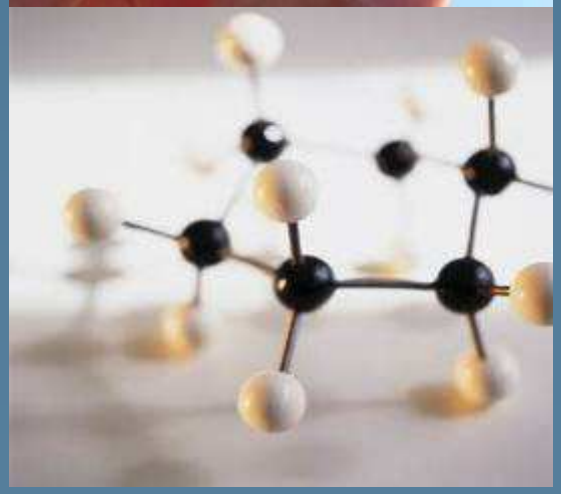





Advanced Biofuels: Infrastructure Compatible Biofuels

Presentation to Biomass R&D Technical Advisory Committee

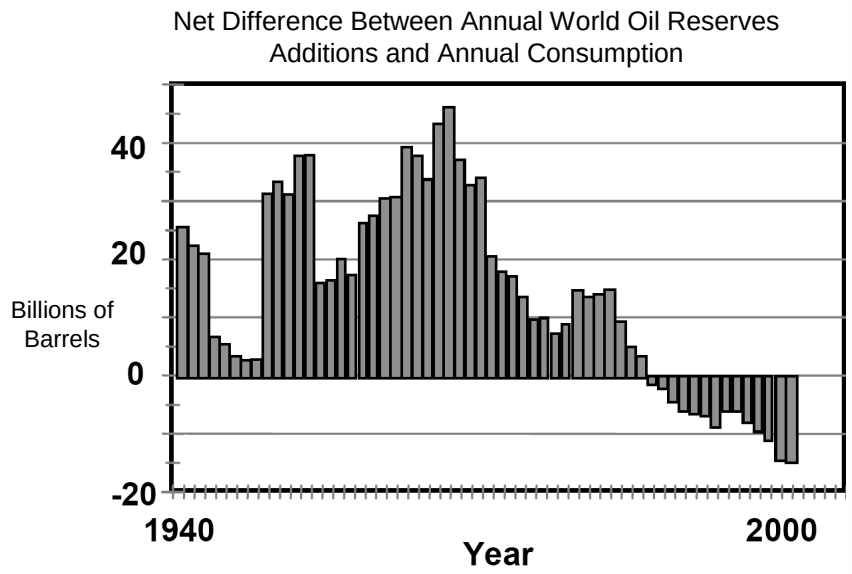
Valerie Sarisky-Reed, Conversion Program Manager

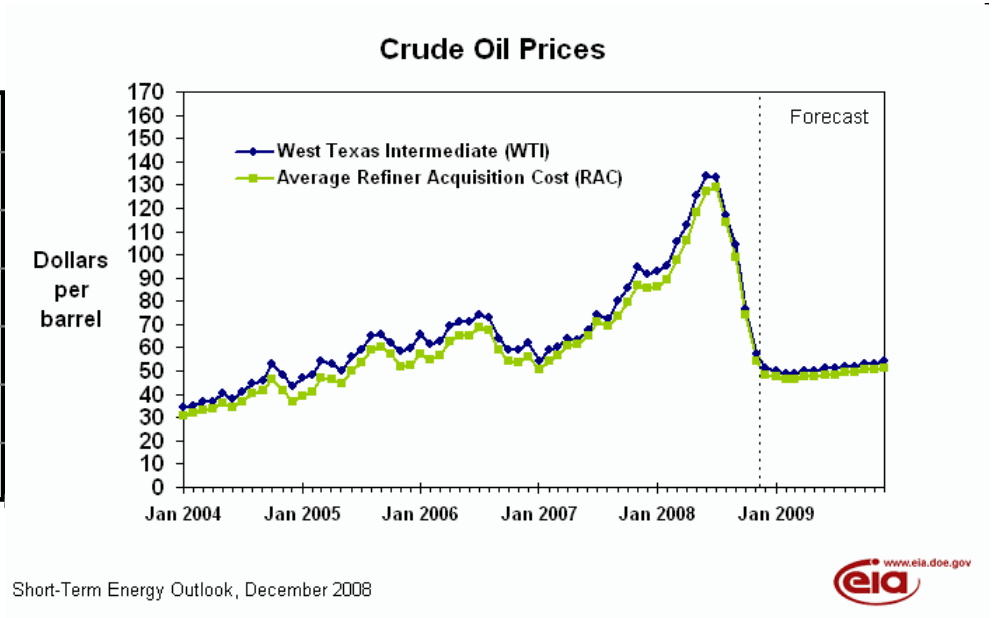
December 1, 2009

Why Biofuels?

The peaking of world oil production presents the U.S. and the world with an unprecedented risk management problem. As peaking is approached, liquid fuel prices and price volatility will increase dramatically, and, without timely mitigation, the economic, social, and political costs will be unprecedented.

Hirsch et al*., 2005*
Peaking of World Oil Production: Impacts, Mitigation & Risk Management





