Enabling Industry with Research and Deployment of Biofuels, Biopower, and Bioproducts

SPM4
4th Stakeholder Plenary Meeting
European Biofuels Technology Platform
Brussels, Belgium – September, 14 2011

Paul E. Grabowski
Office of the Biomass Program
U.S. Department of Energy
Science & Discovery
• Connecting basic and applied bioscience
• Conducting breakthrough R&D
• Supporting commercialization of new technology

Economic Prosperity
• Creating jobs and maintaining competitive technology edge
• Supporting the emerging U.S. bioenergy industry and market

Climate Change
• Reducing GHG emissions by 60% for cellulosic biofuels and 50% with advanced biofuels
• Validating and demonstrating low-carbon power generation technologies
• Influencing development of criteria and indicators for sustainable biofuel production

Clean, Secure Energy
• Developing & demonstrating advanced biofuels technologies
- At low % blends, refiners can adapt
- As % blend increases, issues arise in refining and blending:
  - Refinery “balance” (light / heavy, H₂, octane, vapor pressure, …)
  - Petrochemical feedstocks (naphtha, pen-hex, BTX, light paraffins & olefins, …)
- Ethanol competes with gasoline, batteries, H₂, mass-transit, …, while only hydrocarbon liquid fuels compete in diesel & jet markets

Biomass Program Mission, Objectives, Goals

R&D Priorities

• Achieving biofuel cost targets (modeled)
  <$2/gal for cellulosic ethanol;
  <$3 for cellulosic “drop-ins”
• Developing bio-power and bio-products
• Meeting the EISA Renewable Fuel Standard
• Investing to meet targets (~$200M/yr)

Encourage Markets

• Close collaboration with USDA, EPA, DoD, and other Agencies, States, and NGO’s
• Pilot and commercial demonstrations
• Infrastructure for biofuels delivery (including fuel dispensers)
• Subsidies & other policy drivers

Research, Development, and Demonstration

- Feedstocks
- Biochemical and Thermochemical Conversion
- Biopower Biofuels Bioproducts
- Integrated Biorefineries
- Infrastructure

Crosscutting Activities

Analysis; Sustainability; Partnerships, Communications, and Outreach
Feedstock Supply R&D
Regional Feedstock Bioenergy Crop Trials

http://www1.eere.energy.gov/biomass/pdfs/field_trials_map2v2.pdf

Energy Efficiency & Renewable Energy

Wednesday, September 14, 2011
Feedstock Logistics

Five projects selected August 2009 to design and demonstrate systems to handle:
• Harvesting
• Collection
• Preprocessing
• Transport
• Storage

Development of the Deployable Process Demonstration Unit (PDU) will help bridge gap between producers and refineries
• Test supply system concepts, new equipment designs, and deploy new technologies
• Produce engineered feedstocks to meet commodity-scale performance metrics and advanced conversion characteristics
Exploring Routes to Convert Biomass

**Integrated Biorefineries**

**Biochemical Conversion**

- Hydrolysis → Sugars → Fermentation
  - Catalytic Conversion → Upgrading

**Thermochemical Conversion**

- Fast Pyrolysis → Liquid Bio-oil
  - Upgrading
    - Zeolite Cracking
    - Hydrogenolysis
- Gasification → Syngas
  - Fischer Tropsch
  - Alcohol Synthesis

**Feedstock Production & Logistics**

- Energy crops
- Forest Residue
- Agricultural Residue
- Algae

**Refining**

- DDGS
- Lignin
- Ethanol
- Butanol
- Olefins
- Gasoline
- Diesel
- Others

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Biochem Platform Organizational Structure

Feedstock Supply

- Transportation
- Logistics
- Preprocessing

Pretreatment ➔ Hydrolysis ➔ Biological Conversion ➔ Chemical Conversion ➔ Product Recovery

DECONSTRUCTION
- Pretreatment – Decrease recalcitrance
  - Increase C5/C6 yields
  - Decrease sugar degradation
  - Decrease reagent loading

- Hydrolysis – Produce pure & cheap sugars
  - Increase enzymatic activity/decrease enzyme titer
  - Utilization of non-C6 polysaccharides
  - Optimize chemical/catalytic routes

