Biofuels Research and Development:

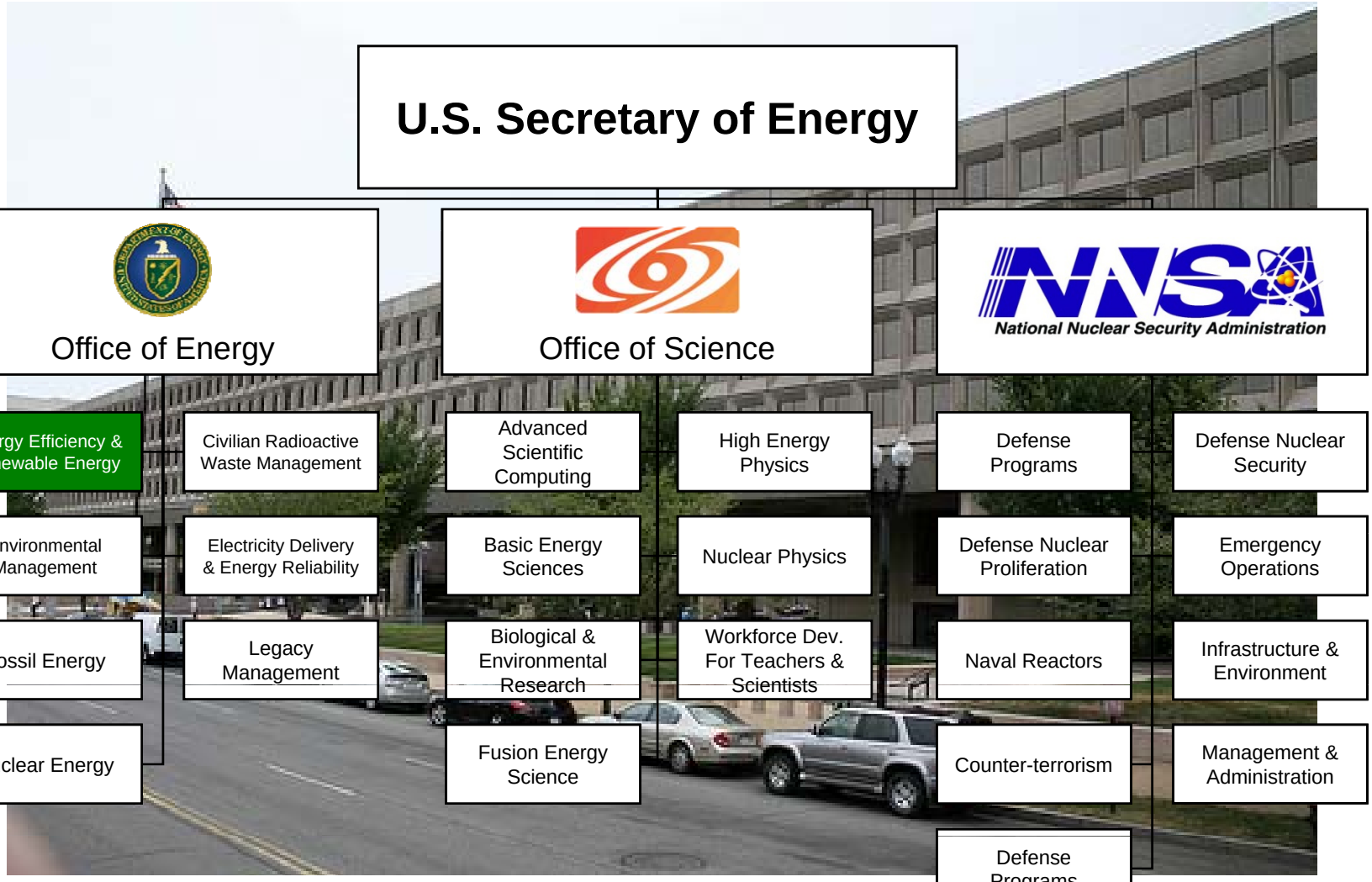
An Overview of the U.S. Department of Energy Office of Biomass Program

CREST International Symposium of Algal Fuel Researches

August 8, 2009

Joyce C.Yang, Ph.D.

