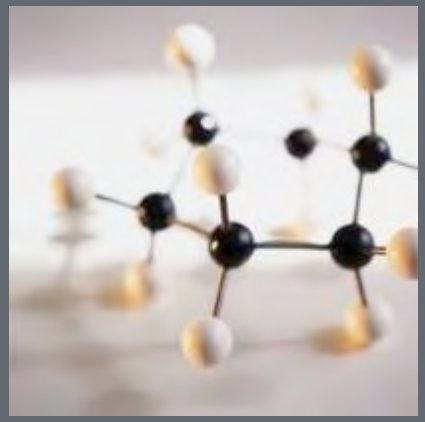
Enabling Industry with Research and Deployment of Biofuels, Biopower, and Bioproducts

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



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

Department of Energy Priorities & Goals: Advancing Presidential Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable 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

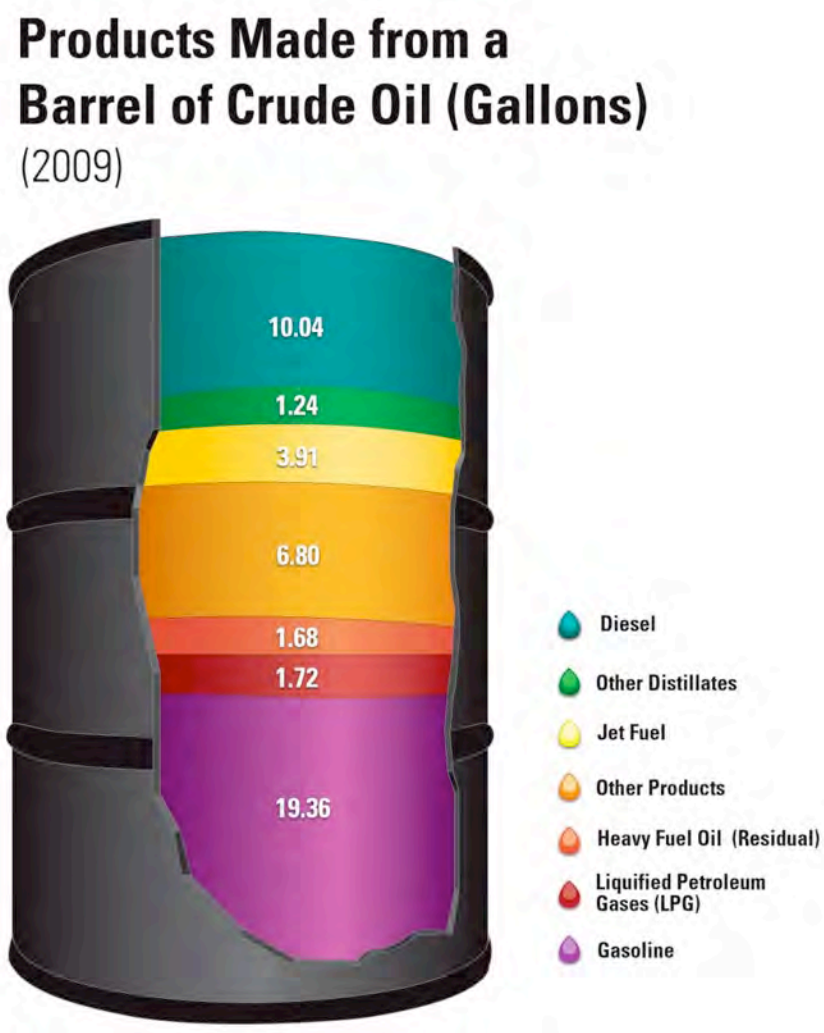
Climate Change

- 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

Displacing a Barrel of Crude - issues?



- **At low % blends, refiners can adapt**
- **As % blend increases, issues arise in refining and blending:**
  - Refinery "balance" (light / heavy, H_2, octane, vapor pressure, …)
  - Petrochemical feedstocks (naphtha, pen-hex, BTX, light paraffins & olefins, …)
- **Ethanol competes with gasoline, batteries, H_2, mass-transit, …, while only hydrocarbon liquid fuels compete in diesel & jet markets**

Source: Energy Information Administration, "Oil: Crude Oil and Petroleum Products Explained" and AEO2009, Updated February 2010, Reference Case.

Biomass Program Mission, Objectives, Goals

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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

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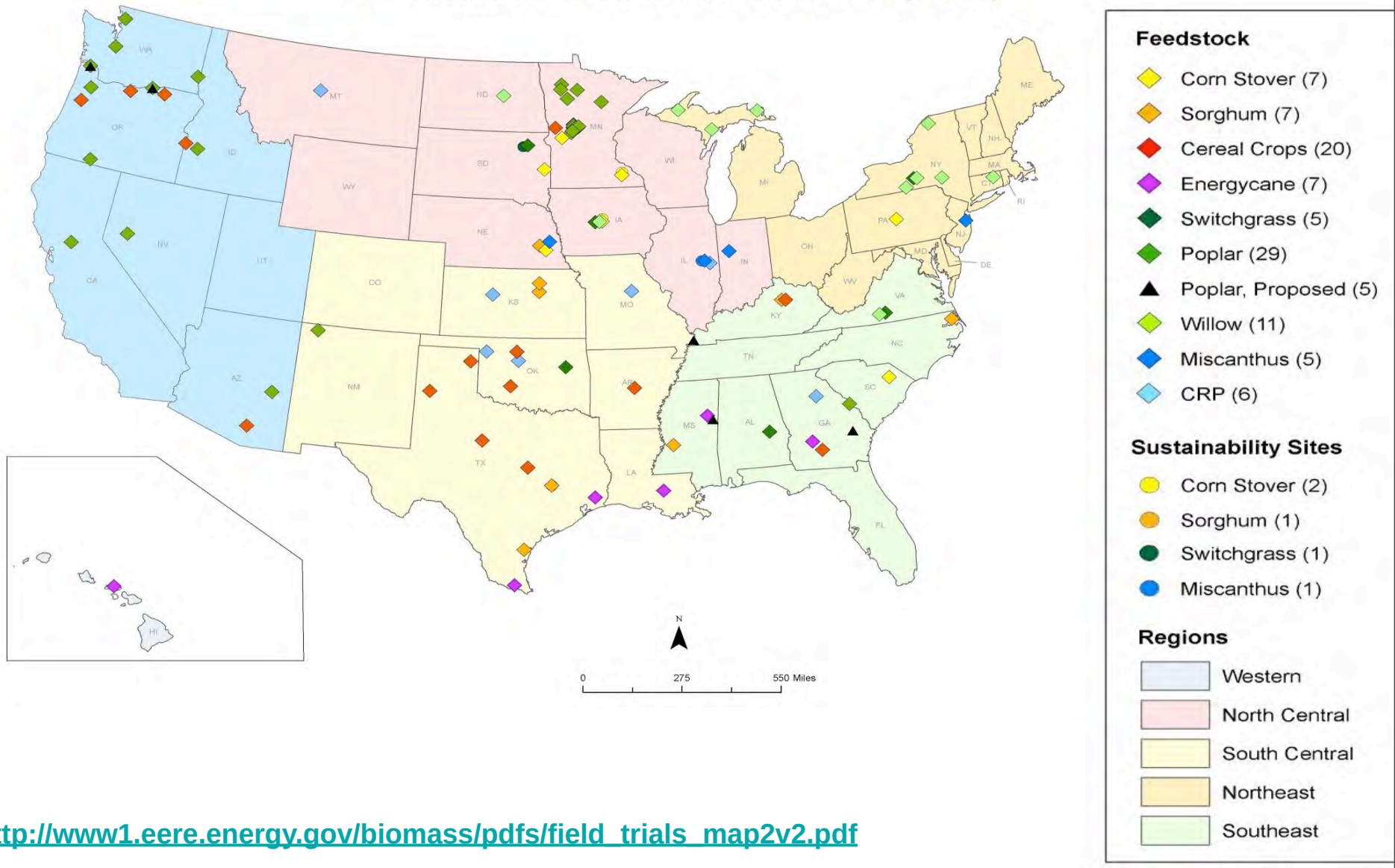
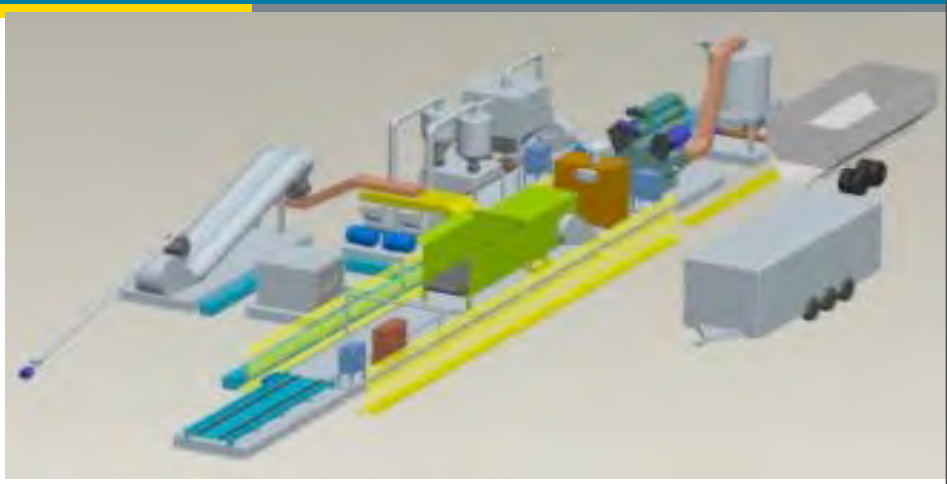