2009 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

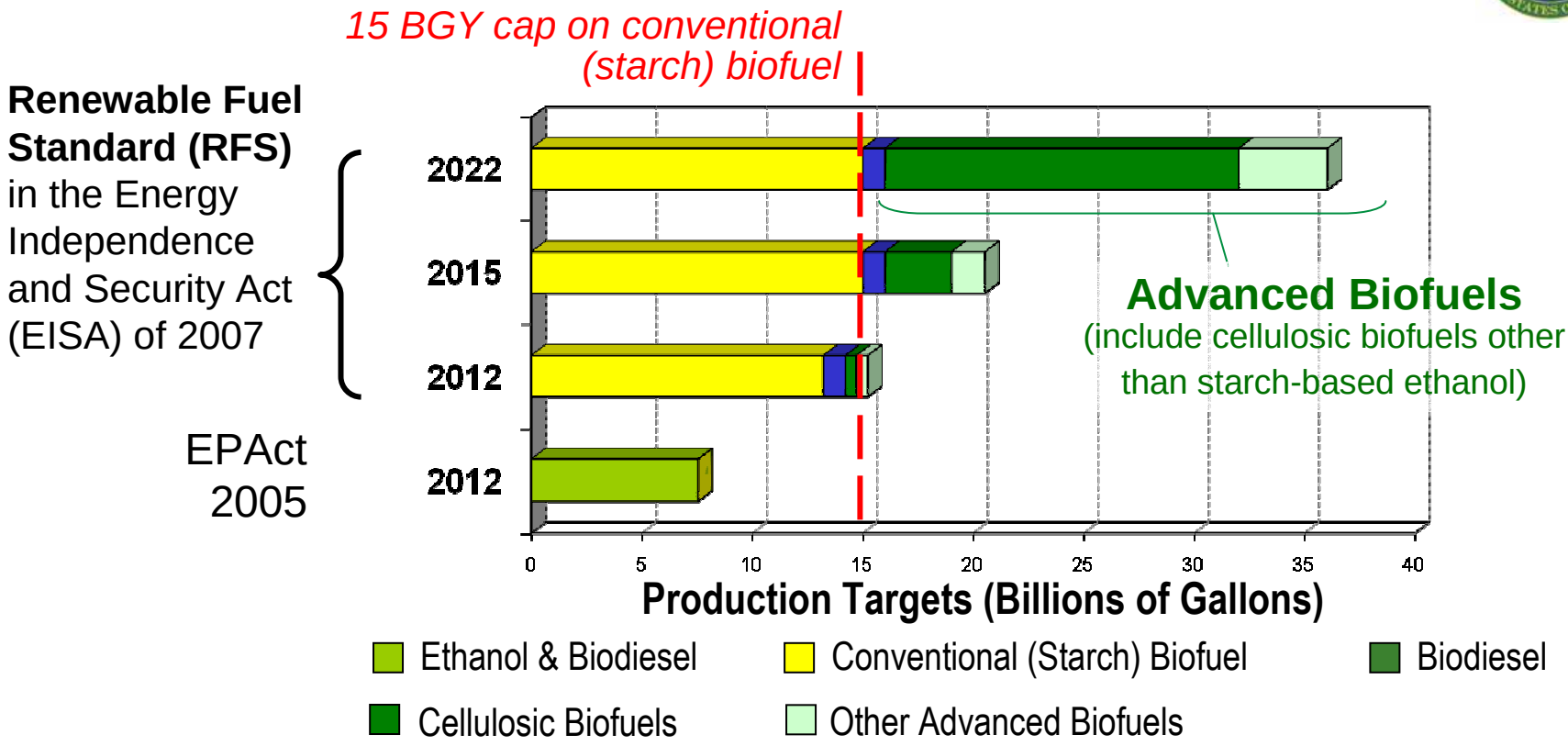
Science & Discovery
- Connecting basic and applied bioscience.
- Conducting breakthrough R&D:
  - Advances in enzymes and catalysis.
  - Engineering of new microorganisms.
  - Novel sustainability indicators.

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).

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 critical to reaching the 2022 EISA target, however, other advanced biofuels can aid in this endeavor.

Where We Are Going

The Nation's Goal:

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

DOE's path forward:

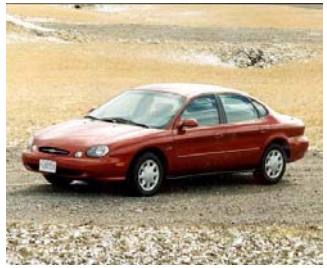
- Integrated programs R&D to solve technical barriers
  - Applied research for short- and mid-term impact
  - Fundamental research for longer-term impact
- Cost-shared programs with industry to reduce risk
- Broadening portfolio to maximize volumetric production

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.

Cellulosic Biofuels: Ethanol is currently the Primary focus of the program.

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).
(14 billion gge)

Research & Development

Feedstock Systems

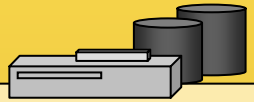
- Sustainable regional biomass resources: 130 million dry tons/yr by 2012.
- Improved logistics systems: $50/dry ton herbaceous by 2012.

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

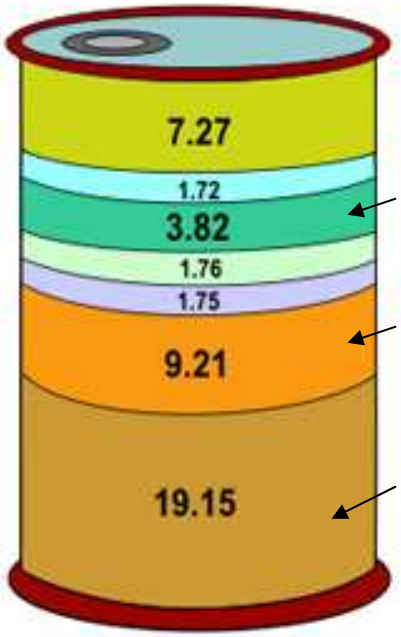
Increase understanding of and impacts on:

Sustainability & Analysis

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

Why Additional Advanced Biofuels?

Petroleum



Source: Energy Information Administration

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.
Need heavy duty/diesel substitutes to displace entire barrel.

Where Does My Gasoline Come From? *Energy Information Administration DOE/EIA-X059* April **2008**
Annual Energy Outlook 2009, March 2009, DOE/EIA-0383**(2009)**

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.

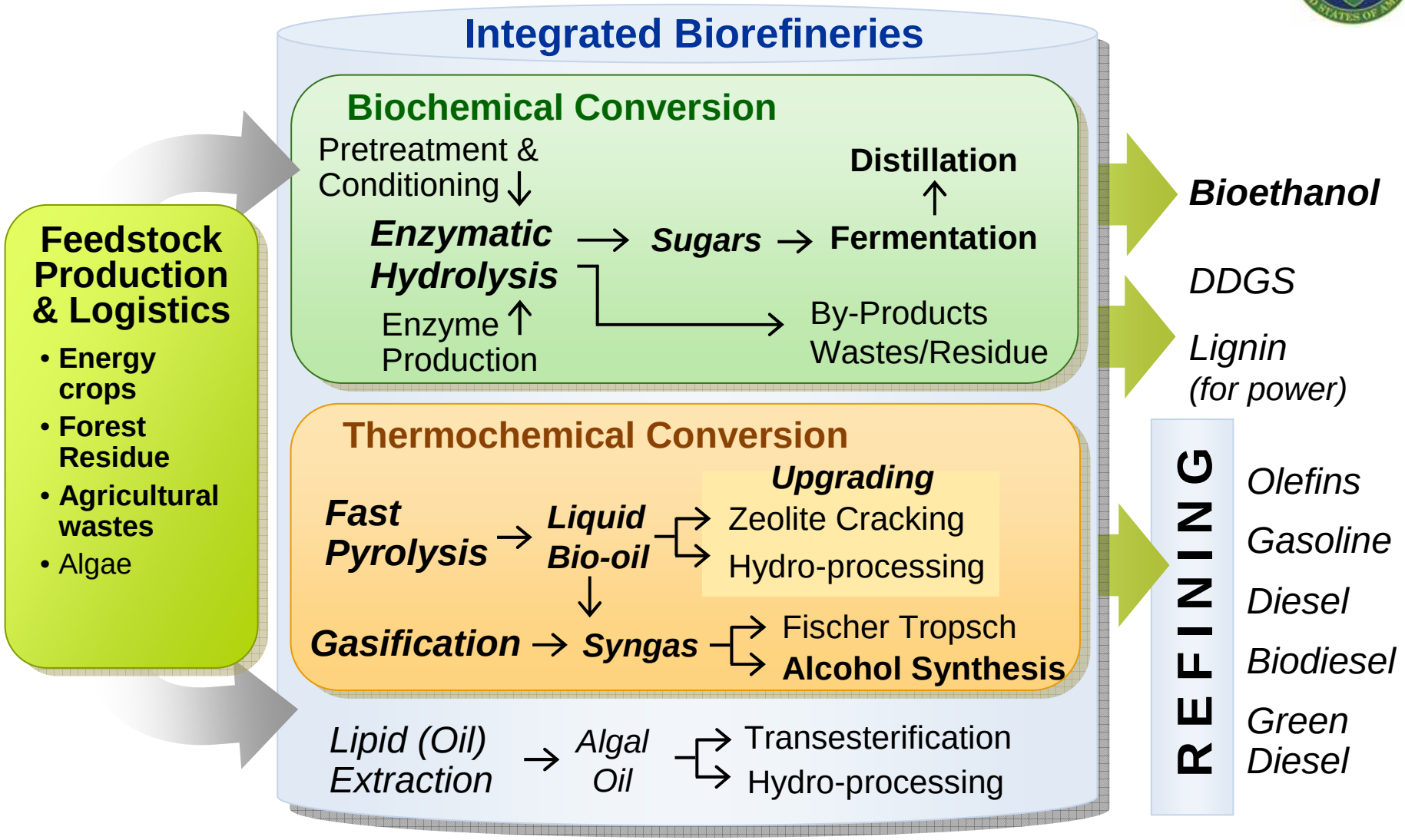
Their compatibility with the existing infrastructure may expedite rapid displacement of petroleum (hydrocarbon-based fuels) in the market.