PRODUCT TRANSFORMATION

- Biological Conversion:
  - Strain development
  - C5/C6 co-fermentation
  - Increased cellular product output rates
  - Increased toxicity resistance and process robustness

- Chemical Conversion:
  - Optimize chemical/catalytic reforming of sugars into fuels and chemicals

Product End-Use

- Optimize separations (i.e., distillation)
- Increase efficiency

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Biochemical Cost Targets

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<td>Prehydrolysis/ treatment</td>
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<td>Enzymes</td>
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<td>Saccharification &amp; Fermentation</td>
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<td>Distillation &amp; Solids Recovery</td>
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<td>Balance of Plant</td>
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<td>$0.64</td>
<td>$0.47</td>
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Thermochemical Conversion

Feedstock Supply

Feed Processing

Minimize ash content, mean particle size, moisture

Gasification

Minimize tar formation
Maximize clean syngas production

Syngas Cleanup

Reform tars and methane, minimize inorganics

Fuel Synthesis

Optimize yield of fuel synthesis catalysts and processes.

Pyrolysis

Minimize char formation
Maximize stable oil production

Stabilization & Upgrading

Reduce reactive oxygen species

Fuel Synthesis

Catalytic upgrading and bio-oil distillation

BIOFUELS

Minimize mean particle size, moisture

Energy Efficiency & Renewable Energy

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Gasification Cost Targets

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<td>Gasification ($ / Gal Ethanol)</td>
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<td>Synthesis Gas Cleanup (Reforming and Quench) ($ / Gal Ethanol)</td>
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<td>$0.58</td>
<td>$0.42</td>
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<td>Acid Gas and Sulfur Removal ($ / Gal Ethanol)</td>
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<td>Synthesis Gas Compression and Power Recovery ($ / Gal Ethanol)</td>
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<td>Fuel Synthesis Reaction ($ / Gal Ethanol)</td>
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<td>Product Recovery and Purification ($ / Gal Ethanol)</td>
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<td>$0.12</td>
<td>$0.11</td>
<td>$0.10</td>
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<td>Balance of Plant ($ / Gal Ethanol)</td>
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<td>$0.11</td>
<td>$0.09</td>
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<td>Processing Total ($ / gal ethanol)</td>
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Pyrolysis Cost Targets

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<tr>
<td>$/gal gasoline</td>
<td>$6.30</td>
<td>$4.92</td>
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<tr>
<td>$/gal diesel</td>
<td>$6.37</td>
<td>$4.99</td>
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<tr>
<td>$/gge total fuel</td>
<td>$6.01</td>
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<td>Feed Drying, Sizing, Fast Pyrolysis, $/gal total fuel</td>
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<td>$0.53</td>
<td>$0.52</td>
<td>$0.34</td>
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<td>Upgrading to Stable Oil, $/gal total fuel</td>
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<td>$3.34</td>
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<td>Fuel Finishing to Gasoline and Diesel, $/gal total fuel</td>
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<td>Balance of Plant, $/gal total fuel</td>
<td>$0.80</td>
<td>$0.79</td>
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</table>
NABC Research Strategies

**Project Objective:** Develop cost-effective technologies that can produce advanced “drop-in” biofuels that are compatible with today’s transportation infrastructure and are produced in a sustainable manner.

DOE Funding $35M/Cost Share $15M over 3 years

NABC matrix of technology and teaming ensures development of complete integrated processes.

**Downselect is currently on-going**

**Consortium Leads:** NREL, PNNL

**Consortium Partners:** Albemarle, Amyris, ANL, BP Products, Catchlight, Colorado School of Mines, Iowa State U, LANL, Pall, RTI, Tesoro, UC Davis, UOP, Virent, Washington State U.
Algal Biofuels Overview

Potential of Algal Biofuels
- High productivity
- Minimizes competition with agriculture
- Can use waste and salt water
- Recycles carbon dioxide
- Integrated production of fuels and co-products

Challenges to commercializing Algal Biofuels
- Affordable and scalable algal biomass production
- Feedstock production & crop protection
- Energy efficient harvesting and drying
- Extraction, conversion, and product purification
- Siting and sustainability of resources
2010 Algae Portfolio