http://www1.eere.energy.gov/biomass/pdfs/field_trials_map2v2.pdf

Feedstock Logistics

Five projects selected August 2009 to design and demonstrate systems to handle:

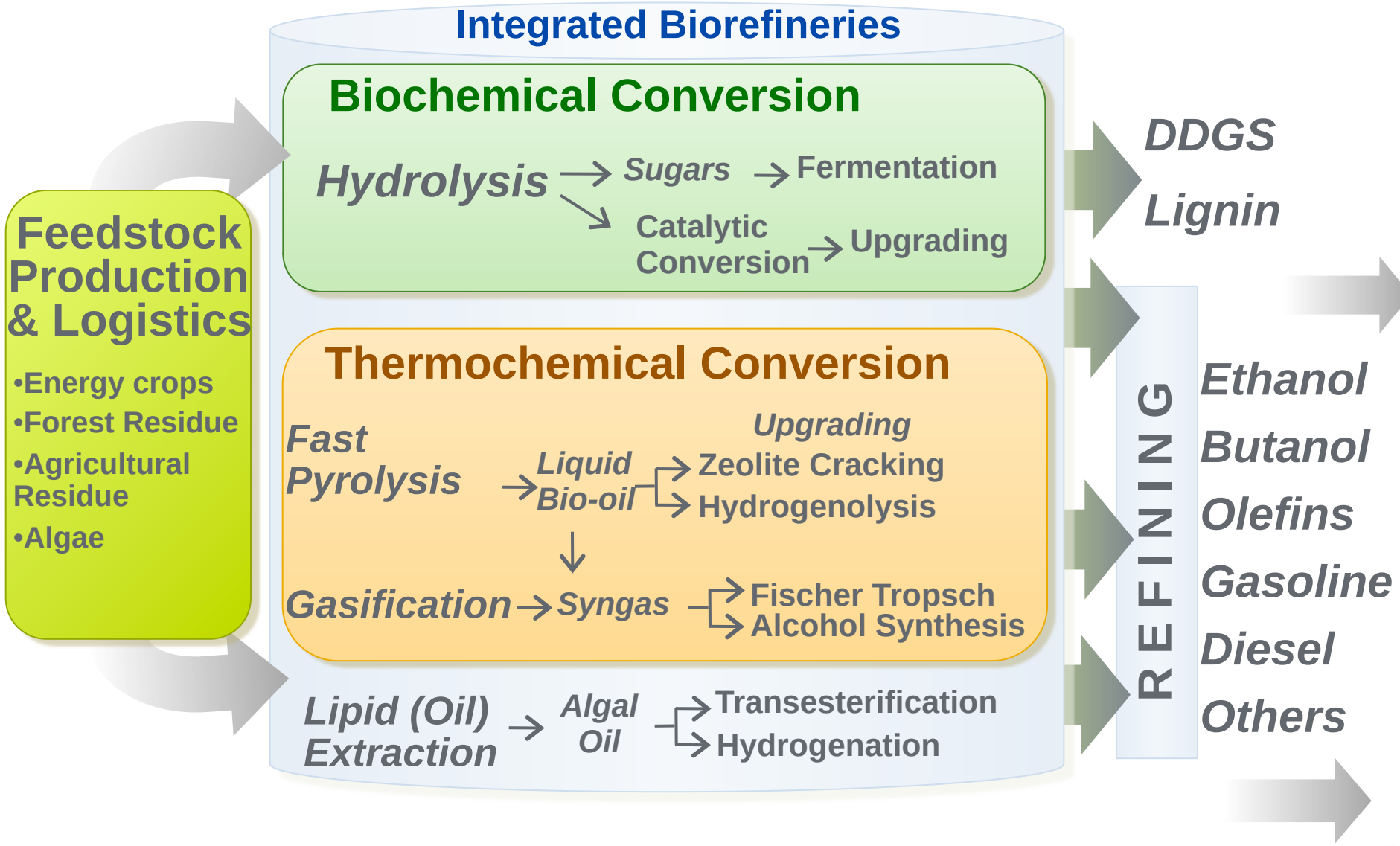
- Harvesting
- Collection
- Preprocessing
- Transport
- Storage



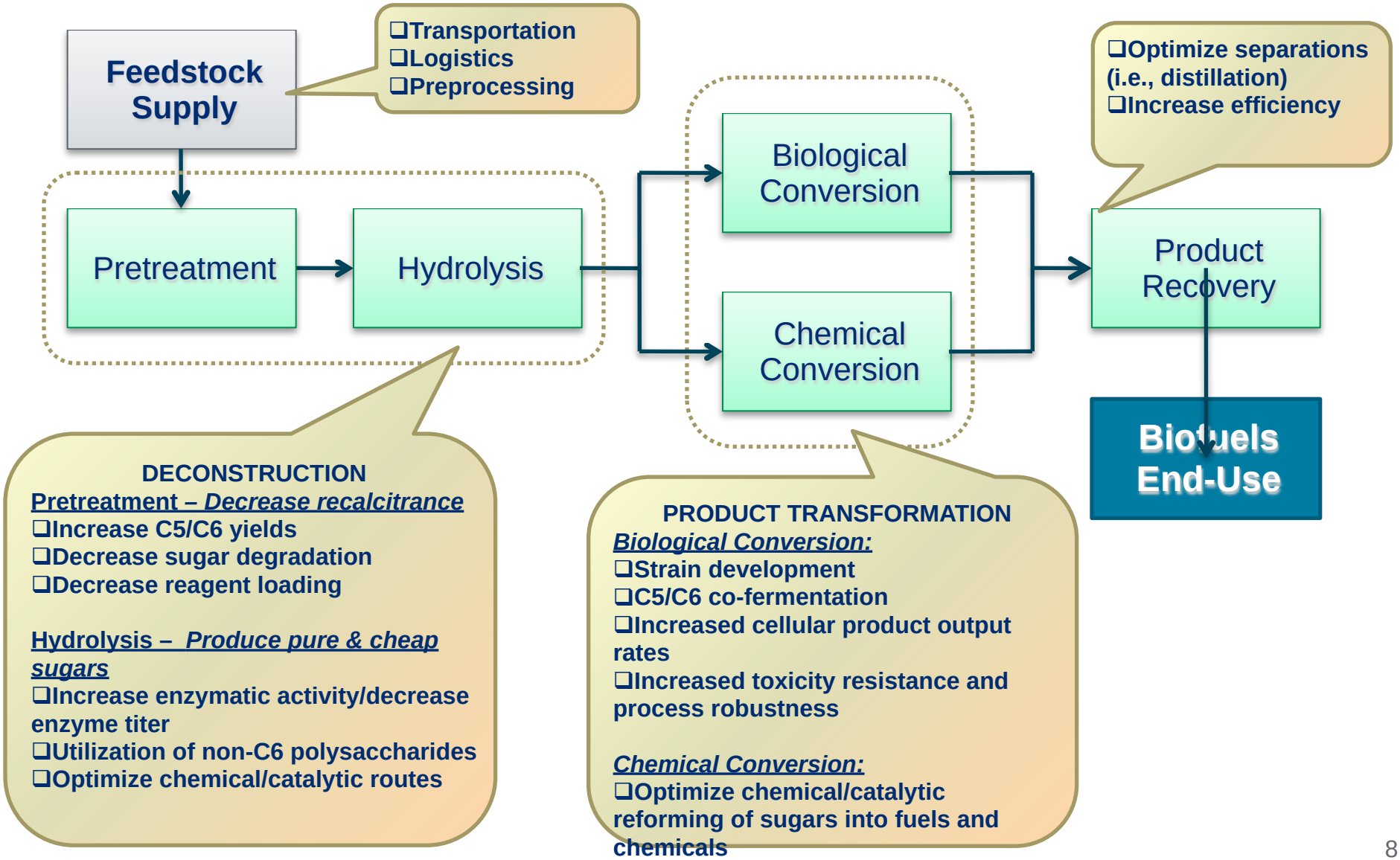
Development of the Deployable Process Demonstration Unit (PDU) will help bridge gap between producers and refineries

