HYDROGEN FROM BIOMASS
FOR URBAN TRANSPORTATION

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DOE Hydrogen Program Review

This presentation does not contain any proprietary or confidential information.
Overview

Timeline

• Project start date: 2003
• Project end date: 2004
• Percent complete: 100%

Barriers

• Feedstock cost and availability
• Efficiency of pyrolysis and reforming technologies
• Durable, efficient and impurity tolerant catalysts
• Hydrogen separation and purification
• Market and delivery

Partners

• National Renewable Energy Lab
• Eprida, Inc.
OBJECTIVES

• **Undertake the engineering research and pilot scale process development studies relating to:**
  - Production of hydrogen from biomass (e.g., agricultural residues) for $2.90/kg H₂ by 2010; $2.30 by 2015
  - Separation, safe storage and utilization of the hydrogen
  - Production and identification of uses of the co-products

• **Increase diversity of the Nation’s workforce and the broader impact of the project through the education and training of underrepresented minorities.**
APPREACH

• Develop process based on biomass pyrolysis and steam reforming of pyrolysis vapors (bio-oils and gases).

• Perform catalytic steam reforming in a fluidized-bed (25-250 kg/day H$_2$ production)

• Conduct pyrolysis at: T: 500°C; P: 10 psig; Feed Rate: 50-500 kg/hr pelletized peanut shells.

• Study reforming at: T: 850°C; P: 6 psig; H$_2$O/C = 5, Catalyst: nickel-based (300-500 microns)
The Peanut Shell to Hydrogen Cycle

Stationary fuel cell power generation
Schematic Flow Diagram of the Biomass Pyrolysis-reformer Process
Photo of Hydrogen Production System
Photo of Hydrogen Flame
Total Gas Composition VS. Time (N2-free basis)
Nitrogen free-Base Gas Composition Vs. Time (24hrs)
Temperature and differential pressure of the catalytic reformer
Typical Analysis of Peanut Shell Feedstock

- **Component**
  - Lignin: 34.8%
  - Glucan: 21.1%
  - Extractives: 14.2%
  - Protein: 11.1%
  - Xylan: 7.9%
  - Ash: 3.4%
  - Arabinan: 0.7%
  - Galactan: 0.2%
  - Mannan: 0.1%
  - Others (e.g., free carbohydrates): 6.5%
# TYPICAL PRODUCT COMPOSITION/ YIELDS

<table>
<thead>
<tr>
<th>Pyrolyzer (Yields)</th>
<th>Reformor (Gas product composition, on dry N\textsubscript{2}-free basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Char</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>32%</td>
<td>49%</td>
</tr>
<tr>
<td>Water</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>32%</td>
<td>36%</td>
</tr>
<tr>
<td>Bio-Oils</td>
<td>Carbon Monoxide</td>
</tr>
<tr>
<td>31%</td>
<td>9%</td>
</tr>
<tr>
<td>Gases</td>
<td>Methane</td>
</tr>
<tr>
<td>5%</td>
<td>8%</td>
</tr>
</tbody>
</table>
Pyrolysis Bio-Oil Product

- **Empirical Formula:** $\text{CH}_{1.9}\text{O}_{0.7}$
- **Water:** 15 – 25%
- **Organics:** 75 – 85%
  - Aldehydes, alcohols and acids from carbohydrate fraction
  - Phenolics from lignin fraction

**Representative Compounds**

<table>
<thead>
<tr>
<th>Water</th>
<th>Ethanol</th>
<th>Methanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclohexanol</td>
<td>Formic Acid</td>
<td>Acetic Acid</td>
</tr>
<tr>
<td>Glucose</td>
<td>Phenol</td>
<td>O-cresol</td>
</tr>
<tr>
<td>2-Butanone</td>
<td>Dodecanoic acid</td>
<td>Tannin</td>
</tr>
</tbody>
</table>
CONCLUSIONS

• The pilot scale plant has increased the hydrogen production rate by orders of magnitude comprising to the bench scale

• Using peanut shells as feedstock, the overall yield from this process is up to 7 wt% hydrogen and 32 wt% charcoal/activated carbon

• The preliminary techno-economic analysis indicates that the integrated process has the potential of producing hydrogen at the cost of about US$6.5/GJ
ACCOMPLISHMENTS

• Completed design, construction and testing of reformer (Phase 1)
• Completed integration of reformer with pyrolyzer (Phase 2)
• Completed 100 hours of successful operation of pilot unit (Phase 2)
• Completed modifications for 1,000 hours operation
• Completed 24 hours catalyst and process testing
• Identified potential co-products options
• Developed partnership and collaboration with potential companies/organizations
• Educated and trained several underrepresented minorities on project
ACKNOWLEDGEMENTS

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  - National Renewable Energy Laboratory, CO
  - University of Georgia, Athens