U.S. DOE Organization Chart



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Office of Energy Efficiency & Renewable Energy

Power Generation

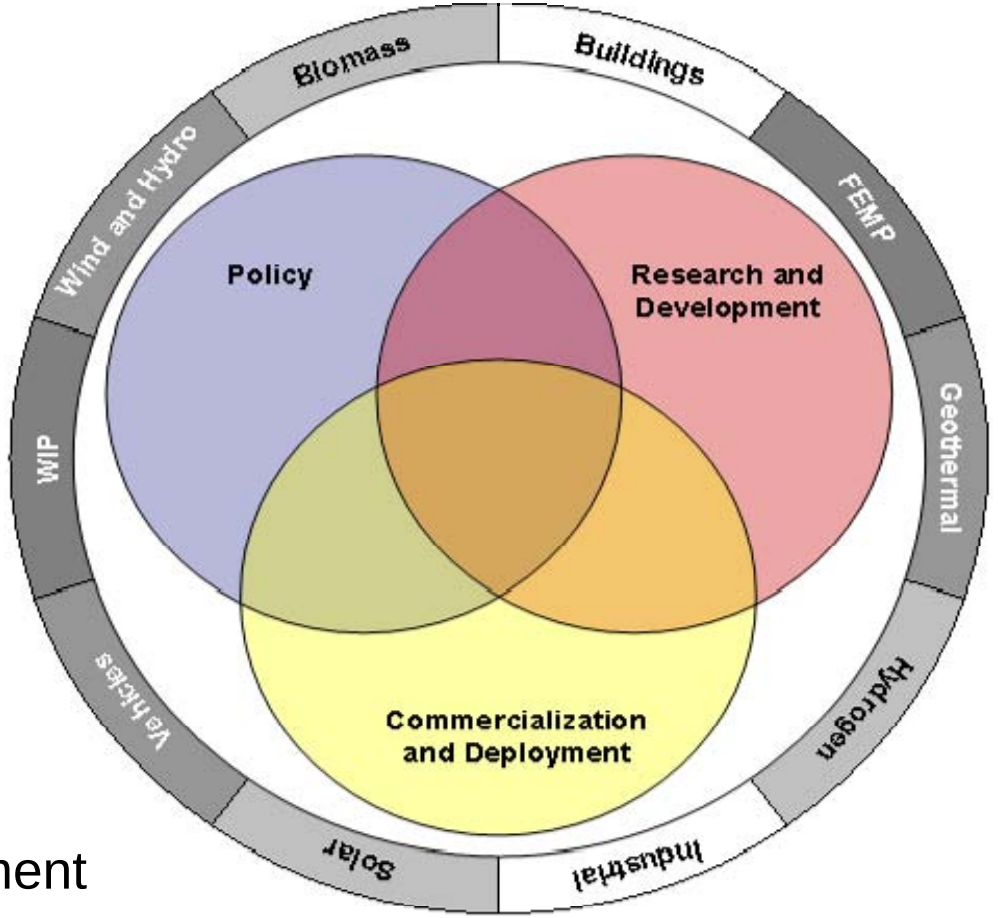
- Geothermal
- Wind & Water Power
- Solar

Fuels & Vehicles

- Biomass/Biofuels
- Hydrogen
- Vehicle Technologies

Energy Efficiency

- Buildings Technologies
- Industrial Technologies
- Weatherization
- Federal Energy Management



