • Volatility & Density
  • Fluidity
  • Combustion
  • Thermal Stability
  • Contaminants, etc

• “Fit-for-Purpose” Properties:
  • Chemistry
  • Bulk Physical & Performance*
  • Electrical Properties
  • Ground Handling/Safety
  • Compatibility

• Component-Interface Considerations

*Includes: Boiling pt, Lubricity, Viscosity, Specific Heat, Density, Surface tension, Solubility of air, Thermal properties…
Fuel/Engine Test & Validation

- Turboprop Test Cell
- Turboshaft Test Stand
- Jet Turbine Cell
- Piston Engine Dynamometer Test Cell
- Zucrow Combustion Test & Design
- Data Center
- Cirrus SR-20 & SR-22 Aircraft
- Very Light Jet Aircraft
- Experimental Beechcraft Duchess
- Aircraft Materials and Components Testing
Thank you.

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