- Test supply system concepts, new equipment designs, and deploy new technologies
- Produce engineered feedstocks to meet commodity-scale performance metrics and advanced conversion characteristics

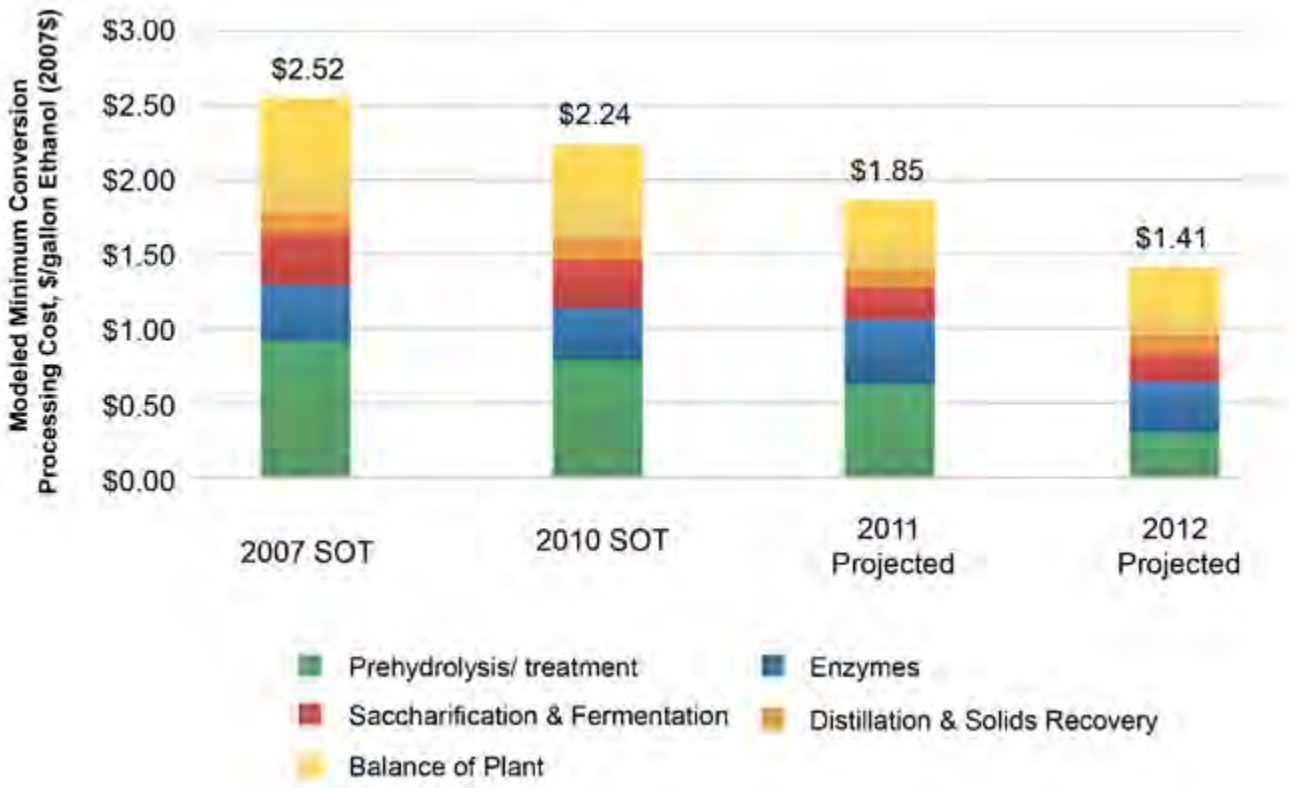
Exploring Routes to Convert Biomass



Biochem Platform Organizational Structure

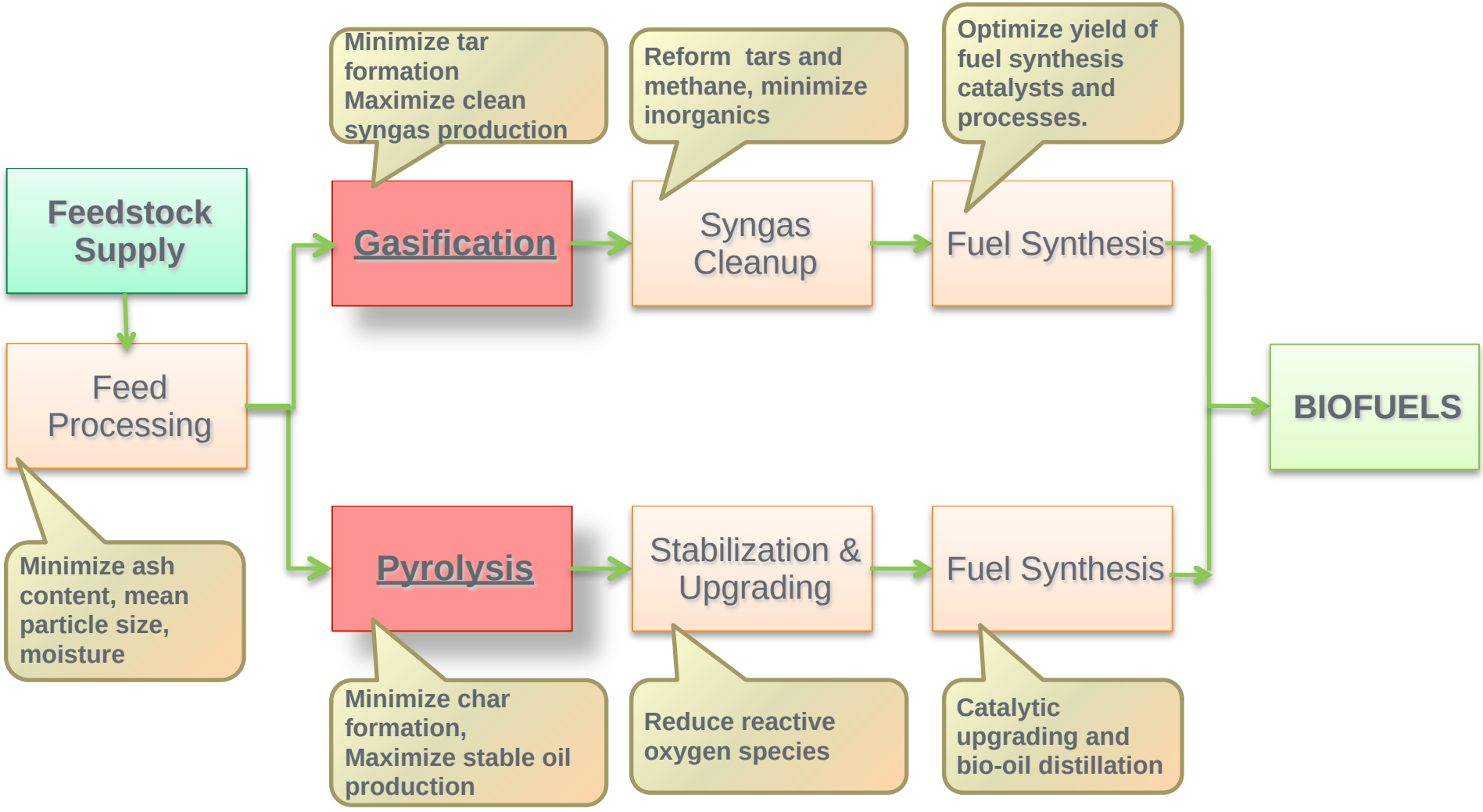


Biochemical Cost Targets

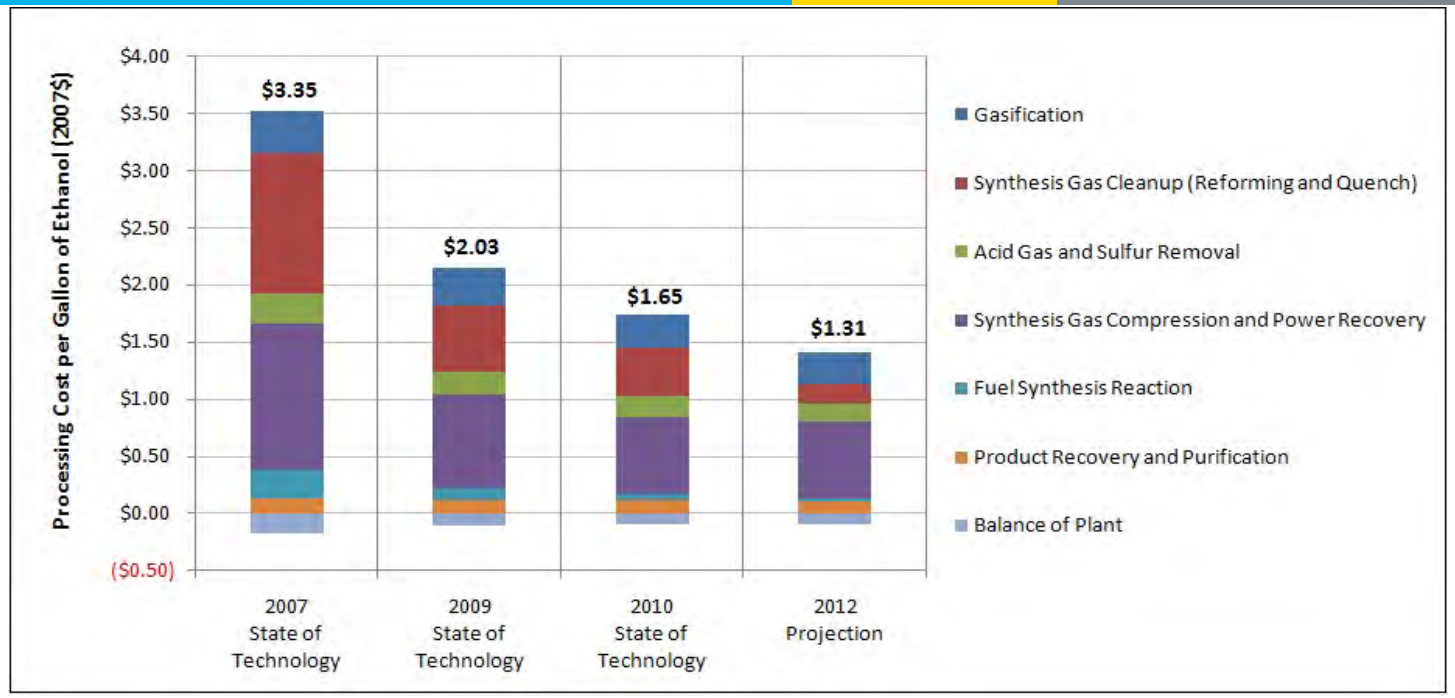


	2007 State of	2009 State of	2011 Projection	2012 Projection
Processing total	**$2.52**	**$2.24**	**$1.85**	**$1.41**
Prehydrolysis/ treatment	$0.89	$0.78	$0.62	$0.29
Enzymes	$0.39	$0.36	$0.43	$0.34
Saccharification & Fermentation	$0.35	$0.33	$0.22	$0.20
Distillation & Solids Recovery	$0.14	$0.13	$0.12	$0.12
Balance of Plant	$0.77	$0.64	$0.47	$0.46

Thermochemical Conversion