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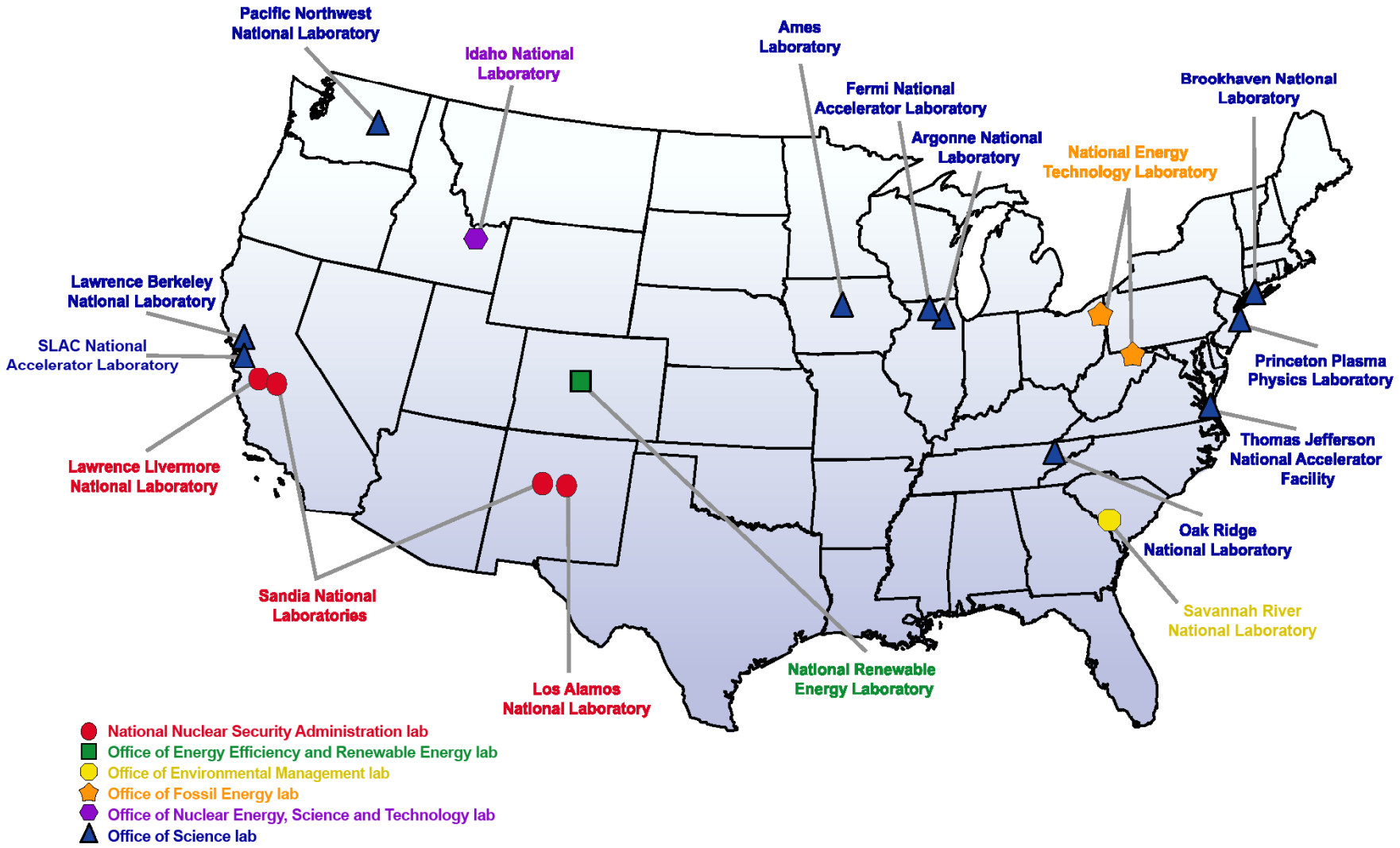
DOE National Laboratories



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Why Biofuels?

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

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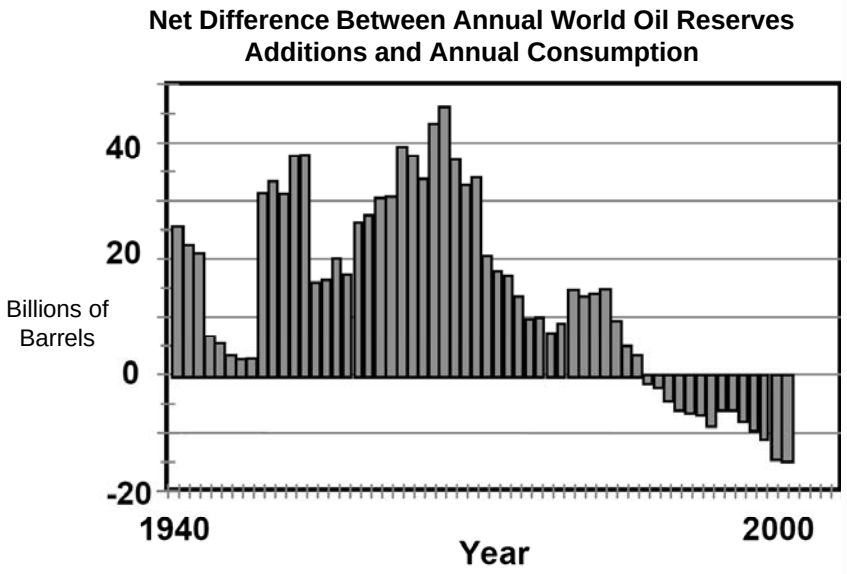

