# The Renewable Fuel Standard and Cellulosic Biofuels: Prospects and Challenges

Biomass Program
Energy Efficiency and Renewable Energy Department of Energy

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Lead Platform R&D

## 2010 Biomass Program Priorities

*"Developing the next generation of biofuels is key to our effort to end our dependence on foreign oil and address the climate crisis -- while creating millions of new jobs that can't be outsourced. With American investment and ingenuity -- and resources grown right here at home -- we can lead the way toward a new green energy economy."*

*Secretary of Energy Steven Chu*

### Advancing Presidential Objectives

**Science & Discovery**
- Connecting basic and applied bioscience.
- Conducting breakthrough R&D:
  - Advances in enzymes and catalysis.
  - Engineering of new microorganisms.
  - Novel sustainability indicators.

**Clean, Secure Energy**
- Developing & demonstrating cellulosic and advanced biofuels to meet RFS.

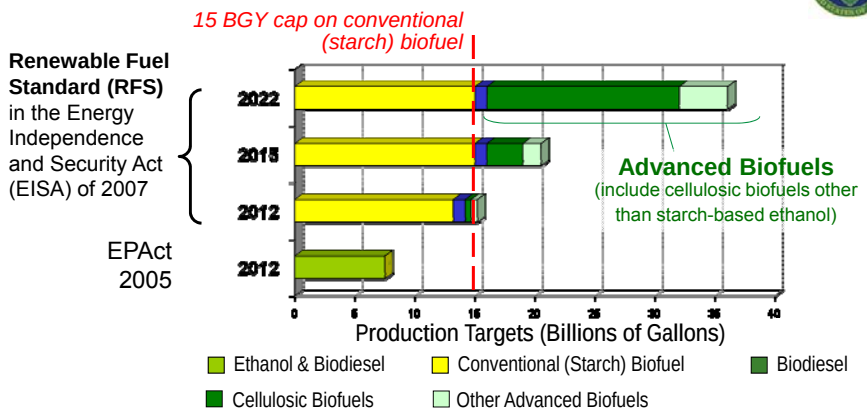
**Economic Prosperity**
- Creating 50 to 75 jobs per new biorefinery.
- Creating major new energy crop markets.
- Reinvigorating rural economies.

**Climate Change**
- Reducing GHG emissions by with advanced biofuels (relative to gasoline).

## Why invest in Biomass?

- Biomass is a sustainable and renewable resource that can contribute to nation's long term energy and environment goals
  - Meet intent of Energy Independence and Security Act (EISA) of 2007 and Renewable Fuels Standard (RFS2) goals – 36 billion gallons per year by 2022
  - When fully implemented, in 2022 the RFS2 is expected to reduce GHG emissions by 138 million metric tons – the equivalent of removing 27 million vehicles off the road
- Biomass is a flexible resource that can be used for fuels, power, and products
- No other technologies are available to produce fungible liquid transportation fuels for national commerce and defense
- Investments in biofuels can be leveraged for broader application to bioproducts and biopower

## EISA Mandated Production Targets




*EISA* defines ***Advanced Biofuel*** as "renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions…that are *at least 50 percent less* than baseline lifecycle greenhouse gas emissions."

*Cellulosic ethanol technology is important to reaching the 2022 EISA target, however, other advanced biofuels will be needed to aid in this endeavor.*

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## Where We Are Going

### The Nation's Goal:

36 billion gallons (136 billion liters)/year of biofuels by 2022

### DOE's path forward:

- Integrated programs R&D to solve technical barriers
  - Applied research for short- and mid-term impact
  - Fundamental research for longer-term impact
- Cost-shared programs with industry to reduce risk
- Broadening portfolio to maximize volumetric production

Sustainability is highly important in all aspects of our work

## US DOE Biomass Program

Feedstock Production → Feedstock Logistics → Biofuels Production → Biofuels Distribution → Biofuels End Use




### Mission Statement

Develop and transform our renewable and abundant biomass resources into cost-competitive, high-performance biofuels, bioproducts, and biopower. Conduct targeted research, development, and demonstrations, leading to deployment in integrated biorefineries, supported through public and private partnerships.

