Renewable Fuels & Vehicles Overview to State Energy Advisory Board

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DOE Programs Supported
Advanced Energy Initiative

“Changing the way we Fuel our Vehicles”

Goals

• Develop advanced battery technologies that allow plug-in hybrid electric vehicles to have a 40 mile range operating solely on battery charge.

• Accelerate progress towards the President’s goal of enabling large numbers of Americans to choose hydrogen fuel cell vehicles by 2020.

• Foster the breakthrough technologies needed to make cellulosic ethanol cost competitive with corn-based ethanol by 2012.
U.S. Biofuels Status

• **Biodiesel** ¹
  – 171 commercial plants
  – 2.2 bg/y capacity (2008)
  – 450 mg produced (2007)

• **Corn ethanol** ²
  – 162 commercial plants
  – 9.4 bg/y capacity (+ 4.2 bg/y planned) (2008)
  – 6.5 bg produced (2007)

• **Cellulosic ethanol (2008)**
  – 13 demo plants DOE-funded
  – ~250 mg/y capacity projected

Sources: 1- National Biodiesel Board, 2 - Renewable Fuels Association
U.S. Transportation Fuel Goals & RFS

- President’s “20-in-10”
  35 billion gallons of alternative fuels by 2017

  36 billion gallons of renewable fuels by 2022

- DOE “30x30 Goal”
  60 billion gallons of ethanol (30% of today’s gasoline consumption) by 2030
1.3 Billion Ton Biomass Scenario

The "Billion Ton Study"

1.3 billion tons of Biomass-Heating Value Equivalent

Yields Based on Mid-Term Conversion Technology

- Biochemically Convert Biochem Residues & Forest Resources (0.5)
- Biochemically Convert Non-Edible Carbohydrates (1.1)
- Near-Term Corn Without Affecting Food Prices (0.3)

U.S. Petroleum Production Levels

- 3.5 U.S. Oil Production - Max. 1970
- 2.0 U.S. Oil Production - 2003

Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
State of Technology – Biochemical

State of technology progress toward the 2012 goal (estimated 2007 dollars)
Technical Barrier Areas for $1.33

Biochemical Ethanol

Pretreatment >> Conditioning >> Enzymatic Hydrolysis >> Co-fermentation of C5 & C6 Sugars >> Product Recovery

- Enzyme Production
- Enzyme Cost
- Feedstock Variation
- Feedstock Quality
- Feedstock Cost

Areas of NREL Research & Development focus

Biochemical Process Development Unit

- Sugar Losses
- Glucose Yield (titer)
- Solid Loading
- Enzyme Cost
- Hydrolyzate Toxicity
- Reactor Costs

Products

By-products

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Technical Barrier Areas for $1.33

**Thermochemical Ethanol**

Areas of NREL Research & Development focus

- Feedstock Interface
- Gasification
- Gas Cleanup & Conditioning
- Fuel Synthesis
- Heat & Power
- Products
- By-products
- Separations
- Recycle
- Selectivity

- Size Reduction
- Storage & Handling
- De-watering
- Drying

- Ethanol
- Methanol
- n-Propanol
- n-Butanol
- n-Pentanol

**Thermochemical Process Development Unit**

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Integrated Cellulosic Ethanol Biorefinery

Starch or Grain → Starch Hydrolysis → Fermentable Sugars

Fermentable Sugars:
- Glucose
- C5/C6 Sugars
- C5 Sugar(s)

Thermochemical Conversion → Lignin Residue

Lignocellulosic Biomass → Pretreatment

Product Recovery:
- Food Products
- Animal Feed
- Ethanol
- Chemicals

- Heat and Power
- Fuels and Chemicals
  - Pyrolysis Oil
  - Synthesis Gas
Major DOE Biofuels Project Locations