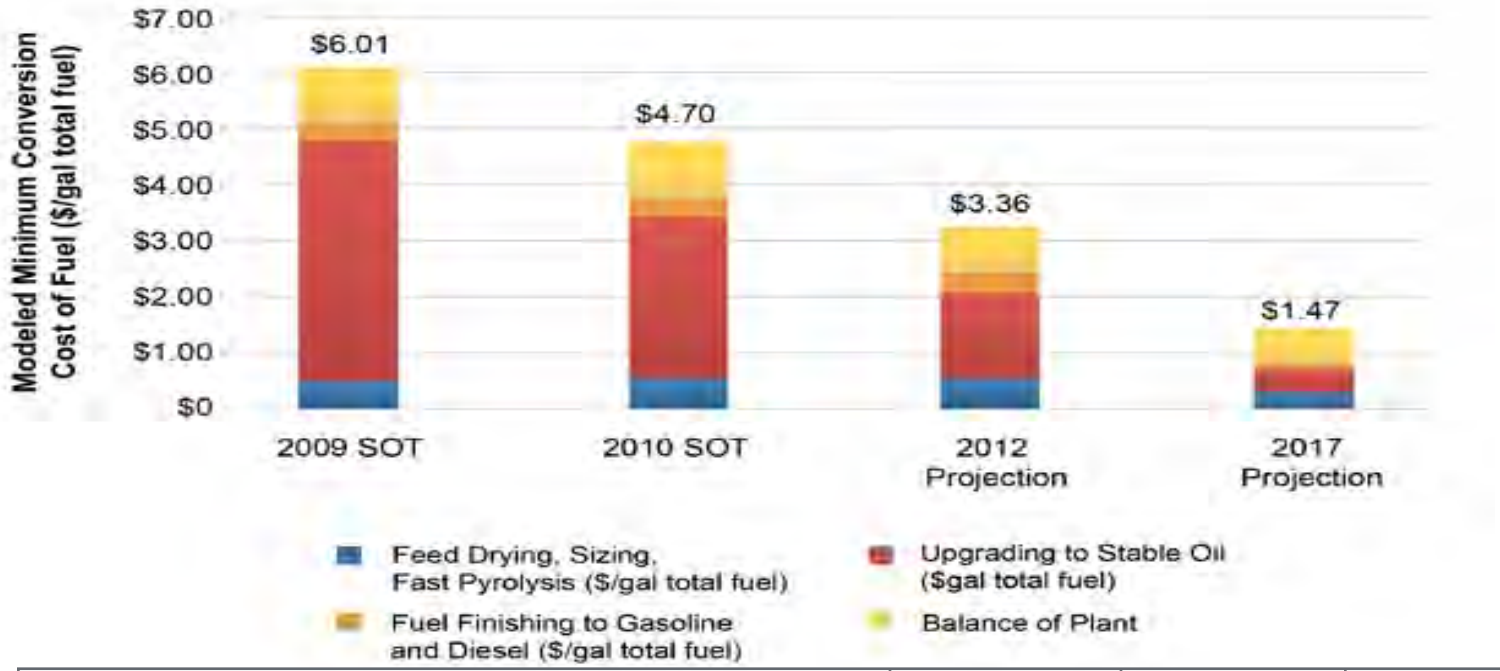


Gasification Cost Targets



Processing Area	2007 State of Technology	2009 State of Technology	2010 State of Technology	2012 Projection
Gasification ($ / Gal Ethanol)	$ 0.37	$ 0.33	$ 0.29	$ 0.28
Synthesis Gas Cleanup (Reforming and Quench) ($ / Gal Ethanol)	$ 1.22	$ 0.58	$ 0.42	$ 0.17
Acid Gas and Sulfur Removal ($ / Gal Ethanol)	$ 0.27	$ 0.20	$ 0.17	$ 0.17
Synthesis Gas Compression and Power Recovery ($ / Gal Ethanol)	$ 1.28	$ 0.81	$ 0.67	$ 0.67
Fuel Synthesis Reaction ($ / Gal Ethanol)	$ 0.24	$ 0.11	$ 0.06	$ 0.03
Product Recovery and Purification ($ / Gal Ethanol)	$ 0.14	$ 0.12	$ 0.11	$ 0.10
Balance of Plant ($ / Gal Ethanol)	$ (0.17)	$ (0.11)	$ (0.09)	$ (0.10)
Processing Total ($ / gal ethanol)	**$ 3.35**	**$ 2.03**	**$ 1.65**	**$ 1.31**