Cellulosic Biofuels: Cellulosic ethanol in the near term with a **transition to liquid** biofuels that are current fuel infrastructure compatible i.e. (renewable) gasoline, diesel and jet fuel.

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## Biomass Program Objectives and Goals

Make biofuels cost competitive with petroleum based on a modeled cost for mature technology at the refinery gate. Forecast to be $2.62/gal gasoline equivalent by 2012

Help create an environment conducive to maximizing production and use of biofuels, 21 billion gallons of advanced biofuels per year by 2022 (EISA).

***Research & Development***

**Feedstock Systems**

- Sustainable regional biomass resources: 130 million dry tons/yr by 2012.
- Improved logistics systems: $50/dry ton herbaceous by 2012.

**Conversion Technologies**

Biochemical
- Cost of converting feedstocks to ethanol: $1.40/gal gasoline equivalent (GGE) by 2012.

Thermochemical
- Cost of converting woody feedstocks to ethanol: $1.31/GGE by 2012.
- Cost of converting woody feedstock to hydrocarbon fuels by pyrolysis : $1.47/GGE by 2017.

***Demonstration & Deployment***

**Integrated Biorefineries**

- Validate integrated process technologies
  - 4 commercial scale
  - 8 demonstration scale
  - Up to 20 pilot or demonstration scale

**Infrastructure**

- Testing of E15 & E20 and develop biofuels distribution infrastructure

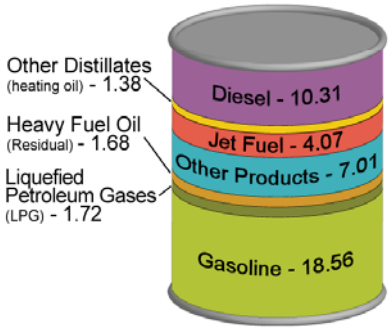
**Increase understanding of and impacts on:**

**Sustainability & Analysis**

- GHG emissions
- Water quality
- Land use
- Socioeconomics
- Predictive Modeling
- International

## Rationale for Advanced Biofuels

**Products Made from a Barrel of Crude Oil (Gallons)**




U.S. Diesel Outlook
(EIA AEO 2009 Reference Case for 2030)
- 75 billion gal/yr
  - 0.5 billion gal/yr biodiesel production (2007)

U.S. Jet Fuel Outlook
(EIA AEO 2009 Reference Case for 2030)
- 31 billion gal/yr

- **Cellulosic ethanol displaces light duty gasoline fraction only**
- **Heavy duty/diesel and jet fuel substitutes are needed to displace other components of the barrel**

Source: Energy Information Administration, "Petroleum Explained" and AEO2009, Updated (post-ARRA), Reference Case.

## Infrastructure Compatible Advanced Biofuels

Recent studies highlight the potential of advanced biofuels other than cellulosic ethanol.

Compared to ethanol, this next generation of biofuels would be more similar in chemical makeup to gasoline, jet fuel and diesel fuels.

Their compatibility with the existing infrastructure may expedite rapid displacement of petroleum (hydrocarbon-based fuels) in the market.