Four Commercial-Scale Biorefinery Projects: up to $305 million
Nine Small-Scale (10%) Biorefinery Projects: up to $240 million (first round)
Three Bioenergy Centers: up to $405 million
Four Thermochemical Biofuels Projects: up to $7.7 million
Four Improved Enzyme Projects: up to $33.8 million
Five Projects for Advanced Ethanol Conversion Organisms: up to $23 million
Range of Biofuels

**Technology Maturity**

- **Low**
  - Ethanol
  - Biodiesel
  - Green Diesel
  - Butanol
  - Syngas Liquids
  - Bio-oil Derivative
  - H2 from Biomass
  - Diesel from Algae
  - Hydrocarbons from Carbohydrates

- **High**

**Key Drivers**

<table>
<thead>
<tr>
<th>Technology Maturity</th>
<th>Key Drivers</th>
<th>Value Added</th>
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</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td>New market for grain and agriculture products. Large supply of lignocellulose.</td>
<td>High octane gasoline blend stock from carbohydrates.</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>New market for excess oils, fats, and greases.</td>
<td>Petroleum compatible and biodegradable.</td>
</tr>
<tr>
<td>Green Diesel</td>
<td>Lower cost and higher product quality than FAME.</td>
<td>Utilize existing assets. High quality jet fuel or diesel.</td>
</tr>
<tr>
<td>Butanol</td>
<td>New market for grain and agriculture products. Large supply of lignocellulose.</td>
<td>Better gasoline blending properties than ethanol.</td>
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<tr>
<td>Syngas Liquids</td>
<td>Integration of biomass with Coal, Coke, Shale, or Heavy Oils.</td>
<td>High quality jet fuel or diesel. Reduced criteria for sequestration, and economy of scale (in combination with fossil).</td>
</tr>
<tr>
<td>Bio-oil Derivative</td>
<td>Technical fit with woody biomass and liquid bio-crude.</td>
<td>Potential to integrate into existing large scale refinery and pipeline infrastructure.</td>
</tr>
<tr>
<td>H2 from Biomass</td>
<td>Potential transportation fuel from any fuel/power source.</td>
<td>Ideal feed for fuel cells, and lowest tail pipe emissions.</td>
</tr>
<tr>
<td>Diesel from Algae</td>
<td>Lg. source of biomass on non-arable land, and capture of CO2.</td>
<td>High quality jet fuel or diesel yield per acre, with both off-shore and on-shore potential.</td>
</tr>
<tr>
<td>Hydrocarbons from Carbohydrates</td>
<td>Better compatibility with petroleum products.</td>
<td>Potential for higher reaction rates than fermentation, and potential as H2 carrier.</td>
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**Organizations Leading the R&D**

- **Grain/Agriculture**
- **Coal**
- **Petroleum**
- **Forestry**
- **Academia & Startups**

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Current Biodiesel Conversion Process

Seed Oils → Feedstock Preparation
Seed Oils, Fats & Greases → Transesterification Process
Methanol → Transesterification Process

Product Recovery
- Biodiesel
- Glycerol

(Existing Biodiesel “Biorefineries”)
Green or Renewable Diesel

Oils, Fats, and Greases as Bio-Renewable Petroleum Refinery Feedstocks

- Co-processing of oils and greases with petroleum fractions
- Utilize existing refinery process capacity
- Lower conversion costs than biodiesel
- Higher quality diesel blending component
- Gasoline/Diesel ratio flexibility, depending upon season, needs, etc.
Green Diesel and Jet Fuel

- Hydrotreating of biorenewable oils in existing refinery units
- Lower capital costs than biodiesel
- Excellent fuel properties

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<tr>
<th>Feed</th>
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<tbody>
<tr>
<td>% Oil or Grease</td>
<td>100</td>
</tr>
<tr>
<td>% H₂</td>
<td>1.5-3.8</td>
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</table>