Pyrolysis Cost Targets



	2009 State of Technology	2010 State of Technology	2012 Projection	2017 Projection
Conversion Contribution, $/gal gasoline	**$6.30**	**$4.92**	**$3.51**	**$1.56**
Conversion Contribution, $/gal diesel	**$6.37**	**$4.99**	**$3.57**	**$1.56**
Conversion Contribution, $/gge total fuel	**$6.01**	**$4.70**	**$3.36**	**$1.47**
Feed Drying, Sizing, Fast Pyrolysis, $/gal total fuel	$0.54	$0.53	$0.52	$0.34
Upgrading to Stable Oil, $/gal total fuel	$4.69	$3.34	$2.01	$0.47
Fuel Finishing to Gasoline and Diesel, $/gal total fuel	$0.30	$0.30	$0.29	$0.11
Balance of Plant, $/gal total fuel	$0.80	$0.79	$0.72	$0.65

NABC Research Strategies

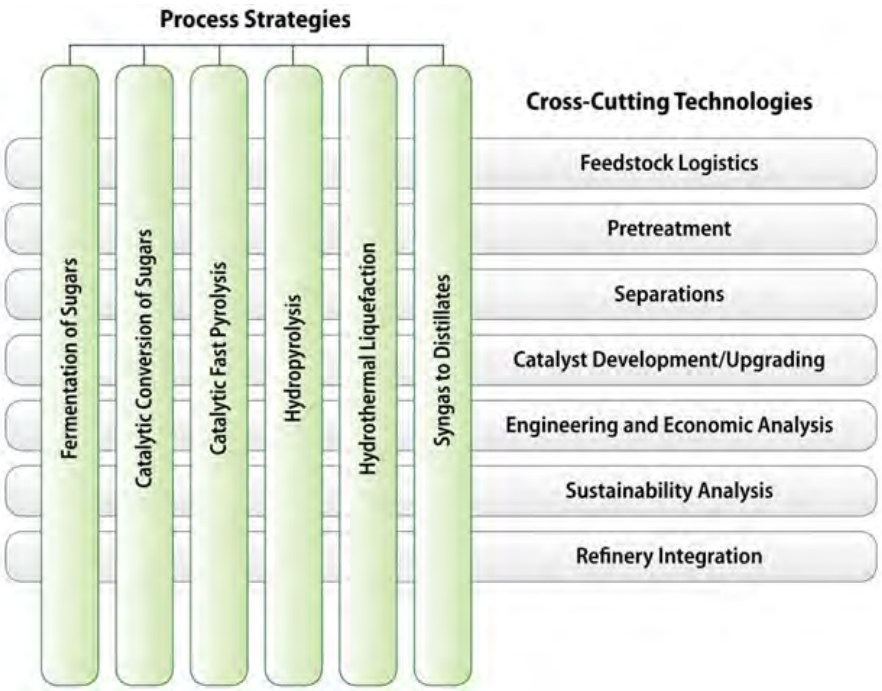
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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

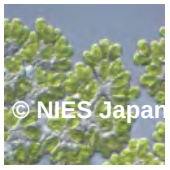


NABC National Advanced Biofuels Consortium

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

Pilot-scale raceway ponds, courtesy of Cellana LLC

Pilot-scale photobioreactor systems, courtesy of ASU

$178M

- 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

Biopower Initiative

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

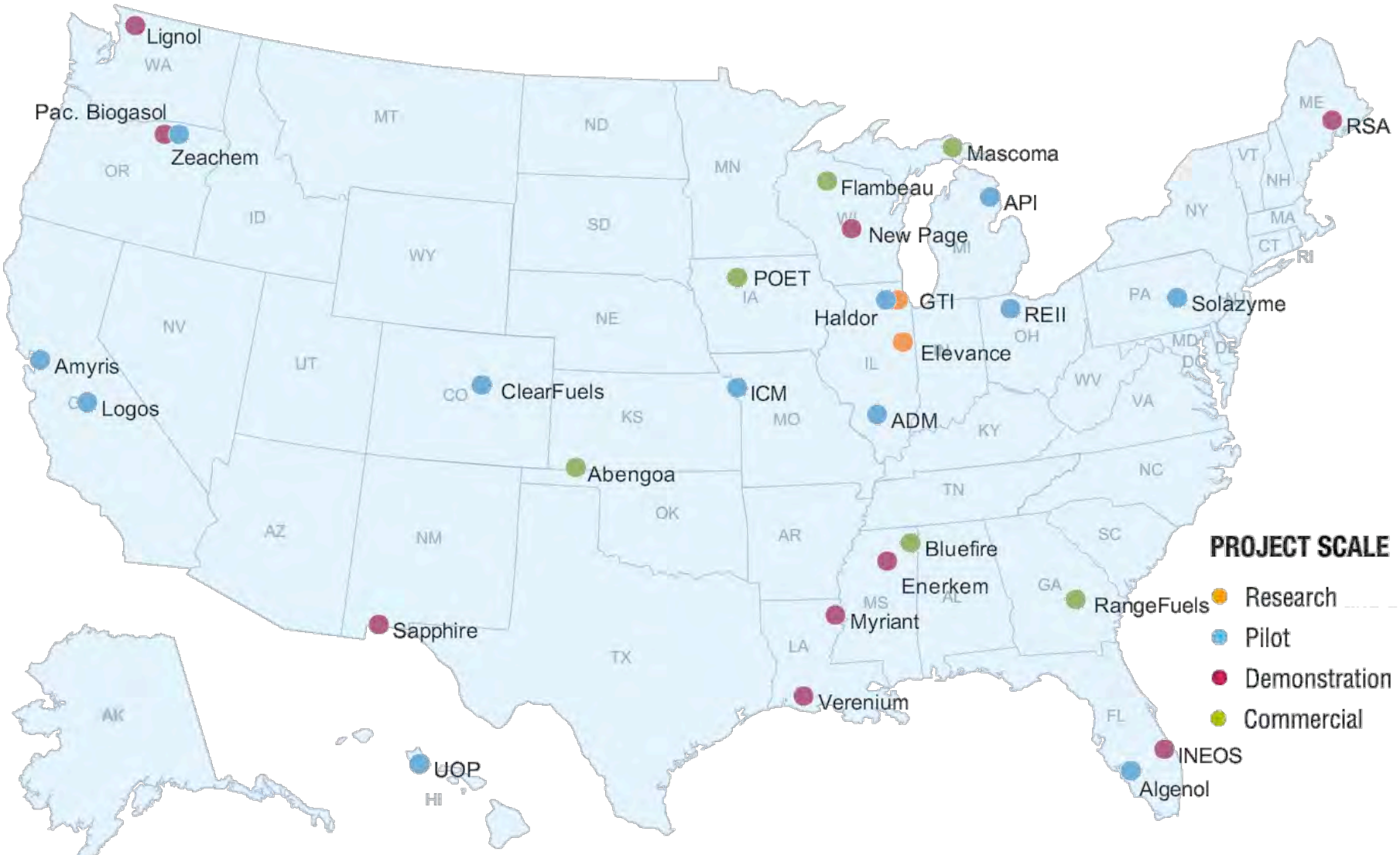
- **29 R&D, pilot, demonstration and commercial scale projects selected to validate IBR technologies**