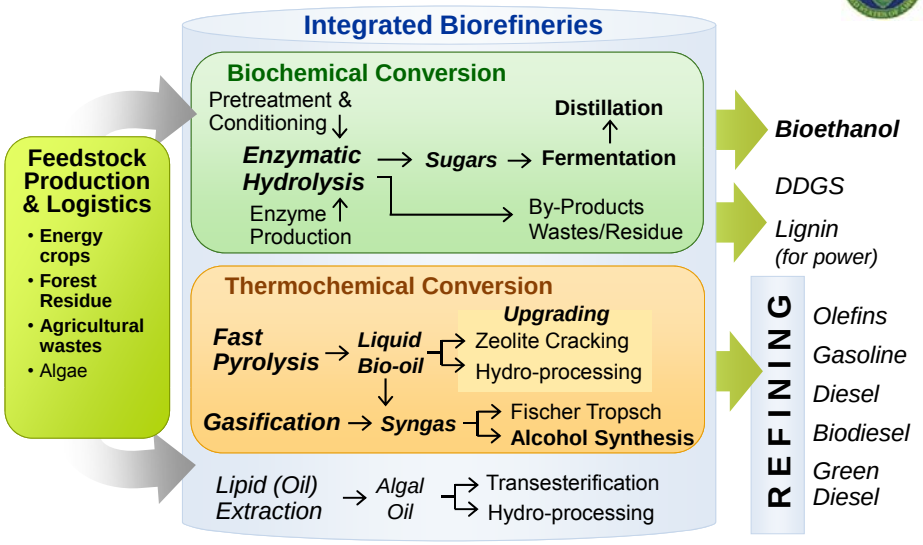
- Renewable gasoline
- Renewable diesel
- Renewable jet fuel
- Cellulosic biobutanol
- Algae-derived biofuels

} Infrastructure-Compatible Advanced Biofuels

*Gaps in Research of 2nd Generation Transportation Biofuels* Task 41, Project 2 IEA Bioenergy, **2008**:01.
*Biofuels: Where are we headed?* Chemical Engineering Progress, **2008** August, AIChE S1-S23.
*Breaking the Chemical and Engineering Barriers to Lignocellulosic Biofuels: Next Generation Hydrocarbon Biorefineries*, **2008** March, Ed. George W. Huber, University of Massachusetts Amherst, National Science Foundation, Chemical Bioenegineering, Environmental and Transport Systems Division, Washington, DC.



## Exploring Routes to Convert Biomass

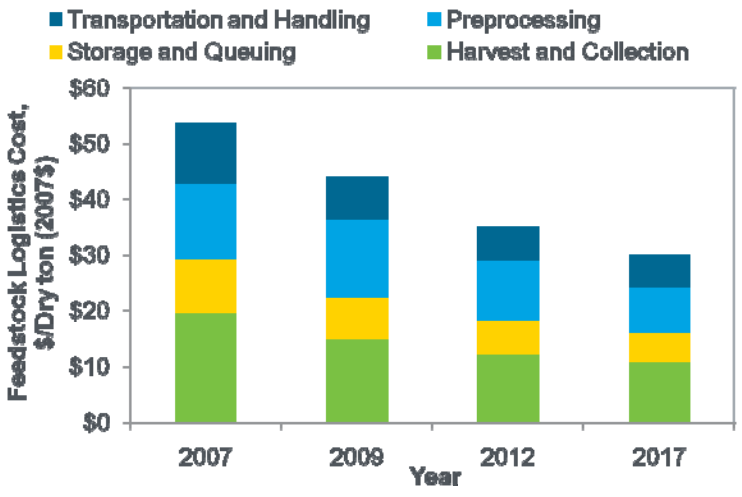



**Research on biochemical and thermochemical conversion pathways is improving the efficiency and economics of biofuels production.**

## First Need – Abundant, Low Cost Feedstock

- Dry Herbaceous – Agriculture Residues/crops at less than 15% moisture
- Energy Crops – Wet, dry, and woody
- Woody – Forest resources and woody energy crops
- Strategies to increase feedstock amounts that can be sustainably harvested.
- Develop optimal-performing systems integrating feedstock development, production, and conversion components.
- Economic assessment of production costs, including logistics.