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

} Infrastructure-Compatible Advanced Biofuels

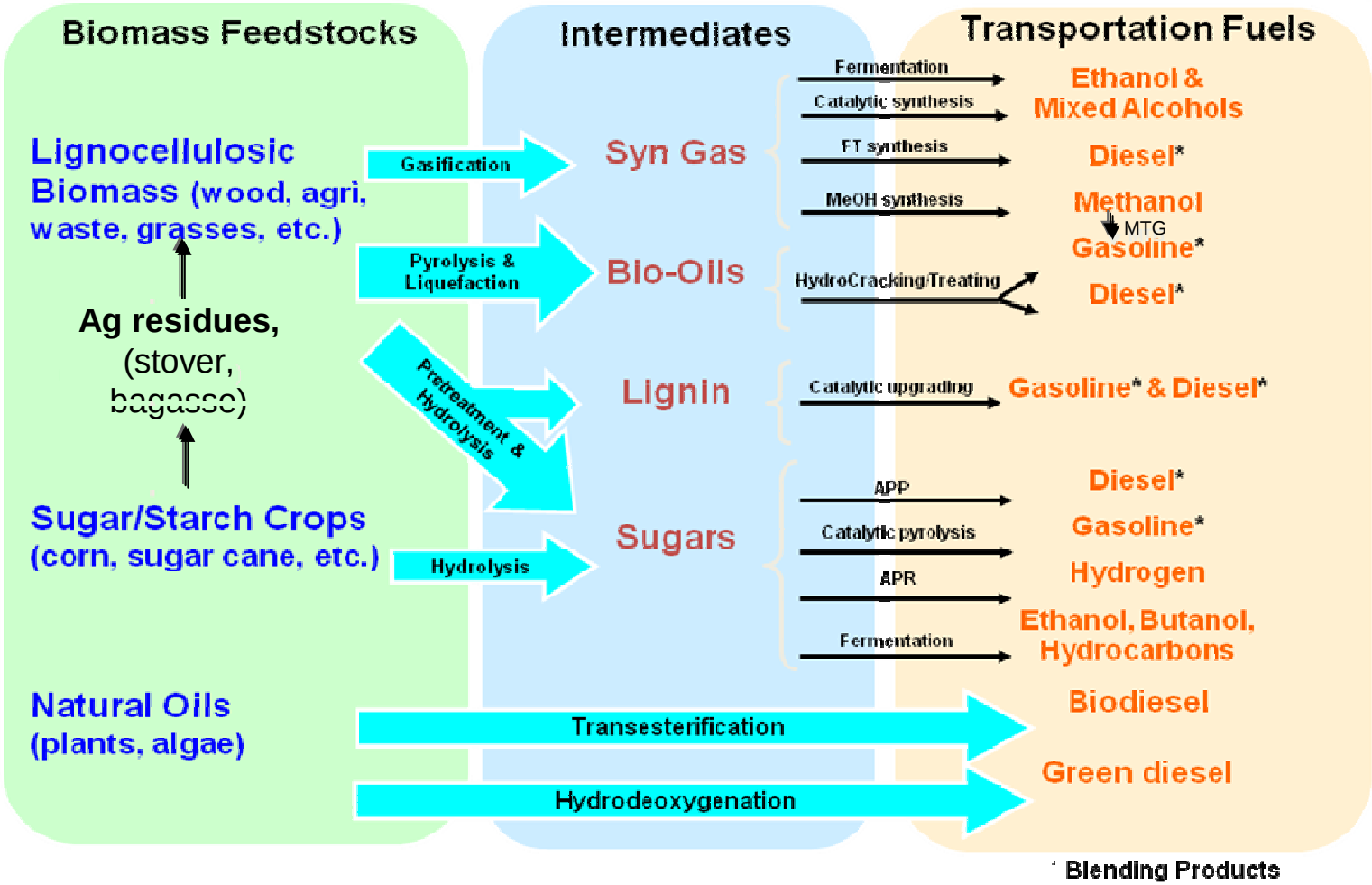
Gaps in Research of 2nd Generation Transportation Biofuels Task 41, Project 2 IEA Bioenergy, **2008**:01.
Biofuels: Where are we headed? Chemical Engineering Progress, **2008** August, AIChE S1-S23.
Breaking the Chemical and Engineering Barriers to Lignocellulosic Biofuels: Next Generation Hydrocarbon 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 Cellulosic Biomass



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

Transportation Options For Biofuels



Both Biochemical and Thermochemical Platforms have an Important Role to Play

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.