- **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

Integrated Biorefineries

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

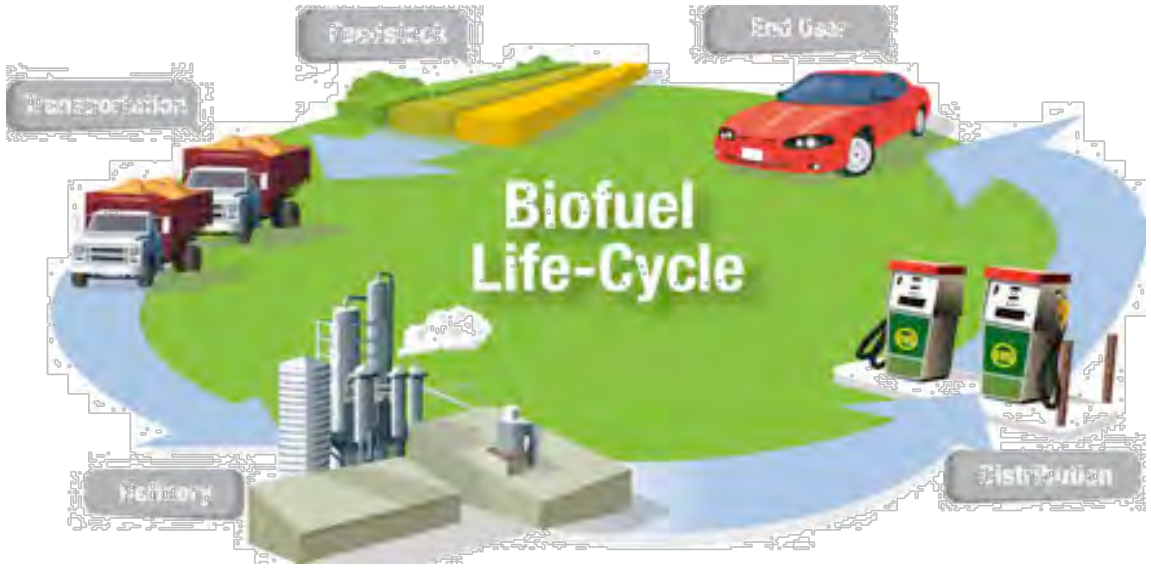


http://www.eere.energy.gov/biomass/integrated_biorefineries.html

Analysis Activities - guide our research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- **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

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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

ethanol
diesel
gasoline
jet fuel
biopower
bioproducts

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

Sustainability

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- 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 Activities

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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

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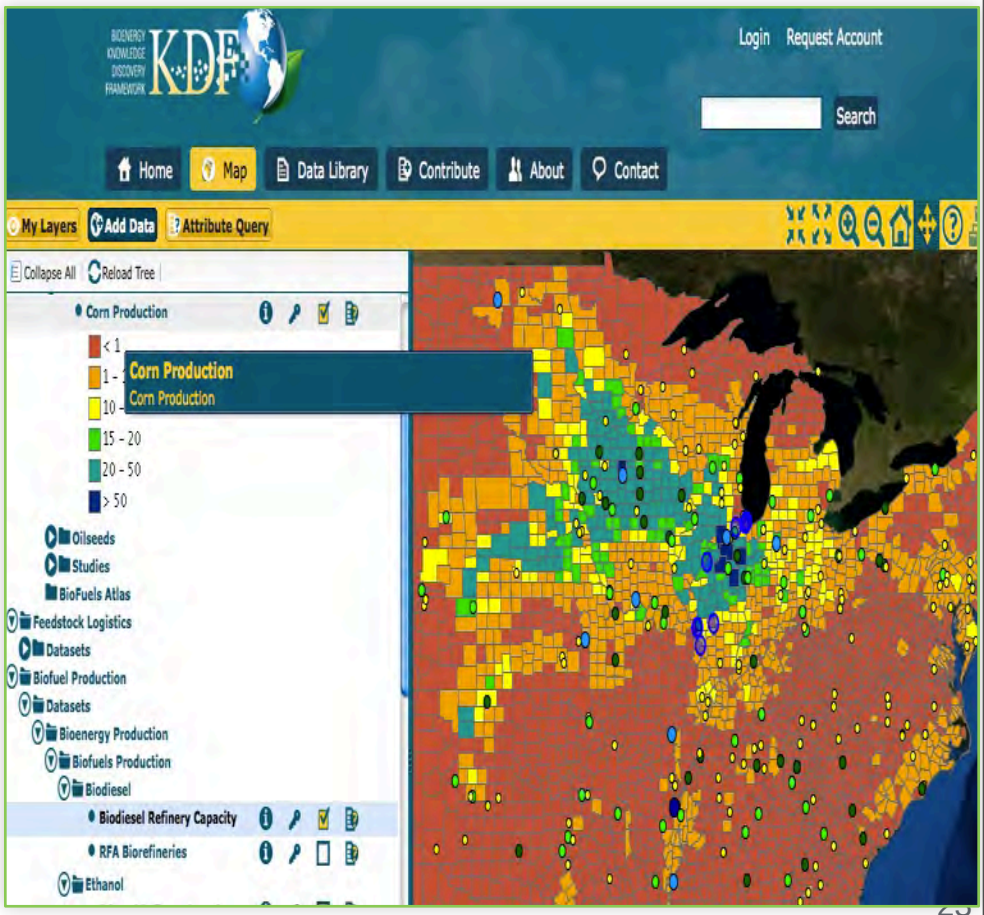
KDF
U.S. DEPARTMENT OF ENERGY

bioenergykdf.net

- 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



Information Resources

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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

Biofuels Atlas - http://maps.nrel.gov/bioenergyatlas
Energy Empowers - http://www.energyempowers.gov
DOE on Twitter - http://twitter.com/energy
Biomass Program – http://www.biomass.energy.gov
EERE Info Center - www1.eere.energy.gov/informationcente
Alternative Fuels Data Center - http://www.eere.energy.gov/a 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
Secretary Chu on Facebook - http://www.facebook.com/stevenchu

Information Resources

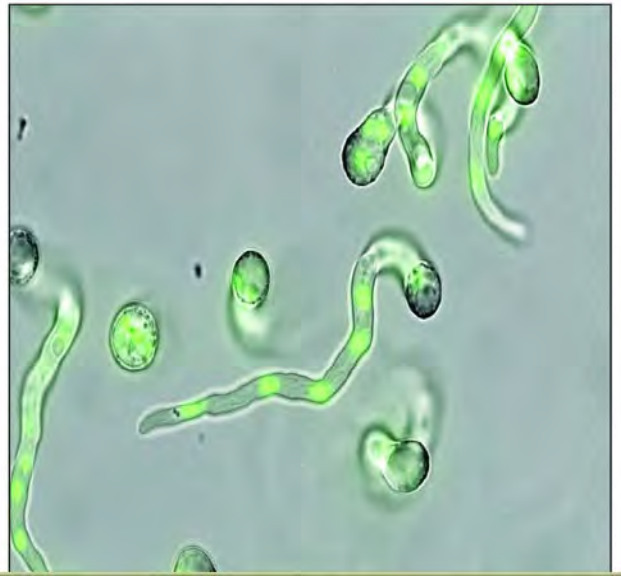
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ENERGYBLOG

Could a Common Household Fungus Reduce Oil Imports?

Submitted by Ben 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 old grapes and onions could double as a key ingredient in the recipe to reduce U.S. dependence on foreign oil. It's an outcome much less imaginary than you might think, thanks to Energy Department research 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.



Browse by category

Select a category...

Browse by state

Select a state...

DOE News

Departments of Energy, Defense Partner to Install Fuel Cell Backup Power Units at Eight Military Installations

U.S. Department of Energy and Ad Council Launch Consumer Education Campaign: Save Money by Saving Energy

New Energy Star Initiative Recognizes Cutting-Edge Products with Highest Energy Efficiency

Department of Energy Offers Severstal Dearborn, LLC a $730 Million Conditional Loan Commitment for Michigan Project

Department of Energy Update on Strategic Petroleum Reserve Sale

more

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DOE OBP IBR –
Volumetric Projections by Project

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project (State)	Fuel Type	Scale	2010	2011	2012	2013	2014
Bluefire (MS)	Cellulosic Ethanol	commercial				18.900	18.900
Abengoa (KS)	Cellulosic Ethanol	commercial				25.000	25.000
Poet (IA)	Cellulosic Ethanol	commercial				25.000	25.000
Mascoma (MI)	Cellulosic Ethanol	commercial				40.000	40.000
Flambeau (WI)	FT diesel and waxes	commercial					7.700
RangeFuels (GA)	Mixed alcohol	commercial		2.500	2.500	20.000	20.000
RSA (ME)	Biobutanol	demonstration				1.300	1.300
NewPage (WI)	FT diesel and waxes	demonstration				4.600	4.600
Pacific Biogasol (OR)	Cellulosic Ethanol	demonstration				2.700	2.700
Lignol (OR)	Cellulosic Ethanol	demonstration				1.800	1.800
Verenium (LA)	Cellulosic Ethanol	demonstration	1.400	1.400	1.400	1.400	1.400
INEOS (FL)	Cellulosic Ethanol	demonstration			8.000	8.000	8.000
Enerkem (MS)	Cellulosic Ethanol	demonstration				10.000	10.000
Sapphire (NM)	Jet fuel and diesel	demonstration			1.000	1.000	1.000
Solazymes (PA)	Biodiesel and renewable diesel	pilot				0.300	0.300
Alpena (MI)	Cellulosic Ethanol	pilot		0.760	0.760	0.760	0.760
ICM (MO)	Cellulosic Ethanol	pilot		0.260	0.260	0.260	0.260
Logos/EdenIQ (CA)	Cellulosic Ethanol	pilot			0.050	0.050	0.050
ADM (IL)	Cellulosic Ethanol	pilot			0.026	0.026	0.026
Zeachem (OR)	Cellulosic Ethanol	pilot			0.250	0.250	0.250
Algenol (FL)	Cellulosic Ethanol	pilot			0.100	0.100	0.100
REII (OH)	Diesel	pilot			0.625	0.625	0.625
Amyris (CA)	Diesel	pilot		0.001	0.001	0.001	0.001
UOP (HI)	Diesel, gas, jet fuel	pilot			0.060	0.060	0.060
Clearfuels (CO)	FT diesel and jet fuel	pilot		0.151	0.151	0.151	0.151
Haldor Topsoe (IL)	Green gasoline	pilot				0.345	0.345
		Cumulative Capacity in Million Gals / Year	**1.400**	**5.072**	**15.183**	**162.628**	**170.328**