## Feedstock Logistics Cost Targets/Goals

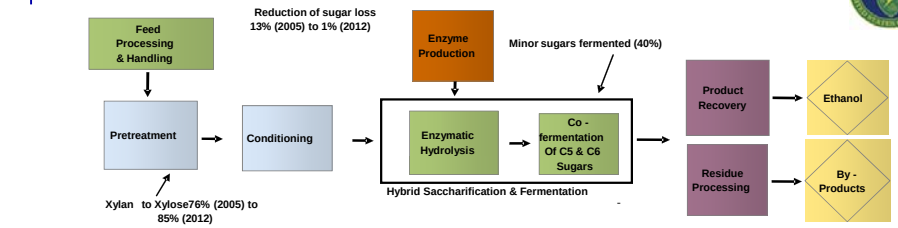


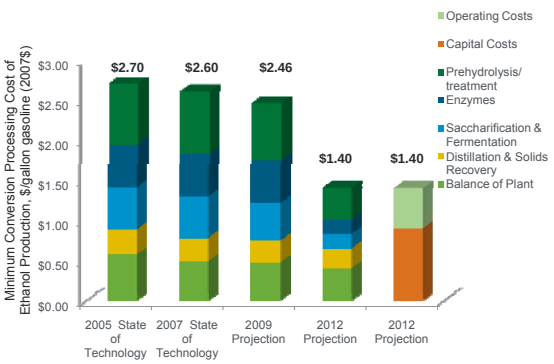
## Conversion Critical Barriers

| Challenges | Solutions |
|---|---|
| • High enzymatic conversion costs | • R&D to improve effectiveness and reduce costs of enzymatic conversion |
| • Low C5 sugars conversion | • R&D on advanced micro-organisms for fermentation of sugars |
| • Low syngas-to-fuel yields | • R&D to improve syngas clean-up and catalyst for alcohol/fuel synthesis |
| • Low pyrolysis oil quality | • R&D to improve py-oil stabilization and compatibility with current infrastructure |
| • Infancy of commercial-scale integration of process components | • Fund loan guarantees, commercial biorefinery demonstrations, and 10% scale validation projects [13] |

Future efforts address obstacles to conversion routes to biofuels, support demonstrations, and resolve infrastructure issues