<table>
<thead>
<tr>
<th>Products</th>
<th></th>
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<tbody>
<tr>
<td>% water, CO₂</td>
<td>12-16</td>
</tr>
<tr>
<td>% Lt HIC</td>
<td>2-5</td>
</tr>
<tr>
<td>% Diesel</td>
<td>83-89</td>
</tr>
<tr>
<td>Cetane Number</td>
<td>80-100</td>
</tr>
<tr>
<td>ppm S</td>
<td>&lt;10</td>
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</tbody>
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Source: U.O.P. Corp.
1st International Biorefinery Conference, August 2005
Algae as a Source of Biofuels

- **Source of additional lipids (oils) and/or carbohydrates**
- **Complements terrestrial biomass production**
  - Reduces pressure on land use
  - Avoids food vs fuel debate
  - Saline, brackish, waste water-compatible
  - Option to utilize large waste CO₂ resource (e.g. coal power plant)
- **Potential for greater productivity than their terrestrial cousins**
  - Up to 50 times more productive than traditional oilseed crops
  - Very large resource potential for producing additional biodiesel
- **Growing DOE, DoD, and Industry interest and funding**
Algae to Jet Fuel

Offers oil source for utilization of existing refinery assets

Productivity
SOT: 10gm/m²/day
Target: 50gm/m²/day
Land Use Required

(Basis -- algal oil needed for 5 Billion gal/yr jet fuel)

Near Term: with current state of the art
4,000,000 acres
(6,500 square miles)

Longer Term: with targeted research plan
530,000 acres
(830 square miles)

Arizona: 73 million acres
114,000 sq. mi.
Emerging Biofuels Challenges

• Overcoming the corn ethanol Food vs Fuel debate

• Sustainability considerations for all aspects of Biofuel production and use

• Looking beyond second generation Cellulosic Ethanol to third generation feedstocks and fuels
  – “Infrastructure compatible biofuels”
  – Higher energy density
Hydrogen & Fuel Cells
U.S. Hydrogen & FCV Status

- DOE Technology Validation “Learning Demonstration”
  - 122 FCVs
  - 16 fueling stations

*Chevy Equinox*

*Honda Clarity*
Learning Demonstration Locations

Northern California

SE Michigan

Mid-Atlantic

Southern California

Florida

Legend

- ▲ Chevron & Hyundai/Kia
- △ DaimlerChrysler & BP
- ▲ Ford & BP
- ▲ General Motors & Shell
- △ Air Products
- ▲ Other Companies
President’s Hydrogen Fuel Initiative

• Originally announced in 2003, then restated as part of 2006 Advanced Energy Initiative (AEI)
  
  o “Make it practical and cost-effective for large numbers of Americans to choose to use clean, hydrogen fuel cell vehicles by 2020.”

  o “Reduce our oil demand by over 11 million barrels per day by 2040 – approximately the same amount of crude oil America imports today.”

  o $1.2B over FY04 – FY08
Hydrogen Economy Timeline

**Transitional Phases:**

I. **Technology Development Phase:** Research to meet customer requirements and establish business case leads to the technology readiness milestone

II. **Initial Market Penetration Phase:** Portable power and stationary/transport systems are validated; infrastructure investment begins with governmental policies

III. **Infrastructure Investment Phase:** H2 power and transport systems commercially available; infrastructure business case realized

IV. **Fully Developed Market and Infrastructure Phase:** H2 power and transport systems commercially available in all regions; national infrastructure

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**Graphical Representation:**

- Phase I: RD&D
- Phase II: Transition to the Marketplace
- Phase III: Expansion of Markets and Infrastructure
- Phase IV: Realization of the Hydrogen Economy
DOE’s Hydrogen Program 2015 Goals

Onboard Storage
- 300 miles
- Sorption Center of Excellence

Fuel Cells
- $30/kw - 5,000 hrs
- Manufacturing R&D
- Market Transformation

Production
- ≤ $3.00/kg
- H2 from Renewables
- Technology Validation Demos
- Safety, Codes & Standards
- Education
- Analysis
NREL Hydrogen Technology Thrusts

Hydrogen production

Hydrogen delivery

Hydrogen storage

Hydrogen manufacturing

Fuel cells

Technology validation

Safety, codes, & standards

Analysis
Renewable Hydrogen Production

- Photoelectrochemical hydrogen production from water
- Photobiological hydrogen production by algae and cyanobacteria
- Dark fermentation
- Biomass thermochemical hydrogen production
- Solar thermochemical hydrogen production
- Renewable energy electrolysis
Photoelectrochemical materials are specialized semiconductors that use energy from sunlight to dissociate water molecules into hydrogen and oxygen.