Projects in **GREEN** funded through the American Reinvestment and Recovery Act.

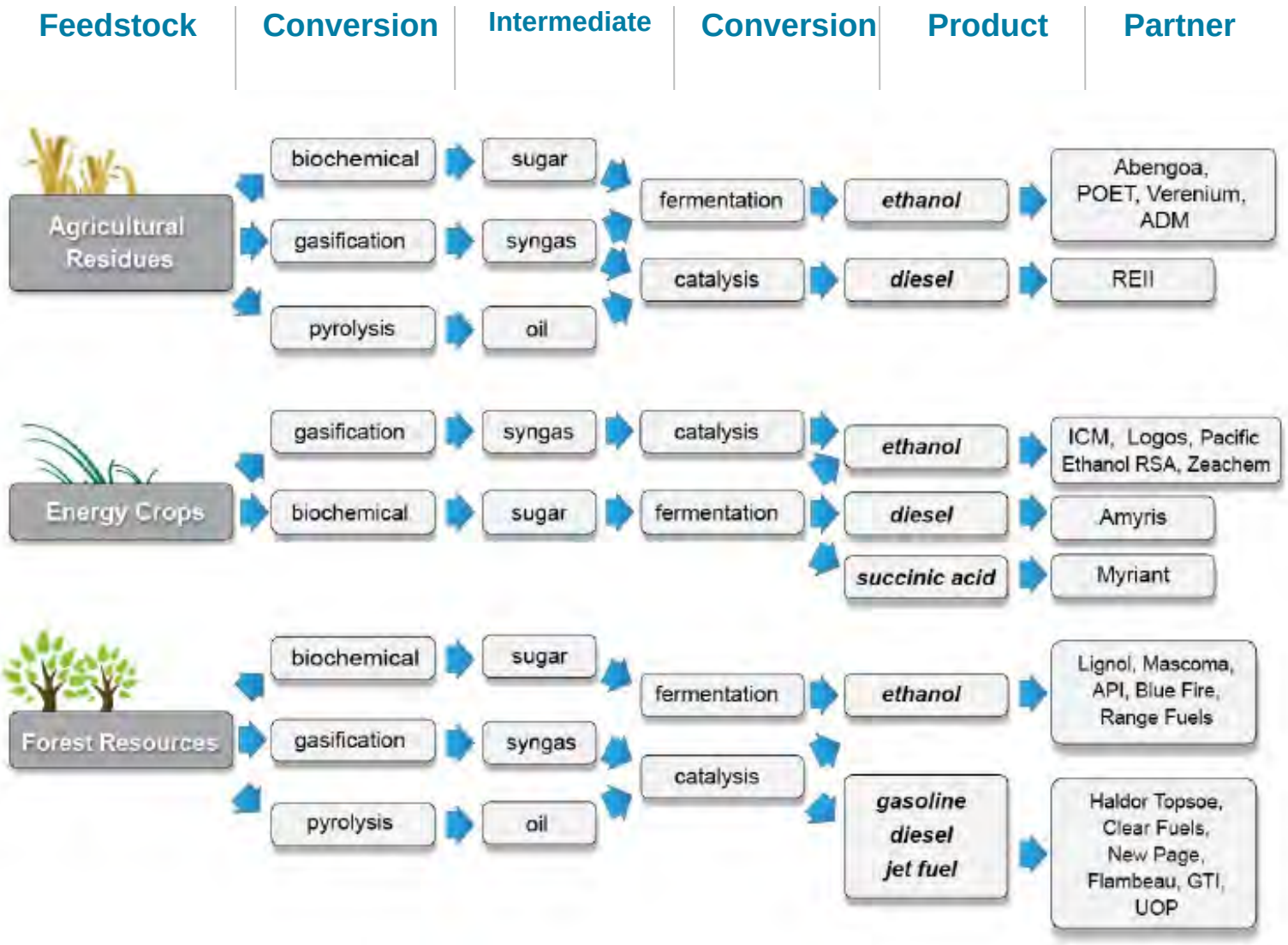
Projected volumes and dates for capacity coming online are based on information presented by IBR projects at the Peer Review conducted on Feb 1-3, 2011 and the project fact sheets located on the Program's IBR website, found at:

http://www1.eere.energy.gov/biomass/integrated_biorefineries.html

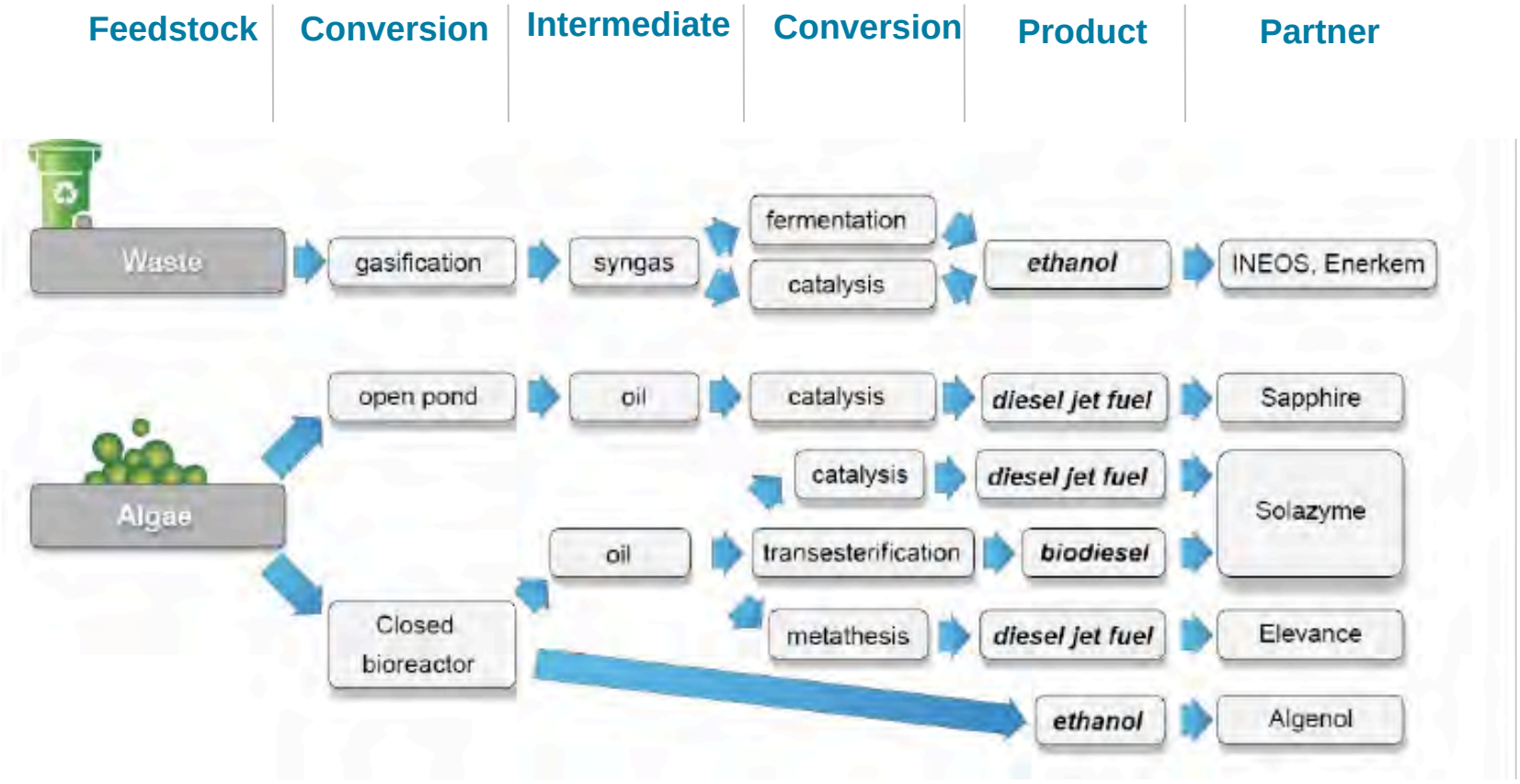
http://obpreview2011.govtools.us/IBR/

Integrated Biorefinery Pathways

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Integrated Biorefinery Pathways