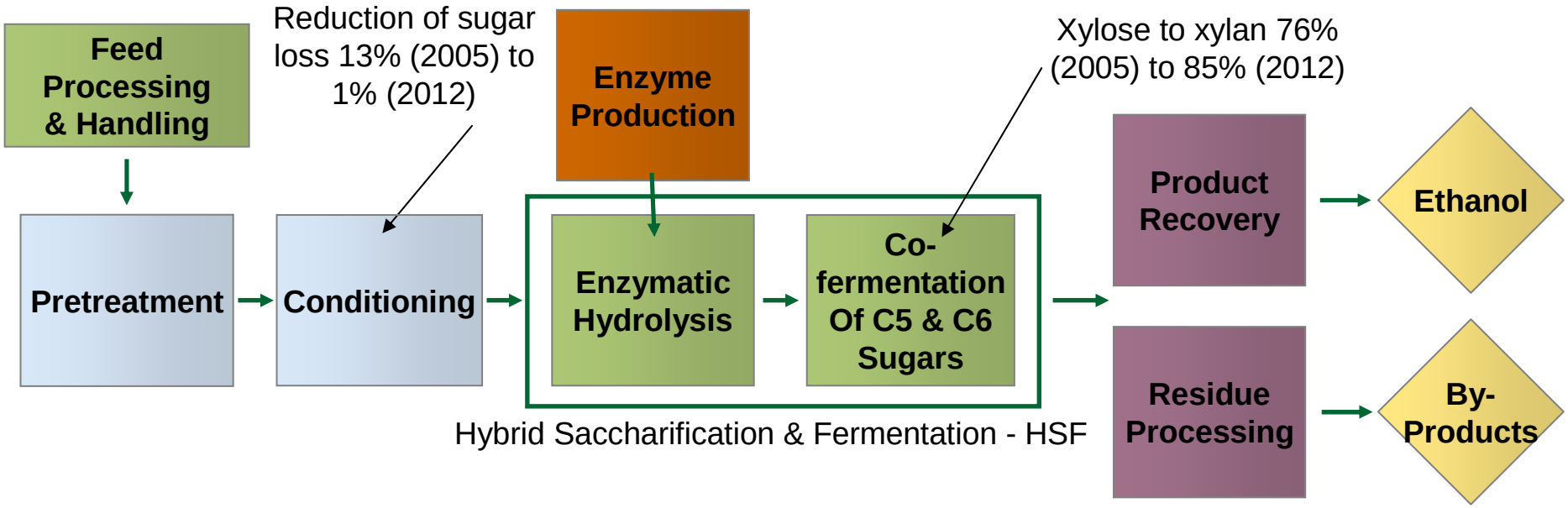
Conversion Critical Barriers

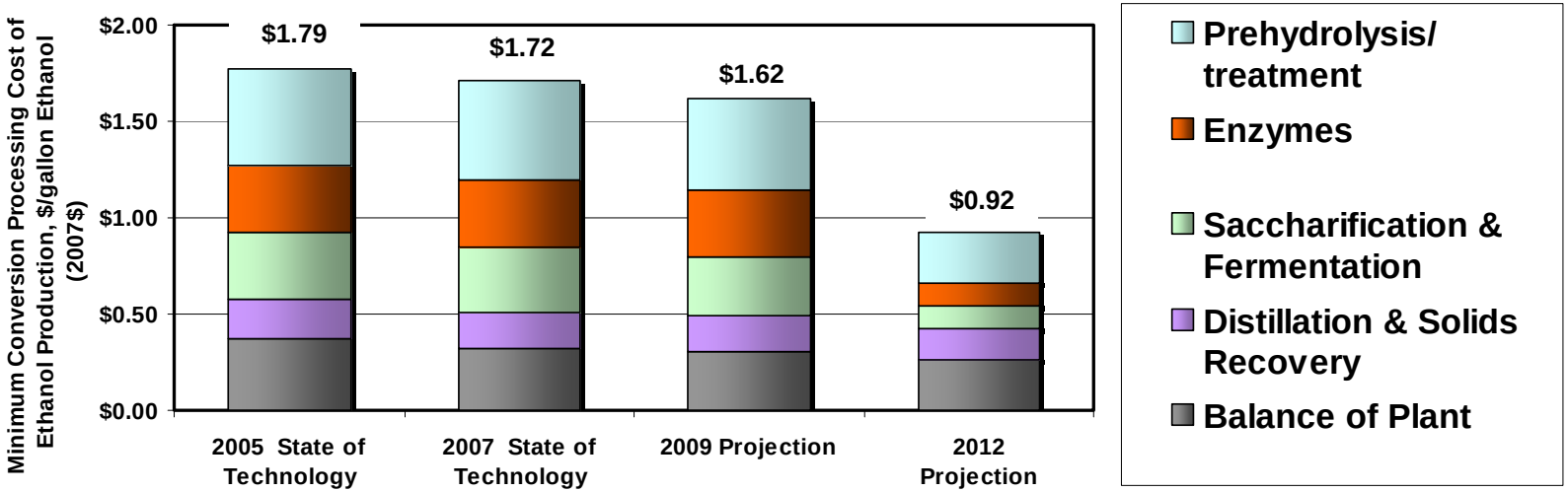
Barriers	Solutions
• High enzymatic conversion costs	• R&D to improve effectiveness and reduce costs of enzymatic conversion
• Low C5 sugars conversion	• R&D on advanced micro-organisms for fermentation of sugars
• Low syngas-to-fuel yields	• R&D to improve syngas clean-up and catalyst for alcohol/fuel 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