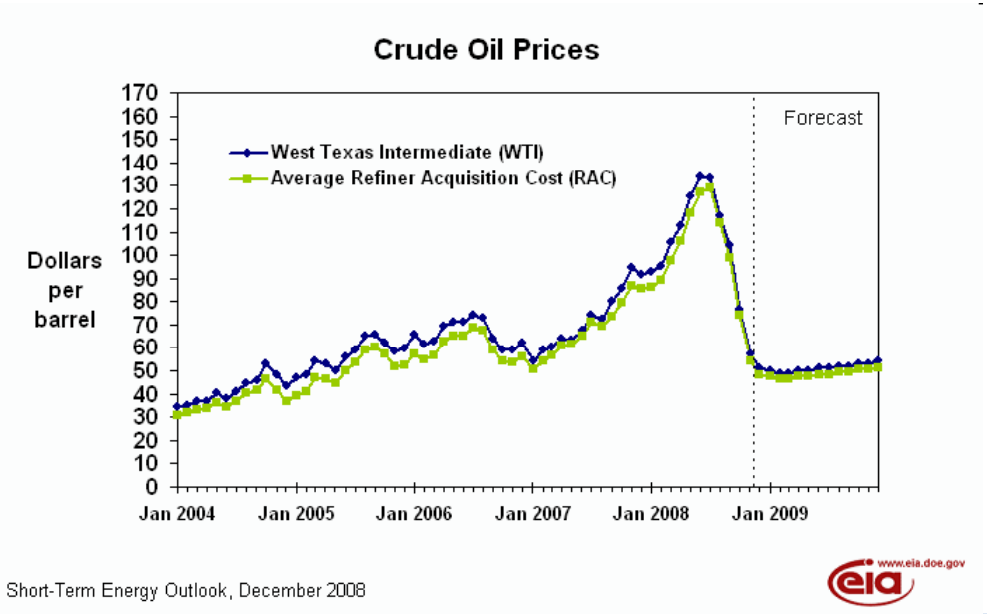

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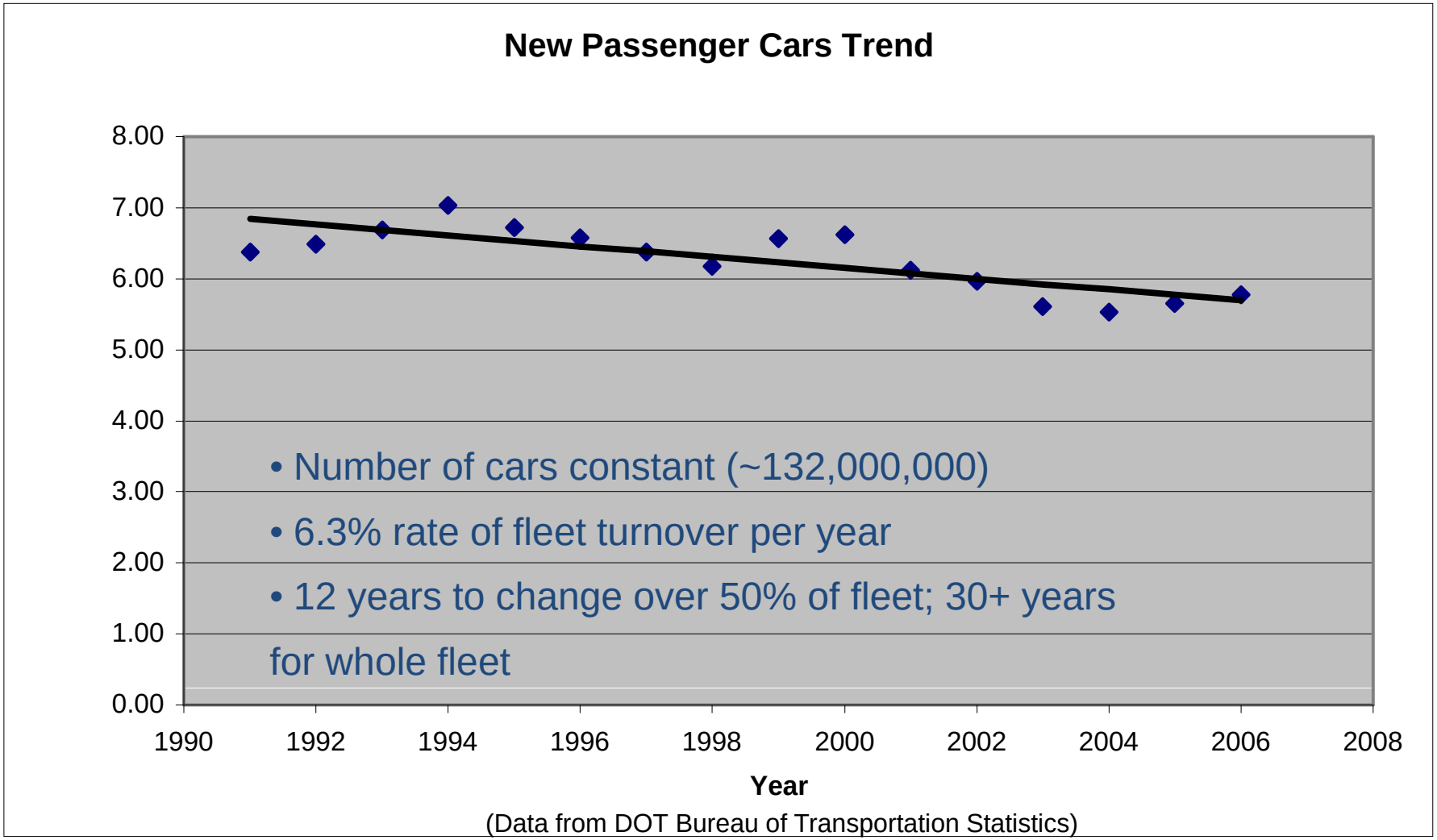