- Feedstock production and crop protection: R&D consortia, 3 integrated biorefinery (IBR) projects, Sandia Laboratory project

- Energy efficient harvesting and drying: R&D consortia, 3 IBR projects, INL project

- Extraction, conversion, and product purification: R&D consortia, 3 IBR projects, NREL and PNNL projects

- Siting and sustainability of resources: National Academies of Science study, 3 IBR projects; ANL, PNNL, and ORNL projects

$178M

Pilot-scale raceway ponds, courtesy of Cellana LLC

Pilot-scale photobioreactor systems, courtesy of ASU
Biopower Initiative

Proposed DOE initiative to accelerate the development and deployment of advanced biopower technologies

– The Initiative is establishing partnerships with industry and supporting efforts to:
  – Analyze and develop a knowledge base for co-firing biomass (at amounts up to 20% HHV) with coal as a near-term deployment option for reducing GHG emissions.
  – Conduct R&D on pretreatment and conversion technologies to develop enhanced biomass fuels optimized for integration with advanced power systems and reduced production costs.
  – Demonstrate the use of densified biomass in advanced technology power systems.

This FY2011 initiative is on hold pending disposition of continuing budget resolution.

Biopower activities have also been included in the FY2012 Federal budget released February 14, 2011.
Integrated Biorefineries

- 29 R&D, pilot, demonstration and commercial scale projects selected to validate IBR technologies

- Diverse feedstocks represented
  - Agricultural Residues
  - Energy Crops
  - Algae/CO2
  - Forest Resources
  - Municipal Solid Waste
  - Non-edible oils

- A variety of transportation fuels, biobased products, and biopower will be developed
  - Cellulosic Ethanol
  - Butanol
  - Methanol
  - Renewable Gasoline
  - Renewable Diesel
  - Jet Fuel
  - Biodiesel
  - Biobased Chemicals
  - Process heat and steam
  - Electricity

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Analysis Activities - guide our research

- State-of-technology assessment conducted by NREL, ORNL, PNNL, SNL, INL
- Land-use Change Model Development conducted by NREL, University of Minnesota, ORNL, PNNL, ANL, Purdue University

- Improving the compatibility of hydrocarbon-based biofuels through summarizing barriers to widespread distribution; conducted by ORNL
- Well-to-wheels analysis and expansion of Greenhouse Gases Regulated Emissions and Energy Use in Transportation (GREET) model for emerging biofuels production pathways, conducted by ANL
Sustainability across the Biomass Program

- **Feedstock production and logistics**
  - Evaluate nutrient and carbon cycling
  - Assess impact on land and resource use

- **Conversion**
  - Minimize water consumption, air pollution, and waste
  - Maximize efficiency

- **End use**
  - Minimize GHG emissions
  - Avoid negative impacts on human health

**Cross-cutting**
- Life cycle analysis of water consumption and GHG emissions
- Land use change modeling
- Water quality analysis

**Key Materials**
- Ethanol
- Diesel
- Gasoline
- Jet fuel
- Biopower
- Bioproducts
Sustainability

- Reduce greenhouse gas emissions
- Reduce negative environmental impacts (fertilizer runoff, land use change, water consumption) and promote benefits

- Lower costs
- Improve fuel properties
- Enhance economic opportunities for all stakeholders along the supply chain

- Promote rural development and workforce training
- Reduce oil imports

Sustainability Platform Activities
- Monitor and support sustainability of emerging industry
- Apply sustainability criteria in funding biorefineries
- Develop technologies and best practices to further mitigate GHG emissions and with improved environmental impacts
OBP International Priorities and Goals:
• Accelerate progress toward biofuels R&D goals
• Reduce global greenhouse gas emissions and reliance on oil
• Promote industry partnerships and economic development

Scope of International Work:
• Collaborative activities span our scope of research priorities
• Partnerships with:
  • Brazil
  • Canada
  • China
  • Europe
  • India
  • Israel
  • Japan
  • Sweden
  • Key multilateral forums
    International Energy Agency (IEA)
    Global Bioenergy Partnership (GBEP)
    International Panel on Climate Change (IPCC)
    Asia-Pacific Economic Coop. (APEC)
    Roundtable on Sustainable Biofuels (RSB)
Cross-cutting efforts: Bioenergy Knowledge Discovery Framework

- Access to collaboration, data management, analysis, and visualization tools designed to support bioenergy infrastructure research
- Integrates bioenergy spatial data with socioeconomic and industrial factors to improve planning, development, and management decisions

bioenergykdf.net
The U.S. Department of Energy Biomass Program produces a variety of publications focused on biomass technologies including factsheets, reports, case studies, presentations, analyses, and statistics.