Conversion Platform Design Cases

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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-5100-47764
May 2011

Contract No. DE-AC36-08GO28308

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

PNNL-18284

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

SB Jones, JE Holladay
C Valkenburg, DJ Stevens
CW Walton, C Kinchin
DC Elliott, S Czernik

February 2009

Pacific Northwest NATIONAL LABORATORY

Comparison of Wood-Derived Bio-Oils and Petroleum Fuel

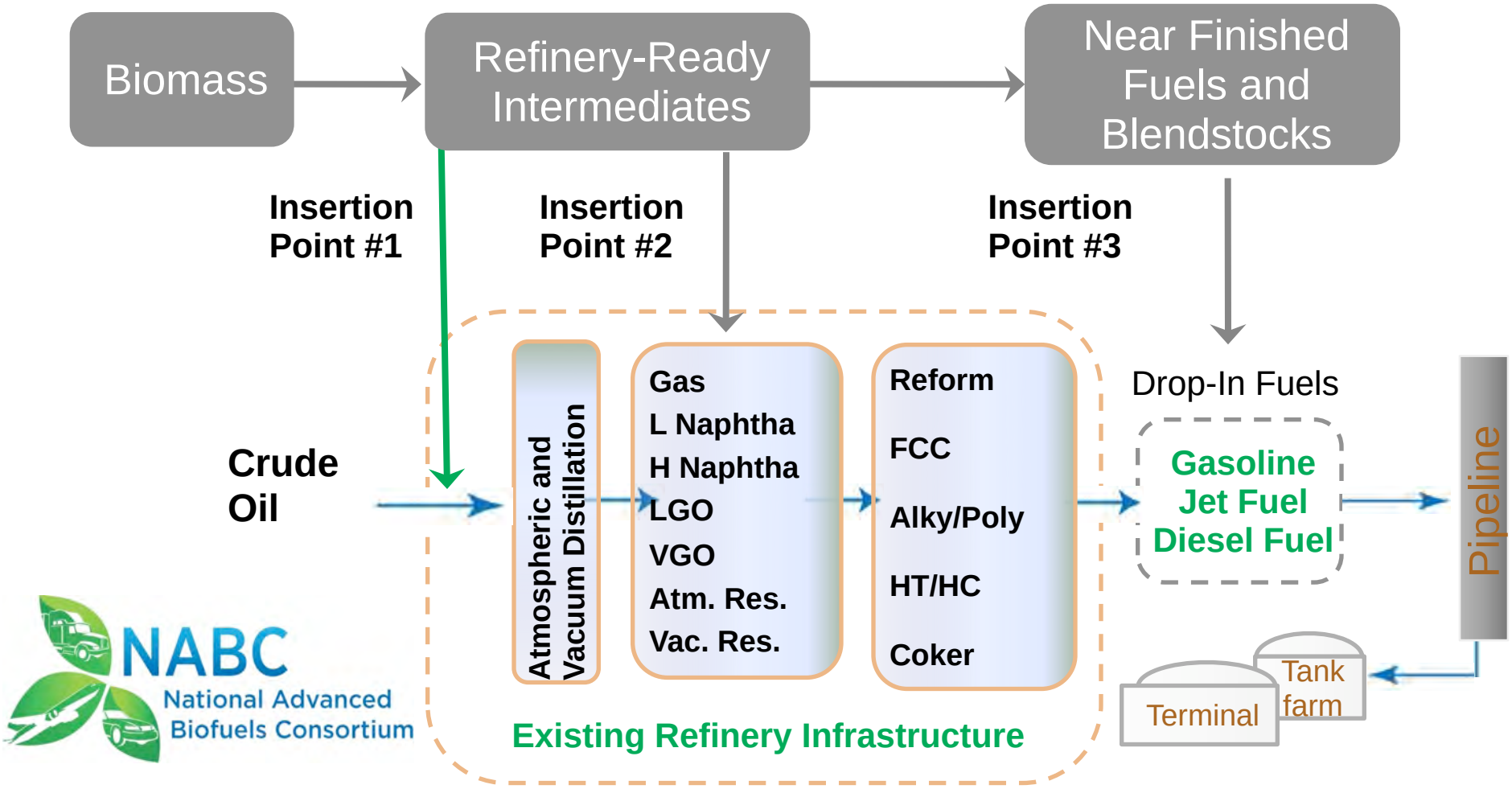
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Characteristic	Fast Pyrolysis Bio-oil	Hydrothermal Bio-oil	Heavy Petroleum Fuel
Water content, wt%	15-25	3-5	0.1
Insoluble solids, %	0.5-0.8	1	0.01%
Carbon, %	39.5	72.6-74.8	85.2
Hydrogen, %	7.5	8.0	11.1
Oxygen, %	52.6	16.3-16.6	1.0
Nitrogen, %	<0.1	<0.1	0.3
Sulfur, %	<0.05	<0.05	2.3
Ash	0.2-0.3	0.3-0.5	<0.1
HHV, MJ/kg	17	30	40
Density, g/ml	1.23	1.10	0.94
Viscosity, cp	10-150@50ºC	3,000-17,000 @ 60ºC	180@50ºC

Applications of Biomass for Biopower

- **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 furthe 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%, an 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

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Gasoline (cars & trucks)

137 bgy

Diesel (on-road, rail)

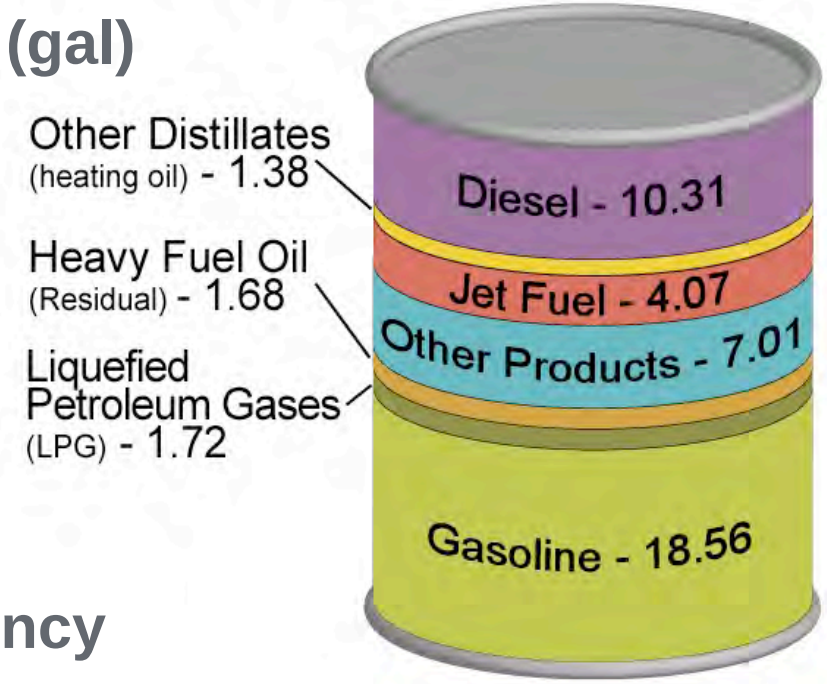
43 bgy

Aviation (jet fuel)

23 bgy

	2008	2030
Motor gasoline	137	126
Diesel	43	71
Jet fuel	23	30

Products in a Barrel of Crude (gal)



Source: Energy Information Agency