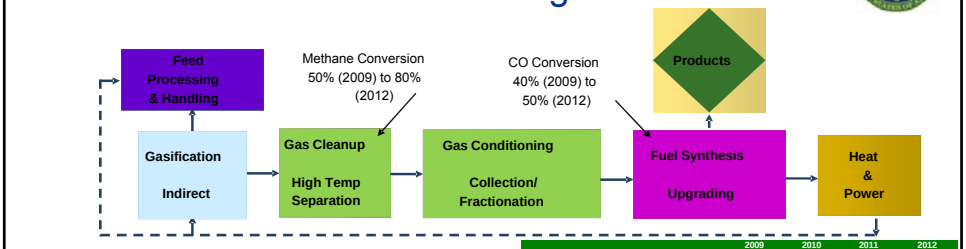
## Biochemical Conversion

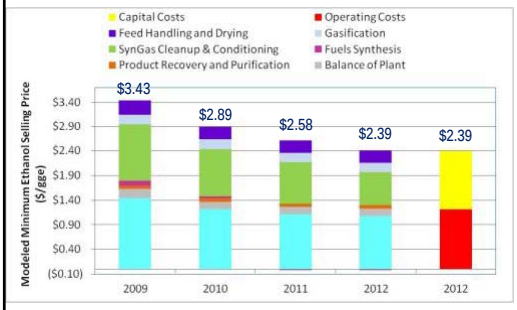



| | 2009 | 2012 |
|---|---|---|
| **Minimum Ethanol Selling Price ($/gge)** | $3.58 | $2.26 |
| Feedstock Contribution ($/gge) | $1.12 | $0.86 |
| Conversion Contribution ($/gge) | $2.42 | $1.40 |
| Yield (Gallon ethanol/dry ton) | 77.7 | 89.9 |
| Yield (gge/dry ton) | 51.3 | 59.2 |
| **Technical Projections** | | |
| ***Feedstock*** | | |
| Feedstock Cost ($/dry ton) | $57.50 | $50.87 |
| ***Pretreatment*** | | |
| Solids Loading (wt%) | 30% | 30% |
| Xylan to Xylose | 80% | 90% |
| Xylan to Degradation Products | 8% | 5% |
| ***Conditioning*** | | |
| Ammonia Loading (mL of 30wt% per L hydrolyzate) | 50 | 25 |
| Hydrolyzate solid-liquid separation | yes | no |
| Xylose Sugar Loss | 2% | 1% |
| Glucose Sugar Loss | 1% | 0% |
| ***Enzymes*** | | |
| Enzyme Contribution ($/gge) | $0.52 | $0.18 |
| ***Saccharification & Fermentation*** | | |
| Toal Solids Loading (wt%) | 20% | 20% |
| Combined Saccharification & Fermentation Time | 7 | 3 |
| Corn Steep Liquor Loading (wt%) | 1% | 0.25% |
| Overall Cellulose to Ethanol | 85% | 85% |
| Xylose to Ethanol | 80% | 85% |
| Minor Sugars to Ethanol | 40% | 85% |

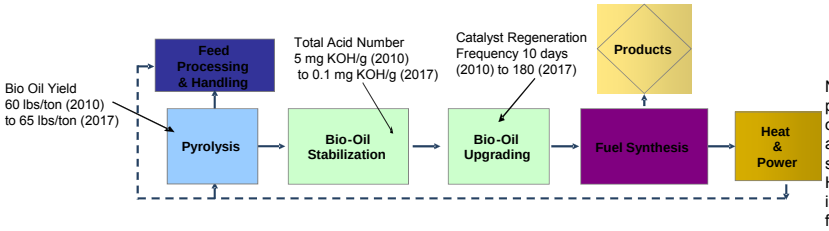
# Thermochemical Conversion – Gasification Research Planning



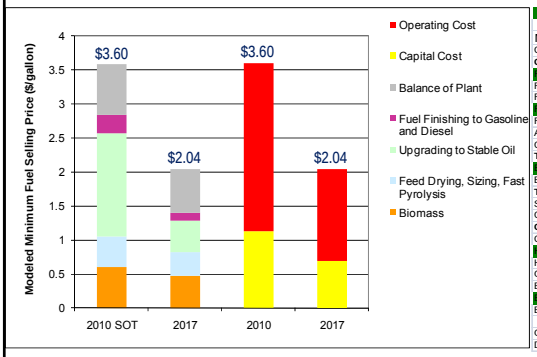




| | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|
| **Minimum Ethanol Selling Price ($/gge)** | $3.43 | $2.89 | $2.58 | $2.39 |
| **Conversion Contribution ($/gge)** | $1.99 | $1.67 | $1.47 | $1.31 |
| Ethanol Yield (gal EtOH/dry ton) | 61.5 | 67.5 | 71.0 | 71.1 |
| Ethanol Yield (gge/dry ton) | 40.5 | 44.4 | 46.7 | 46.8 |
| Mixed Alcohol Yield (gal MA/dry ton) | 72.5 | 79.6 | 83.7 | 83.7 |
| *Feedstock* | | | | |
| Total Cost Contribution ($/gge) | $1.44 | $1.22 | $1.11 | $1.08 |
| Feedstock Cost ($/dry ton) | $58.20 | $54.20 | $51.80 | $50.70 |
| *Gasification* | | | | |
| Total Cost Contribution | $0.22 | $0.20 | $0.19 | $0.19 |
| Raw Syngas Yield (lb/lb dry feed) | 0.82 | 0.82 | 0.82 | 0.82 |
| Raw Syngas Methane (dry basis,mol%) | 15% | 15% | 15% | 15% |
| Gasifier Efficiency (% LHV) | 76.1% | 76.1% | 76.1% | 76.1% |
| *Synthesis Gas Clean-up & Conditioning* | | | | |
| Total Cost Contribution | $1.14 | $0.95 | $0.84 | $0.67 |
| Tar Reformer (TR) Exit $CH_4$ (dry basis) (mole %) | 3% | 1% | 1% | 1% |
| **TR Light $CH_4$ Conversion (%)** | **56%** | **80%** | **80%** | **80%** |
| **TR Benzene Conversion (%)** | **90%** | **99%** | **99%** | **99%** |
| **TR Heavy HC/Tar Conversion (%)** | **97%** | **99%** | **99%** | **99%** |
| *Fuels Synthesis* | | | | |
| Total Cost Contribution | $0.10 | $0.05 | ($0.02) | ($0.02) |
| **Pressure (psia)** | **2000** | **1500** | **1500** | **1500** |
| Single Pass CO Conversion (%CO) | 40.0% | 40.0% | 50.0% | 50% |
| **Overall CO Conversion (%CO)** | **40.0%** | **40.0%** | **50.0%** | **50%** |
| **Selectivity to Alcohols (%C))** | **80.0%** | **80.0%** | **80.0%** | **80.0%** |