To learn more visit: www.biomass.energy.gov/pdfs/publications.pdf or the Biomass Publication and Product Library at www.biomass.energy.gov/publications.html

Additional Items of Interest

DOE on Twitter - http://twitter.com/energy
EERE Info Center - www1.eere.energy.gov/informationcenter
Alternative Fuels Data Center - http://www.eere.energy.gov/fuels/ethanol.html
Bioenergy Feedstock Information Network - http://bioenergy.ornl.gov/
Biomass R&D Initiative – www.biomass.govtools.us
Grant Solicitations - www.grants.gov
Office of Science - http://www.er.doe.gov/
Secretary Chu on Facebook - http://www.facebook.com/stevenchu
Could a Common Household Fungus Reduce Oil Imports?

Submitted by Ron Squires on June 21, 2011 - 11:37am

Nobody likes opening a fridge to find food that's spoiled, but imagine if the same mold that ruins Egyptians and oranges could double as a key ingredient in the recipe to reduce U.S. dependence on foreign oil. It's an outcome even less imaginary than you might think, thanks to Energy Department researchers on the common fungus Aspergillus niger. Scientists at the Department's Pacific Northwest National Laboratory (PNNL) are working to harness the natural process that spoils fruits and vegetables as a way to make fuel and other petroleum substitutes from the parts of plants that we can't eat.
Projects in **GREEN** funded through the American Reinvestment and Recovery Act.
Projected volumes and dates for capacity coming online are based on information presented by IBR projects at the Peer Review conducted on Feb 1-3, 2011 and the project fact sheets located on the Program’s IBR website, found at:

http://www1.eere.energy.gov/biomass/integrated_biorefineries.html
http://obpreview2011.govtools.us/IBR/

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<th>Project (State)</th>
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<th>2013</th>
<th>2014</th>
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<td>Bluefire (MS)</td>
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Cumulative Capacity in Million Gals / Year

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<th>2011</th>
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# Integrated Biorefinery Pathways

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<td>Agricultural Residues</td>
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<td>sugar</td>
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<td>ICM, Logos, Pacific Ethanol RSA, Zeacem</td>
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<tr>
<td></td>
<td>biochemical</td>
<td>sugar</td>
<td>fermentation</td>
<td>diesel</td>
<td>Amyris</td>
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<td>succinic acid</td>
<td>Myriant</td>
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<td>Forest Resources</td>
<td>biochemical</td>
<td>sugar</td>
<td>fermentation</td>
<td>ethanol</td>
<td>Lignol, Mascoma, API, Blue Fire, Range Fuels</td>
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<td></td>
<td>gasification</td>
<td>syngas</td>
<td>catalysis</td>
<td>diesel</td>
<td>Haldor Topsoe, Clear Fuels, New Page, Flambeau, GTL, UOP</td>
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<tr>
<td></td>
<td>pyrolysis</td>
<td>oil</td>
<td></td>
<td>jet fuel</td>
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## Integrated Biorefinery Pathways

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Conversion</th>
<th>Intermediate</th>
<th>Conversion</th>
<th>Product</th>
<th>Partner</th>
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<tr>
<td>Waste</td>
<td>gasification</td>
<td>syngas</td>
<td>fermentation</td>
<td>ethanol</td>
<td>INEOS, Enerkem</td>
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<tr>
<td>Algae</td>
<td>open pond</td>
<td>oil</td>
<td>catalysis</td>
<td>diesel jet fuel</td>
<td>Sapphire</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>transesterification</td>
<td>biodiesel</td>
<td>Solazyme</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>metathesis</td>
<td>diesel jet fuel</td>
<td>Elevance</td>
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<tr>
<td></td>
<td>Closed bioreactor</td>
<td>oil</td>
<td>catalysis</td>
<td>diesel jet fuel</td>
<td>Algenol</td>
</tr>
</tbody>
</table>
Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol