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

Major Technology Platform

Biochemical Conversion/Enzymatic Hydrolysis

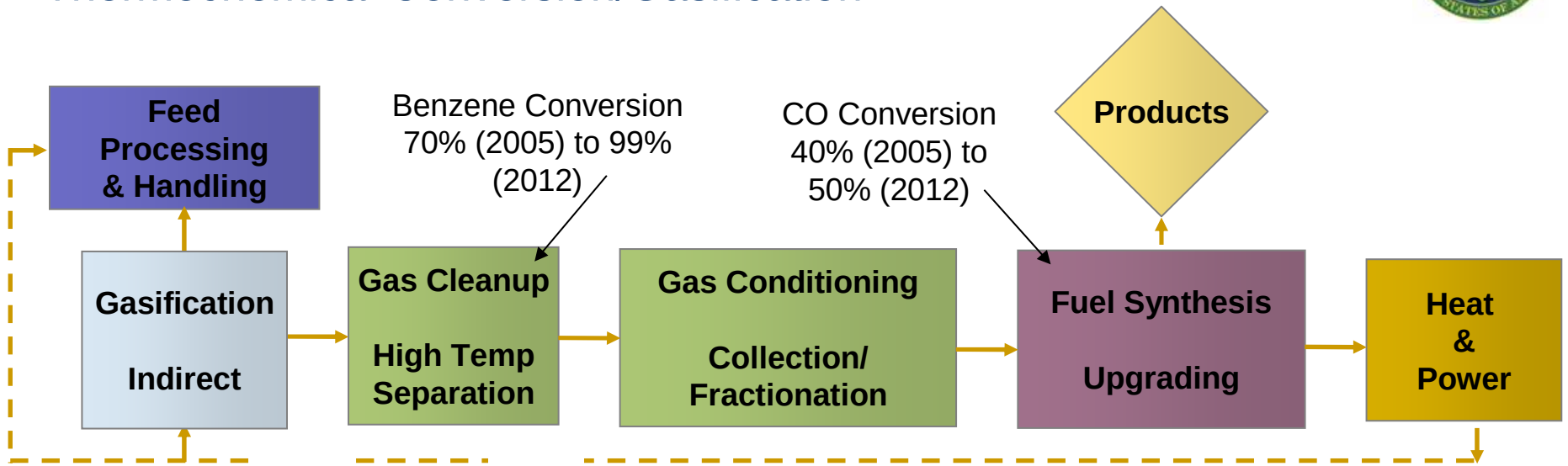


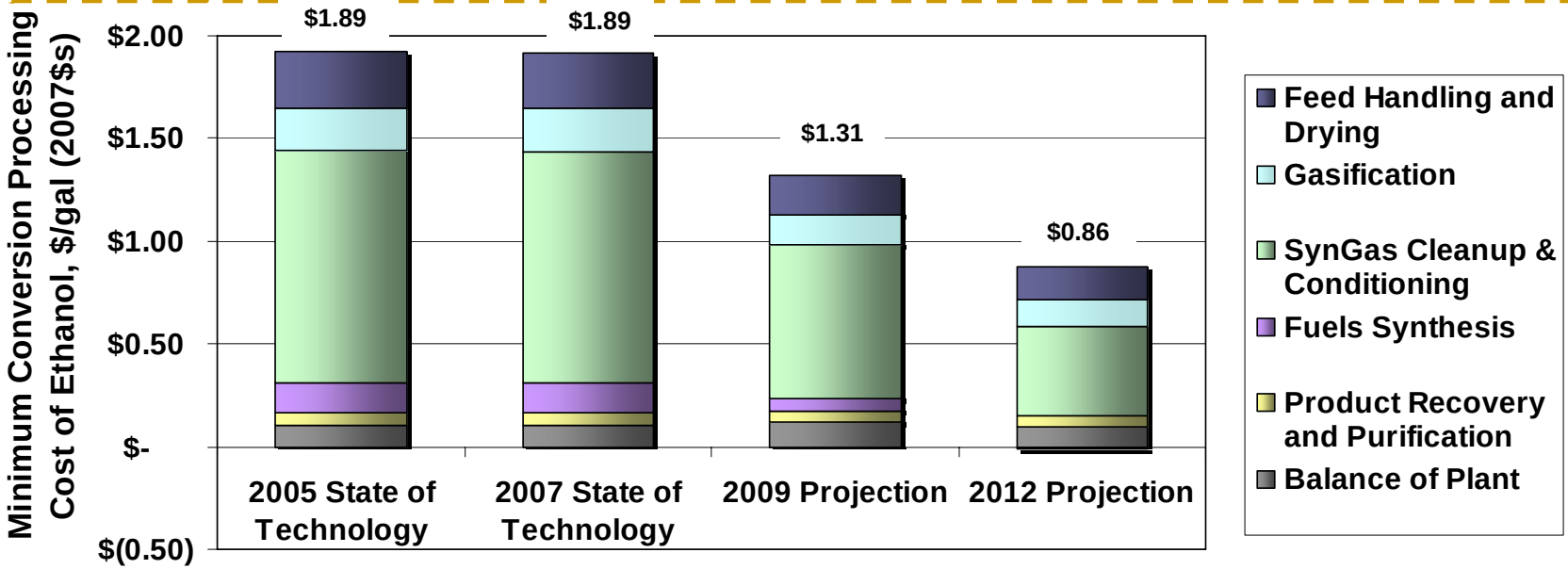


*** Conversion costs represented in the figure above are based on conversion of corn stover and equate to an Minimum Ethanol Selling Price $1.49/ gal ethanol or $2.26/GGE in 2012.**

Major Technology Platform

Thermochemical Conversion/Gasification

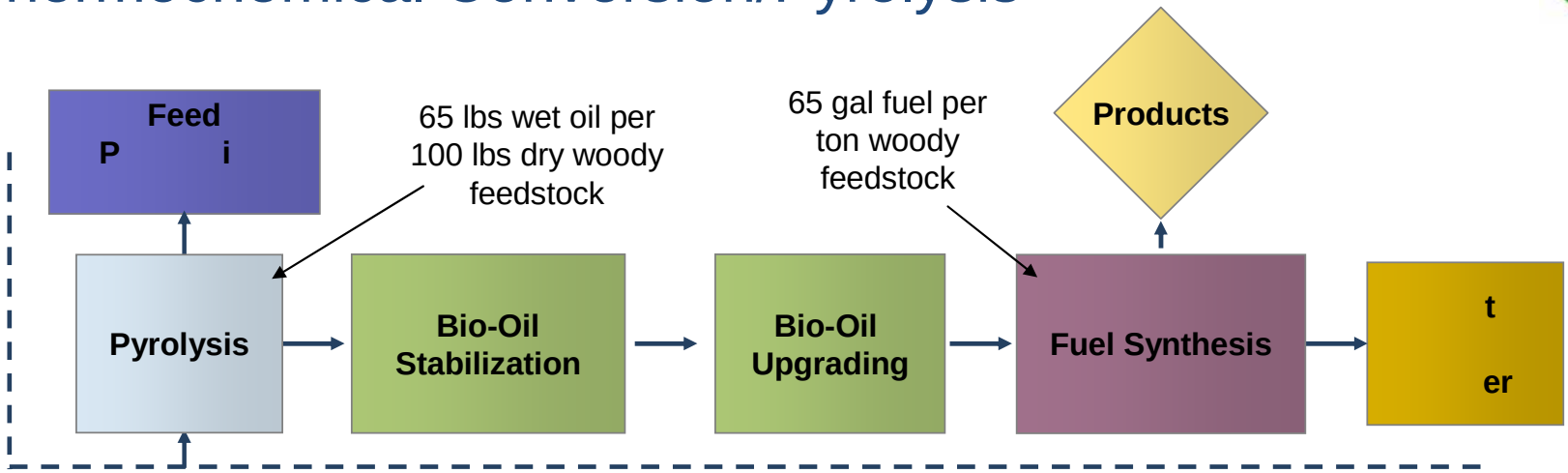


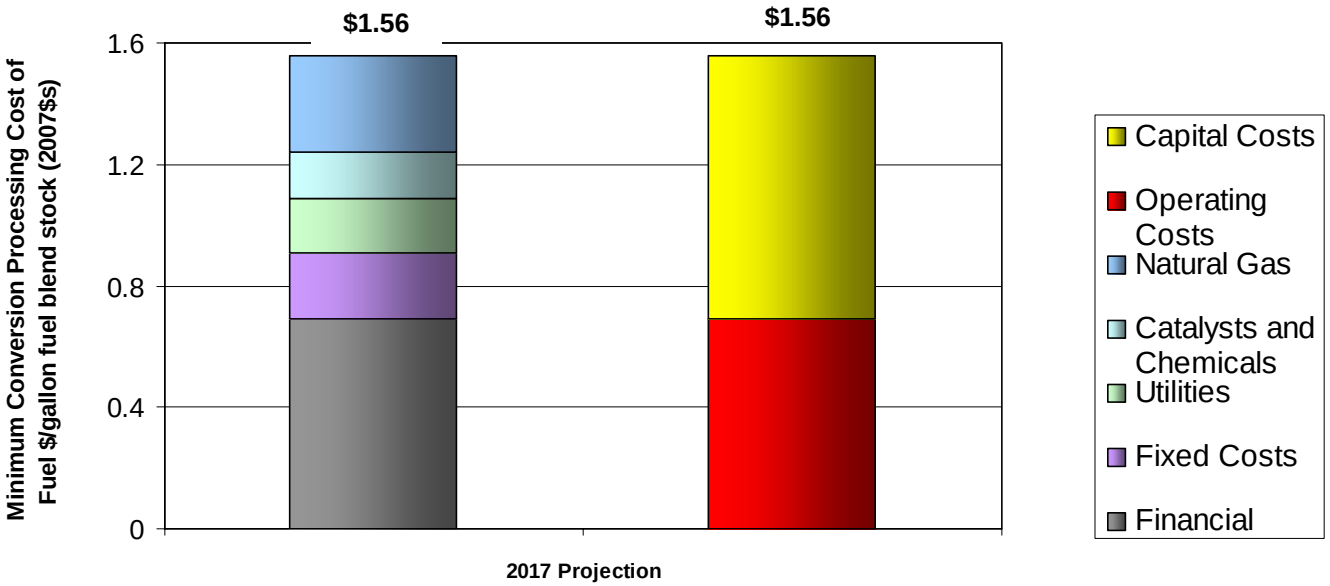


*** Conversion costs represented in the figure above are based on conversion of woody feedstocks and equate to an Minimum Ethanol Selling Price $1.57/gal ethanol or $2.39/GGE in 2012.**

Major Technology Platform

Thermochemical Conversion/Pyrolysis





Numbers are primarily based on literature and bench scale data.