# Thermochemical Conversion – Pyrolysis Research Planning

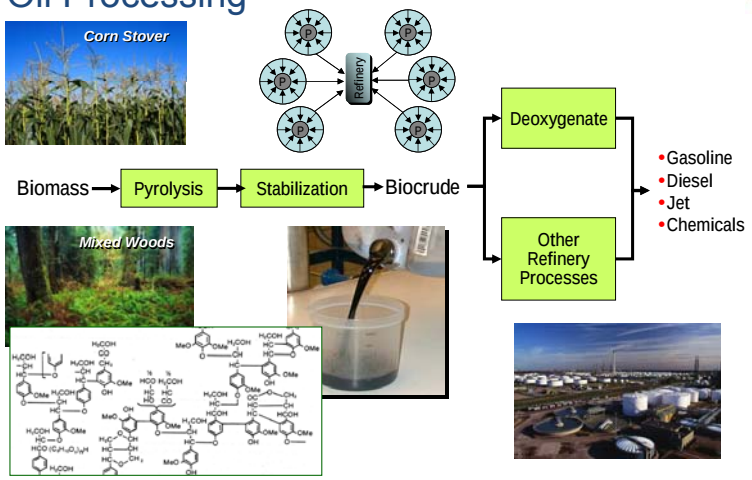



Numbers are primarily based on literature and bench scale data. Hydrogen used is generated from methane.




| | 2010 | 2017 |
|---|---|---|
| Minimum Fuel Selling Price ($/gal) | $3.60 | $2.04 |
| Conversion Contribution ($/gal) | $2.99 | $1.56 |
| **Gasoline + Diesel Yield (gal/ton biomass)** | **88** | **105** |
| Feedstock | | |
| Feedstock Cost ($/gal gge) | $0.61 | $0.48 |
| Feedstock Cost ($/dry ton) | $54.20 | $50.70 |
| Feed Drying, Sizing, Fast Pyrolysis | | |
| Feed Drying, Sizing, Fast Pyrolysis($/gal) | $0.45 | $0.34 |
| Ash content (ppm) | 2500 | <500 |
| Char Content (ppm) | 1000 | <500 |
| **Total Acid Number (mg KOH/g)** | **200** | **100** |
| Bio-Oil stabilization and Upgrading | | |
| Bio Oil Stabilization and Upgrading ($/gal) | $1.51 | $0.46 |
| **Total Acid Number (mg KOH/g)** | **5** | **0.1** |
| Sulfur Content (ppm) | 40-700 | <15 |
| Chlorine (ppm) | 10-1000 | <10 |
| **Catalyst regeneration Frequency (Days)** | **10** | **180** |
| Catalyst Lifetime (months) | 1 | 12 |
| Hydrocarbon Fuel Finishing | | |
| Hydrocarbon Fuel Finishing ($/gal) | $0.27 | $0.12 |
| Gasoline Octane (Octane No.) | 89 | 90 |
| Extent of Hydrocracking | Diesel + heavies | heavies |
| Balance of Plant | | |
| Balance of Plant ($/gal) | $0.75 | $0.64 |
| | | |
| Gasoline ($/gallon gasoline) | $3.54 | $2.04 |
| Diesel ($/gallon diesel) | $3.67 | $2.04 |