Dilute-Acid Pretreatment and Enzymatic Hydrolysis of Corn Stover

D. Humbird, R. Davis, L. Tao, C. Kinchin, D. Hsu, and A. Aden
National Renewable Energy Laboratory
Golden, Colorado

P. Schoen, J. Lukas, B. Olthof, M. Worley, D. Sexton, and D. Dudgeon
Harris Group Inc.
Seattle, Washington and Atlanta, Georgia

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report
NREL/TP-6100-47764
May 2011

Contract No. DE-AC36-08GO28308

Conversion Platform Design Cases

Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating and Hydrocracking: A Design Case

SR Jones
C Valkenburg
CW Walton
DC Elliott

JE Holladay
DJ Stevens
C Kinchin
S Czernik

February 2009

Pacific Northwest
National Laboratory
## Comparison of Wood-Derived Bio-Oils and Petroleum Fuel

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Fast Pyrolysis Bio-oil</th>
<th>Hydrothermal Bio-oil</th>
<th>Heavy Petroleum Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content, wt%</td>
<td>15-25</td>
<td>3-5</td>
<td>0.1</td>
</tr>
<tr>
<td>Insoluble solids, %</td>
<td>0.5-0.8</td>
<td>1</td>
<td>0.01%</td>
</tr>
<tr>
<td>Carbon, %</td>
<td>39.5</td>
<td>72.6-74.8</td>
<td>85.2</td>
</tr>
<tr>
<td>Hydrogen, %</td>
<td>7.5</td>
<td>8.0</td>
<td>11.1</td>
</tr>
<tr>
<td>Oxygen, %</td>
<td>52.6</td>
<td>16.3-16.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Nitrogen, %</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Sulfur, %</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>2.3</td>
</tr>
<tr>
<td>Ash</td>
<td>0.2-0.3</td>
<td>0.3-0.5</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>HHV, MJ/kg</td>
<td>17</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>Density, g/ml</td>
<td>1.23</td>
<td>1.10</td>
<td>0.94</td>
</tr>
<tr>
<td>Viscosity, cp</td>
<td>10-150@50°C</td>
<td>3,000-17,000 @ 60°C</td>
<td>180@50°C</td>
</tr>
</tbody>
</table>
Co-fired: Co-firing systems involve the mixing of biomass with fossil fuels in conventional power plants after some modification of the existing equipment.

Direct-fired: Most biopower plants use direct-fired systems, which burn biomass directly to produce steam.

Gasification: Through gasification, biomass is heated to convert solids into a synthesis gas, which is burned in conventional boilers or used in turbines to produce electricity.

Pyrolysis: Through pyrolysis, biomass is heated and converted into a liquid, which can be used to generate electricity or further converted into fuels or chemical intermediates.

Combined Heat and Power (CHP): Combined heat and power (CHP) systems have system efficiencies as high as 60-80%, and are an effective use of biomass, which enables recovery of
NABC: Deliver pilot-scale technologies for gasoline, diesel, and jet fuel that use today’s infrastructure
U.S. Transportation Demand

- **Gasoline (cars & trucks)**: 137 bgy
- **Diesel (on-road, rail)**: 43 bgy
- **Aviation (jet fuel)**: 23 bgy

<table>
<thead>
<tr>
<th>Products in a Barrel of Crude (gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel - 10.31</td>
</tr>
<tr>
<td>Jet Fuel - 4.07</td>
</tr>
<tr>
<td>Other Products - 7.01</td>
</tr>
<tr>
<td>Liquefied Petroleum Gases (LPG) - 1.72</td>
</tr>
<tr>
<td>Other Distillates (heating oil) - 1.38</td>
</tr>
<tr>
<td>Heavy Fuel Oil (Residual) - 1.68</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor gasoline</td>
<td>137</td>
<td>126</td>
</tr>
<tr>
<td>Diesel</td>
<td>43</td>
<td>71</td>
</tr>
<tr>
<td>Jet fuel</td>
<td>23</td>
<td>30</td>
</tr>
</tbody>
</table>

Source: Energy Information Agency

Wednesday, September 14, 2011