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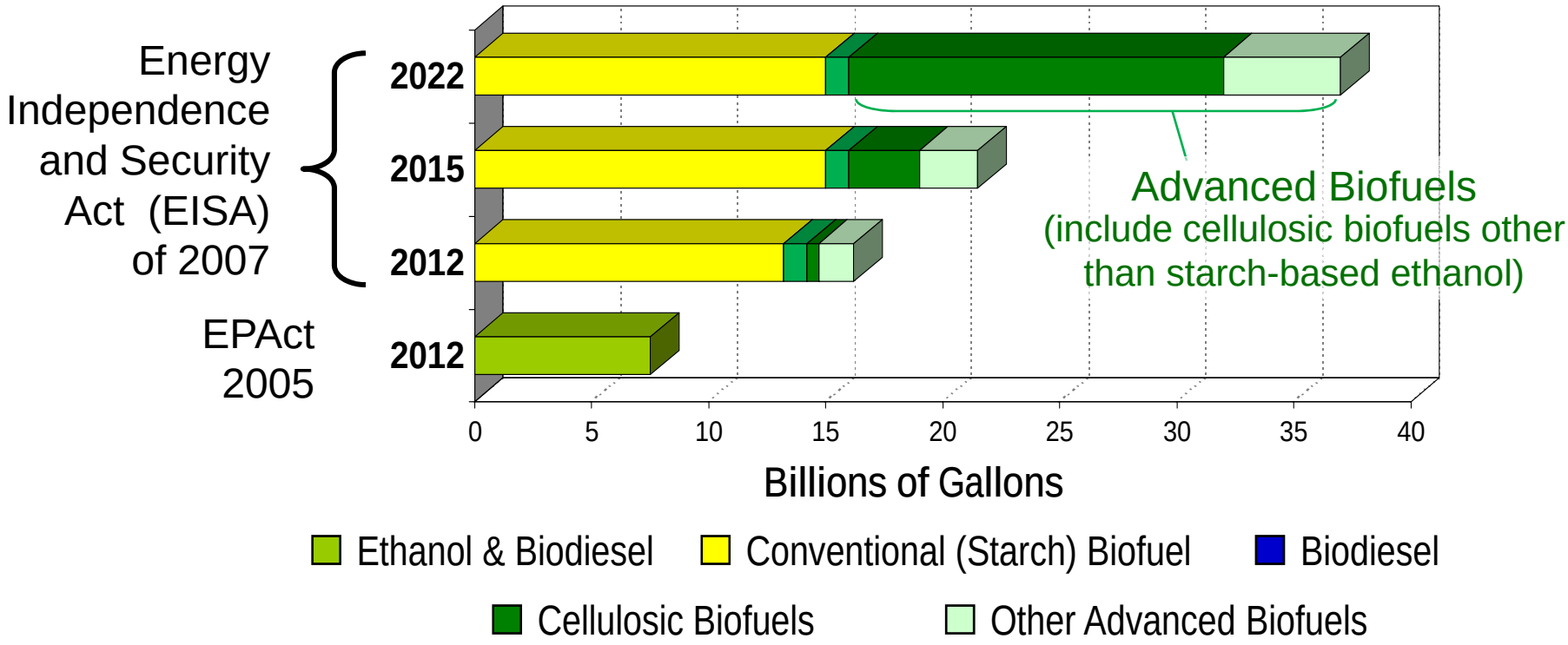
U.S. Legislative Mandates (Selected Years)



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."