*** Conversion costs represented in the figure above are based on conversion of woody feedstocks to a hydrocarbon fuel (57% diesel, 43% gasoline) and equate to an Minimum Fuel Selling Price of $2.04/gal or $1.92/GGE in 2017.**

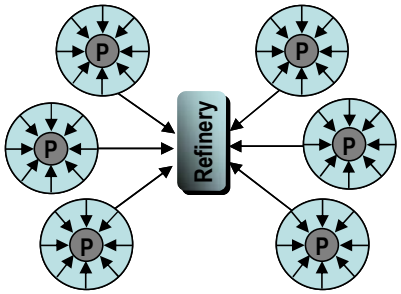
Challenging Characteristics of Pyrolysis Oil (from wood)

- Moisture content 15-30 wt %
- pH 2.5 / TAN >100
- Elemental composition, wt %
- - C: 54-58
- - H: 5.5-7.0
- - O: 35-40
- HHV: 16-19 MJ/kg
- Distillation residue: up to 50 wt %
- Instability / phase separation
- - a lighter, water soluble, carbohydrate-rich fraction
- - a more dense, viscous, oligomeric lignin fraction

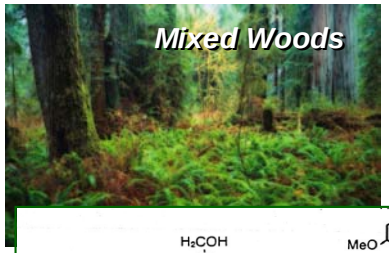
RD&D is currently being done by DOE, USDA and other agencies on addressing these challenges.

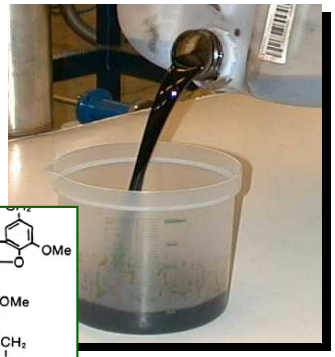
Czernik & Bridgwater, 2004

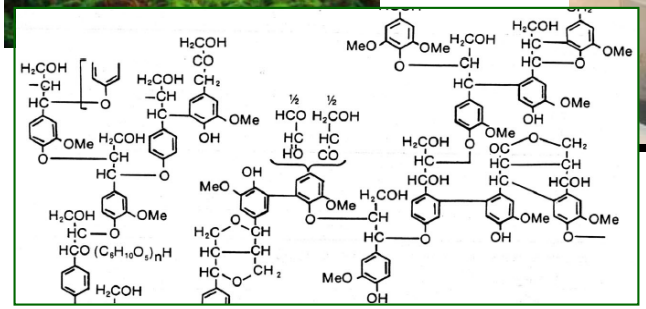
Distributed Pyrolysis and Centralized Bio-Oil Processing



Biomass → Pyrolysis → Stabilization → Biocrude → Deoxygenate / Other Refinery Processes → Gasoline, Diesel, Jet, Chemicals







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

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.

Recovery Act Funding for Acceleration of Biomass RD&D

$480M Pilot and Demonstration-Scale Biorefineries

Validate technologies for integrated production of advanced biofuels, products, and power to enable financing and replication.
10 to 20 awards for refineries to be operational within 3 years

$176.5M Commercial-Scale Biorefineries

Increase in funding for prior awards; two or more projects
Expedite construction; accelerate commissioning and start-up

$110M Fundamental Research

$20M: Integrated Process Development Unit

$5M: Sustainability research with the Office of Science

$35M: Advanced Biofuels Technology Consortium

$50M: Algal Biofuels Consortium to accelerate demonstration

$20M Ethanol Infrastructure Research

Optimize flex-fuel vehicles operating on E85
Evaluate impacts of intermediate blends on conventional vehicles
Upgrade existing infrastructure for compatibility with E85

Fundamental Research in Key Program Areas

Objective:

Establish two new Biofuels Applied R&D Consortia to accelerate the development of algal and advanced biofuels. Collaborate with the Office of Science (SC) and the Bioenergy Research Centers (BRCs).

Procurement Strategy:

New solicitation for Biofuels Applied R&D Consortia open to National Labs, academia and industry. 1 Algal Biofuels Consortium and 1 Advanced Fungible Biofuels Technology Consortium will be selected for up to $85M DOE share over three years. Collaboration with SC and their BRCs for $25M over five years through existing M&O contracts and agreements.

Funding:

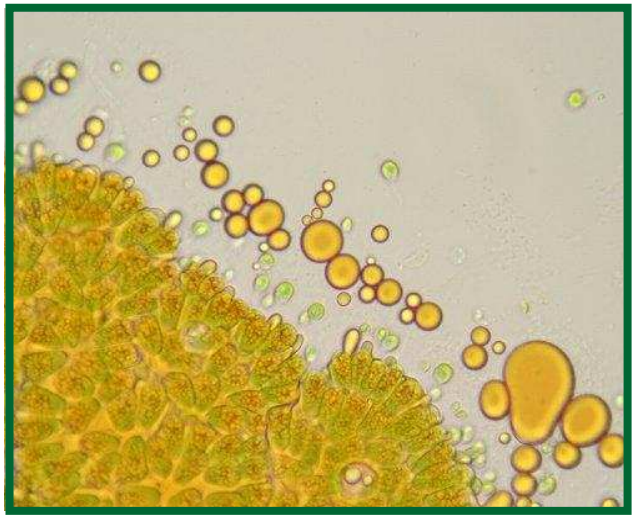
Recovery Act (FY2009-13): $110M

Timeline:

Release of FOA for consortia – Jul. 2009
Public release of algae roadmap – Aug. 2009
Fund sustainability effort – Sept. 2009
Make selection for consortia – Nov. 2009
Award consortia – Dec. 2009
Fund pilot facility (LBNL) – Jan. 2010
Complete costing RA$ – Sept. 2013

Accelerate Transformational Science to Create a Sustainable Biofuels Industry and Extend Biofuels Portfolio.

Why Algae?