NREL’s work involves identifying and developing durable and efficient photoelectrochemical materials, devices, and systems.
Wind-to-Hydrogen Project

Partner with Xcel Energy (utility)

- Convert wind and solar to hydrogen
- Integrated power electronics
- Testing PEM and alkaline electrolyzers
- Compress and store hydrogen for use during peak demand
- Optimizing system controls

2008: H2 Vehicle Fueling Station

Wind2H2 Testing

10kW Wind Turbine
100kW Wind Turbine
PV Array
Electrolyzers
H2 Compressor
H2 Storage
H2 Fuel Cell
H2 Engine

• Convert wind and solar to hydrogen
• Integrated power electronics
• Testing PEM and alkaline electrolyzers
• Compress and store hydrogen for use during peak demand
• Optimizing system controls
Emerging Hydrogen & FC Challenges

• Keeping the momentum -- impediments include:
  – FY08 is end of 5 year Presidential H2 Fuel Initiative
  – Recent focus on “near term” solutions

• H2 fuel infrastructure – significant change from hydrocarbon fuel systems

• Getting past the “million $$ vehicle” image and hydrogen safety perceptions
Transportation
U.S. Alternative Propulsion Status

- **E85 (85% ethanol / 15% gas)**
  - ~1,300 stations
  - ~ 6 million FFVs

- **Compressed Natural Gas (CNG)**
  - 150,000 vehicles
  - Only one passenger vehicle still in production (Honda)

- **Plug-In Hybrid Electric Vehicles**
  - None in OEM production
  - Several kit manufacturers

Sources: 1- National Biodiesel Board, 2 - Renewable Fuels Association, 3 – American Coalition for Ethanol, all other information based on DOE and USDA sources
Plug-In Hybrid Electric Vehicles (PHEVs)

Lithium-Ion Battery Pack

Before

After

Energy Storage R&D Laboratory
Renewable PHEV Charging
Vehicle Ancillary Loads Reduction

Thermal Comfort Assessment Tools

- Thermal Testing
- Human Thermal Physiological Model
- Human Thermal Comfort Empirical Model
NREL Fuels Performance

Coordinating Research Council
- FACE
- Biodiesel Stability
- E10/E20/E85

ReFUEL
- Emissions
- Fuel Economy
- Combustion
- Durability
- Speciation

NBB CRADA - Biodiesel
- Quality/Stability
- Compatibility with Emission Controls
- Real-World Evaluation

Fuel Surveys
- Biodiesel
- E85

Fuels Chemistry Lab
- Test Methods
- Impurities
- Chemical analysis

IQT Projects
- Fundamental Ignition Studies
- Pollutant formation
- FACE Fuels Testing

ASTM
- Specs & Test
- Method Development
- Biodiesel
- E85
Implementation -- Data, Analysis, & Tools
Emerging Vehicle Challenges

• Ethanol
  – Increasing the # of E85 fueling stations and FFVs
  – Intermediate blend (E15, E20) testing and certification

• PHEVs
  – Understanding charging and grid effects
  – Fast-tracking a demonstration program

• Efficiency improvements for gasoline and diesel vehicles
Our Ultimate Challenge

- Getting Renewable Energy and Energy Efficiency to **significance** in our Nation’s infrastructure

- “moving at **speed** – deploying at **scale**”

- And, we must rely on the **States** to lead the charge
Renewable Fuels Science & Technology

Biofuels  Hydrogen  Transportation