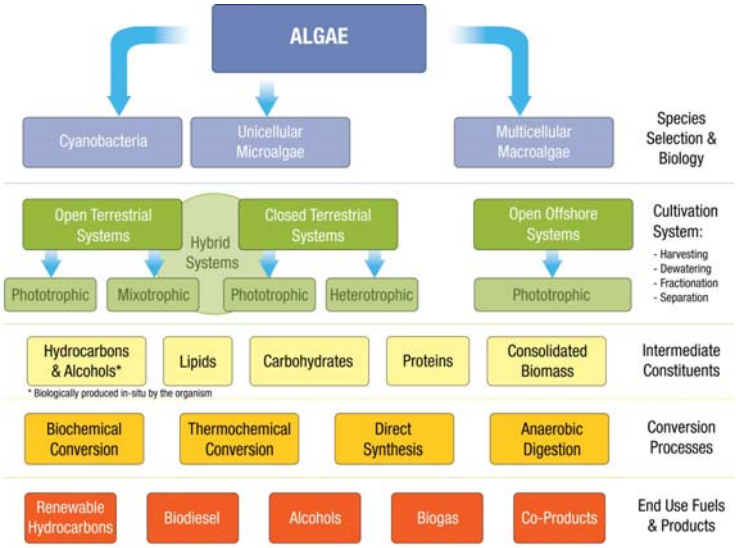
## Distributed Pyrolysis and Centralized Bio-Oil Processing



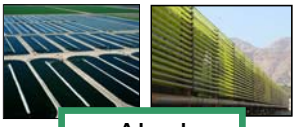

Holmgren, J. et al. NPRA national meeting, San Diego, February 2008.

This work was developed by UOP, Ensyn, NREL and PNNL and is for fully upgraded bio-oil (TAN < 2, oxygen content < 1 wt%) that is refinery ready

## Research Planning: Algal Biofuels *(New Area)*



## Algal Systems Technical Barriers



**Algal Cultivation**

- Bioreactor design
  - Temperature control
  - Invasion and fouling
- Starting species
  - Growth rate
  - Oil content & FA profile
- Nutrient requirements
  - $CO_2$ and $H_2O$ sources

- De-watering methods
- Lipid extraction
- Purification

**Oil (Lipid) Recovery**

- Process optimization
- Fuel characteristics
- Engine testing (ASTM)

**Fuel Production**

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## National Alliance for Advanced Biofuels and Bioproducts

## National Alliance for Advanced Biofuels and Bioproducts

**Donald Danforth Plant Center, lead institution**

### *National Laboratories*

- Los Alamos National Laboratory
- Pacific Northwest National Laboratory

### *Universities*

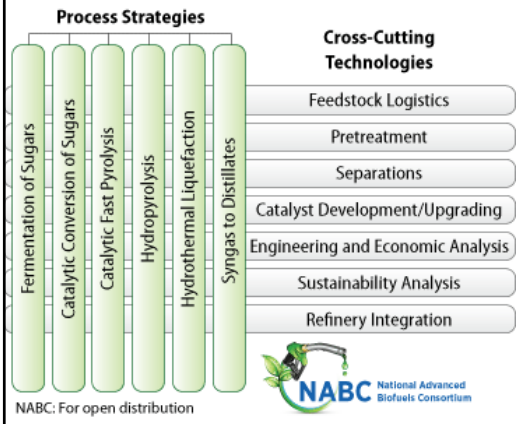
- Brooklyn College
- Colorado State University
- New Mexico State University
- Texas AgriLife Research (TAMU)
- Texas A&M University System
- University of Arizona
- University of California Los Angeles
- University of California San Diego
- University of California Davis
- University of Washington
- Washington University, St. Louis
- Washington State University

### *Industries*

- AXI
- Allied Minds
- Catilin
- Diversified Energy
- Eldorado Biofuels
- Genifuel
- HR Biopetroleum
- Inventure
- Kai BioEnergy
- Palmer Labs
- Pratt & Whitney
- Solix Biofuels
- Targeted Growth
- Terrabon
- UOP