- Algae can produce more lipids (plant oils) per acre than other plants -- *potentially 10x - 20x*
  - Lipids are the preferred starting point to make diesel or jet fuel from biomass
- Algae cultivation can utilize:
  - marginal, non-arable land
  - saline/brackish water
  - large waste CO_2 vent resources
- Minimal competition with food, feed, or fiber

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

Oil (Lipid) Recovery

- De-watering methods
- Lipid extraction
- Purification

Fuel Production

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

Examples of Challenges For Additional Advanced Biofuels

- DOE and Other Agencies are considering:
  - Methanol-to-gasoline.
    - Needs process intensification and robust multifunctional catalysts.
  - Biomass-to-Renewable Methane.
    - Need cost effective conditioning and compression of high quality renewable methane.
  - Biochemical Routes to Saturated Hydrocarbons.
    - Need improved yields and separation of product from aqueous systems.
  - Hybrid Systems.
    - Identify and leverage positive synergies of biochemical and thermochemical processes in a cost effective manner.
      - Gasification-fermentation

Future Program Directions

Biochemical

- **Continued targeted focus on the technical barrier areas on meeting the 2012 cost targets.**
- **Transition beginning in FY12 to infrastructure compatible biofuels using alternative biochemical pathways.**

Thermochemical

- **Currently heavily focused on meeting the 2012 ethanol cost targets.**
- **Modest effort in pyrolysis and Fischer-Tropsch fuels currently underway. Transition accelerating in FY10 to increase infrastructure compatible biofuels using thermochemical routes.**

Integrated Biorefineries

- **Expected to see more IBR proposals competing in the recently closed solicitation that yield infrastructure compatible biofuels**

Advanced Biofuels/Algae Consortia

- **Expecting to fund 1-3 total consortia to develop the necessary technology to support a full scale commercial industry.**

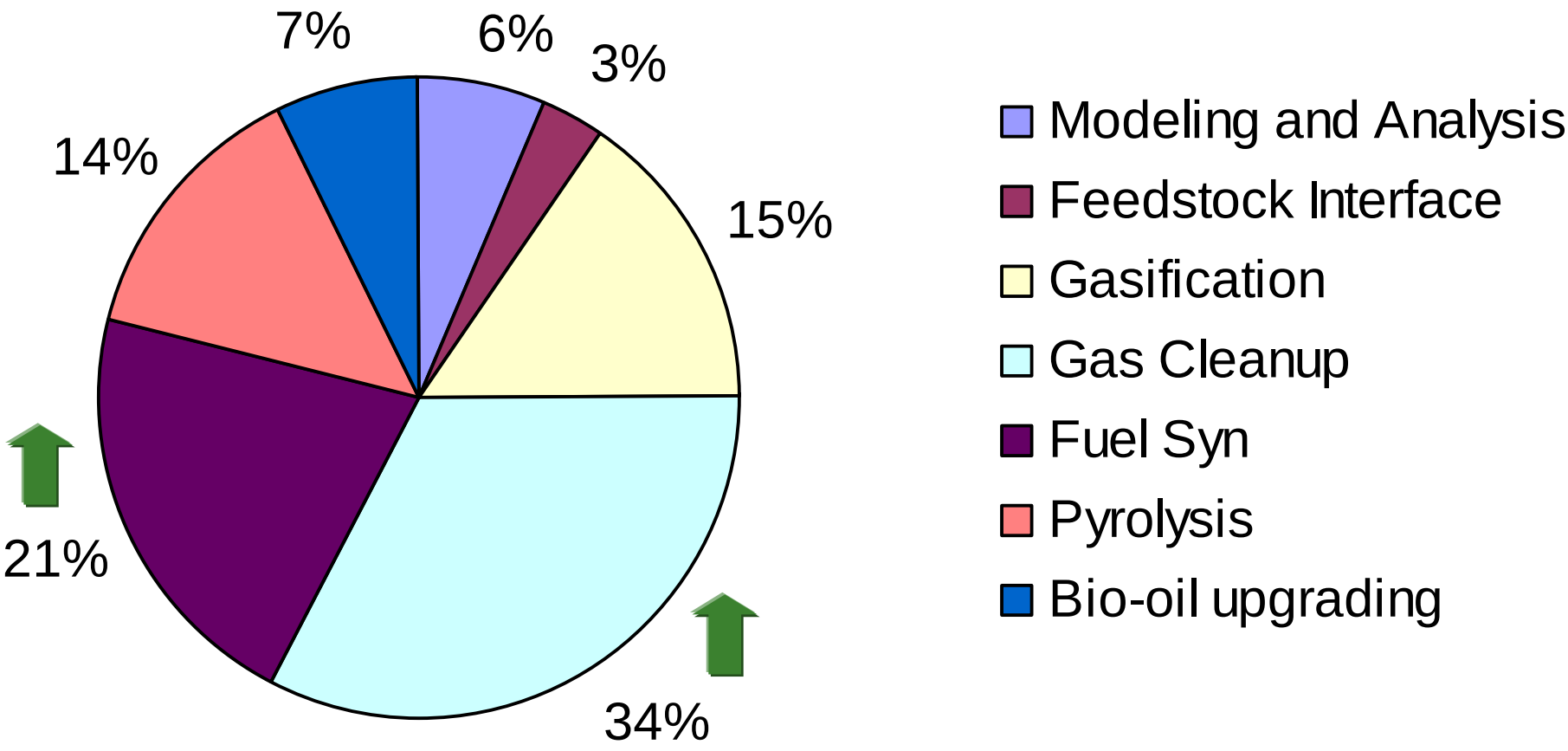
Information Resources

- 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

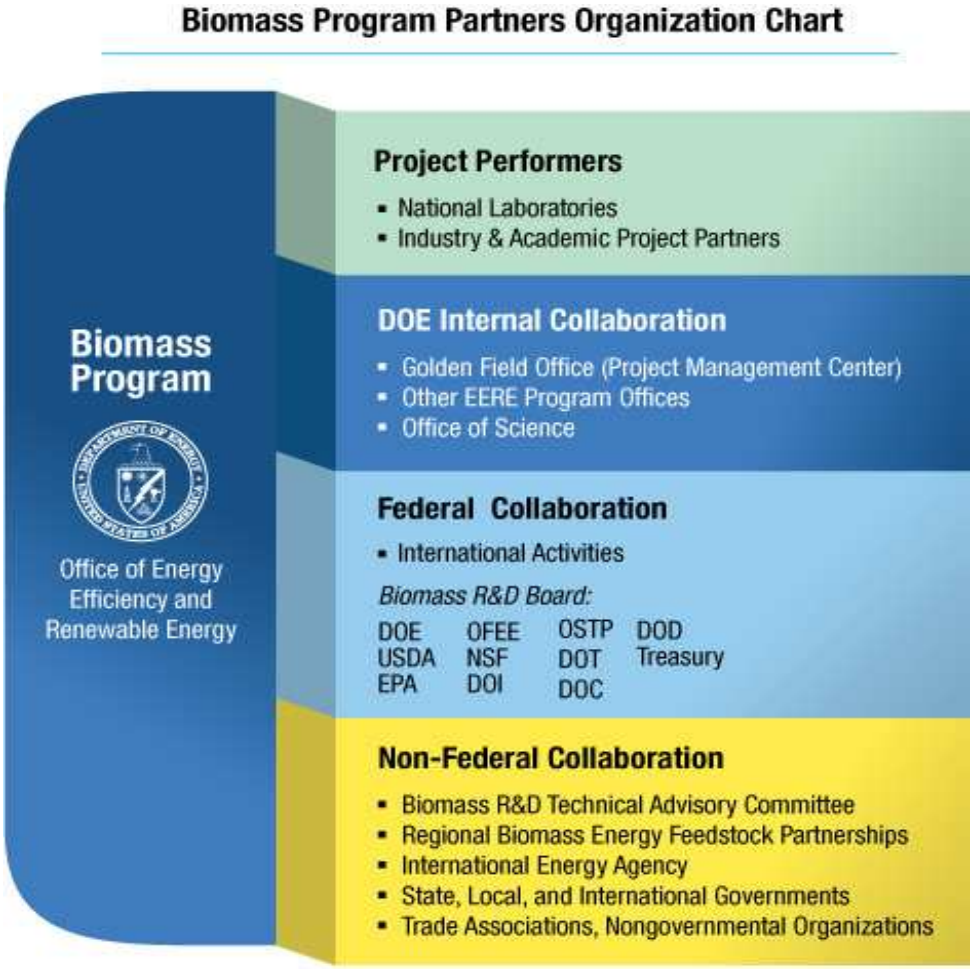
BACKUP

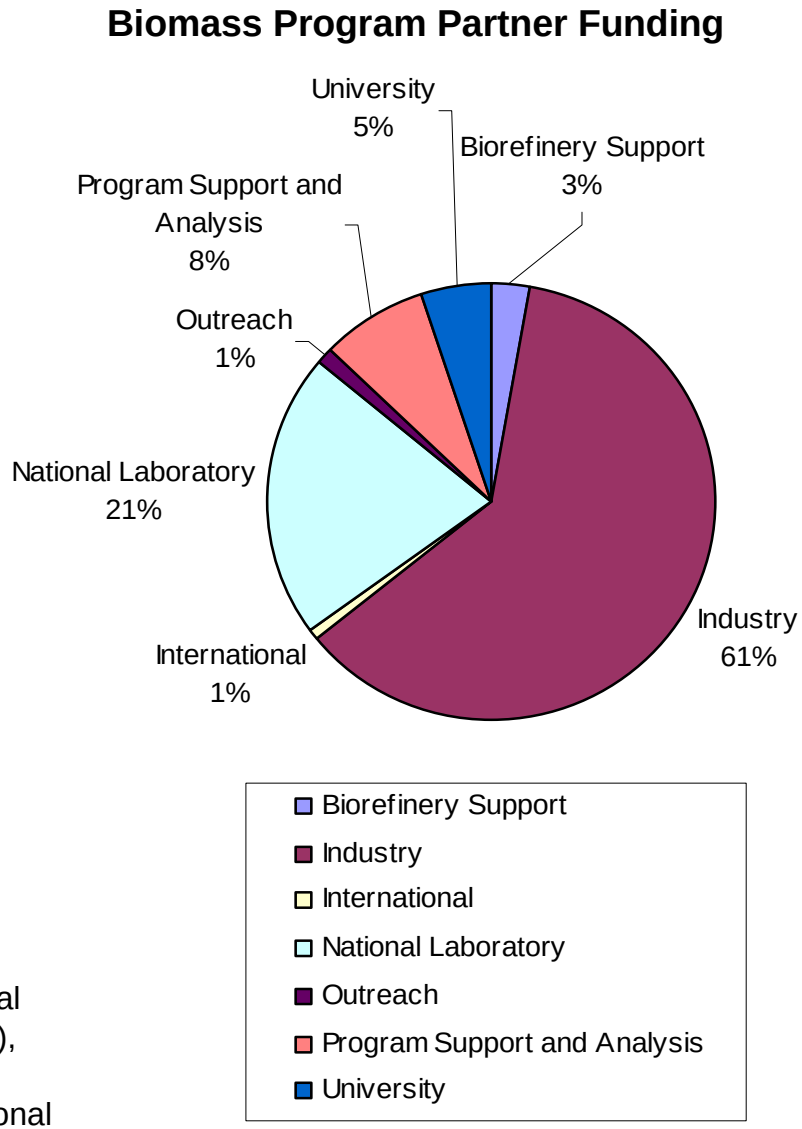
Thermochemical Conversion Platform 2009 Distribution of Funding



36% of the current platform is looking at non-ethanol research (Fast Pyrolysis and Fischer-Tropsch derived alkanes)

Collaborations - Program Partners and Key Stakeholder Relationships





The national laboratories that the Program partners with are the National Renewable Energy Laboratory (NREL), Idaho National Laboratory (INL), Oak Ridge National Laboratory (ORNL), Argonne National Laboratory (ANL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (SNL).

DOE Biofuels Sustainability Research Priorities

Biomass R&D Board Interagency Sustainability Working Group - Engaged in U.S. Government partnership to identify biofuels sustainability indicators

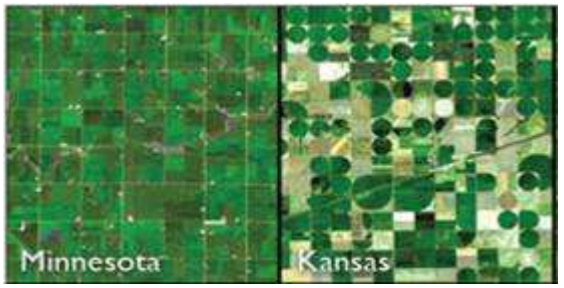
Indirect Land Use - Developing models to help study international land use impact of domestic biofuels production and mandates

Climate Change - Conduct life cycle analysis (LCA) of biofuels production and use through a wide range of existing and future production pathways

Water - Conducting LCA of water demand for biofuel production (compares corn ethanol, sugarcane ethanol, and competing petroleum fuels)

Biodiversity – Study impact of biofuels industry growth on biodiversity and sensitive ecosystems

GIS Tools - Developing GIS tools to analyze current and future U.S. feedstocks, infrastructure availability, and economic and environmental sustainability



Addressing sustainability challenges is critical to industry growth.

Emphasis on Sustainability

Sustainability Program Purpose: To understand and address the potential environmental impacts of biofuels production activities—encouraging the benefits while mitigating any concerns

Feedstocks

- Through a partnership with Sun Grant Initiative, use field trials to collect data on sustainability
- Work with Council for Sustainable Biomass Production to develop criteria

Land Use

- Quantify future land use impacts for various scenarios using Purdue's GTAP, ANL's GREET models
- Incorporate land use data and yield assumptions

Water

- Conduct LCA of water use in production
- Analyze regional variations due to climate & soil
- Evaluate mitigation potential of bioenergy crops

International Efforts

- Work with Conservation International to identify land and preserve best production locations
- Provide data and analysis to Roundtable on Sustainable Biofuels, Global Bioenergy Partnership, others
- Contribute to International Biofuels Forum

Leveraging--Great Lakes Bioenergy Research Center

- Biogeochemical, biodiversity, and socioeconomic responses to expansion and intensification of agriculture and silvicultural practices
- Spatially explicit land use change forecast on crop area changes

Climate Change

- GREET Model development
- EISA Lifecycle Analysis – Monitoring and improving carbon footprint of bioenergy

The goal of the sustainability efforts in the Biomass Program is to anticipate and navigate requirements and inquiries with regard to the environmental benefits and impacts of Biomass Program activities