***Subcontractors:*** Clarkson University, Center of Excellence for Hazardous Materials Management, Iowa State University, North Carolina State University, University of Pennsylvania, University of Texas

## National Advanced Biofuels Consortium




Albemarle Corp.
Amyris Biotechnologies
Argonne National Laboratory
BP Products North America Inc.
Catchlight Energy LLC
Colorado School of Mines
Iowa State University
Los Alamos National Laboratory
National Renewable Energy Laboratory
Pacific Northwest National Laboratory
Pall Corp.
RTI International
Tesoro Companies Inc.
University of California, Davis
UOP LLC
Virent Energy Systems Inc.
Washington State University.

## Three Bioenergy Research Centers

DOE Bioenergy Research Centers

- Joint BioEnergy Institute (LBNL)
- Bioenergy Science Center (ORNL)
- Great Lakes BioEnergy Research Center (Univ. of WI)

Targeting breakthroughs in biofuel technology to make abundant, affordable, low-carbon biofuels a reality.

Already yielding results, such as:

- Bioengineering of yeasts that can produce gasoline-like fuels
- Developing improved ways to generate simple sugars from grasses and waste.

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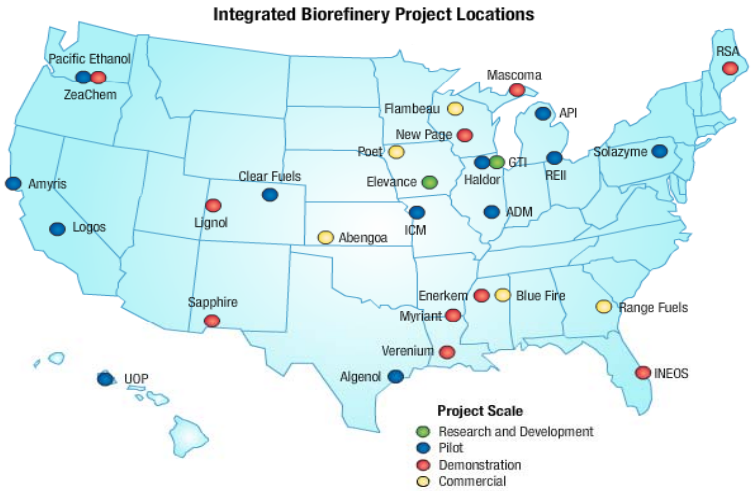
## Integrated Biorefinery Projects



## Barriers to Biofuels Deployment

### Market Barriers

- Lack of cellulosic feedstock market
- High capital and production costs
- Inadequate feedstock, distribution, and end-use infrastructure
- NEPA delays
- Ethanol blend wall

### Technical Barriers

- Collection equipment not optimized for cellulosic feedstocks
- Difficult to access and extract cellulosic energy content
- Lack of proven replicable production pathways
- Lack of fully integrated large-scale systems

### Steps Taken

- EISA and Farm Bill help establish a market demand for cellulosic biofuels
- Cost-shared biorefinery projects will help validate approaches
- Aim to increase extraction efficiency
- DOE testing potential effects of higher ethanol blends on vehicles and other engines

### Remaining Needs

- Expand EISA definition of cellulosic biomass to include woody biomass from federal lands
- Support EPA RFS implementation
- Expand loan guarantee program for biofuels infrastructure such as pipelines
- Allow use of blends between E10 and E85
- Accelerate FFV fleet penetration
- Support research for advanced biofuels beyond ethanol and biodiesel

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## Information Resources

- Office of Biomass Program, John Ferrell

  Web Site: http://www1.eere.energy.gov/biomass/
- EERE Info Center - www1.eere.energy.gov/informationcenter
- Alternative Fuels Data Center - http://www.eere.energy.gov/afdc/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/
- Loan Guarantee Program Office - http://www.lgprogram.energy.gov