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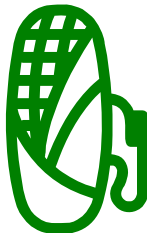
Biomass Program Mission

Develop and transform U.S. renewable and abundant biomass resources into cost-competitive, high-performance biofuels, bioproducts, and biopower.

Focus on targeted research, development, and demonstration

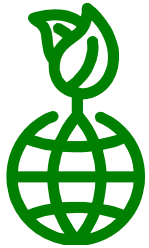
- Support through public and private partnerships
- Deploy in integrated biorefineries

Successive Generations of Biofuels



Corn Ethanol

- Commercially available (no DOE research)
- Reduced GHG emissions
- Capacity constrained



Cellulosic Ethanol

- Focus of current DOE research
- Potential to lower GHG emissions 86%
- Uses biomass from waste and non-agricultural land

Advanced Biofuels

- Focus of planned DOE research
- Could minimize environmental footprint
- Energy content, fuel economy, and chemistry may be more similar to petroleum-based fuels

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Biomass Program Goals

Short Term: Foster breakthrough technologies needed to make cellulosic ethanol cost-competitive by 2012 (cost target: $1.76/gal).

Mid Term: Help create an environment conducive to maximizing the sustainable production of biofuels by 2017, including cost-effective technology, sufficient infrastructure, appropriate policies, and supportive consumers.

Long Term: Increase the supply of cellulosic and advanced biofuels to 21 billion gallons by 2022 (per Renewable Fuel Standard in the Energy Independence and Security Act of 2007)

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Biofuels Supply Chain

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




- **Cellulosic Ethanol**: Primary focus of the program.
- **Alternative Light-Duty and Diesel Replacement Fuels:** Major scoping activities are underway to help prioritize future work on additional alternate fuels that require governmental support and can significantly contribute to achieving the President's goals.

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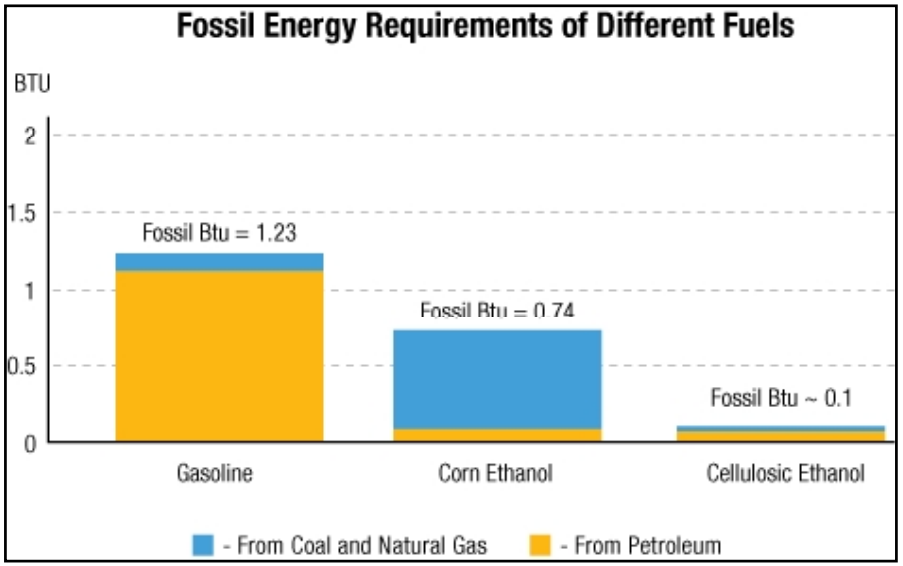
Feedstocks for Today and Tomorrow

Today

- Grains (corn, sorghum, wheat)
- Oilseeds and plants (soybeans)

Tomorrow

- Agricultural residues (stalks, stems, cobs, other crop wastes)
- Energy crops (switchgrass, miscanthus, poplar, willow)
- Forest resources (wood waste, forest thinnings, small-diameter trees)
- Oilseeds and oil crops (Jatropha, rapeseed, microalgae)
- Green wastes (urban wood wastes, sorted municipal solid waste)



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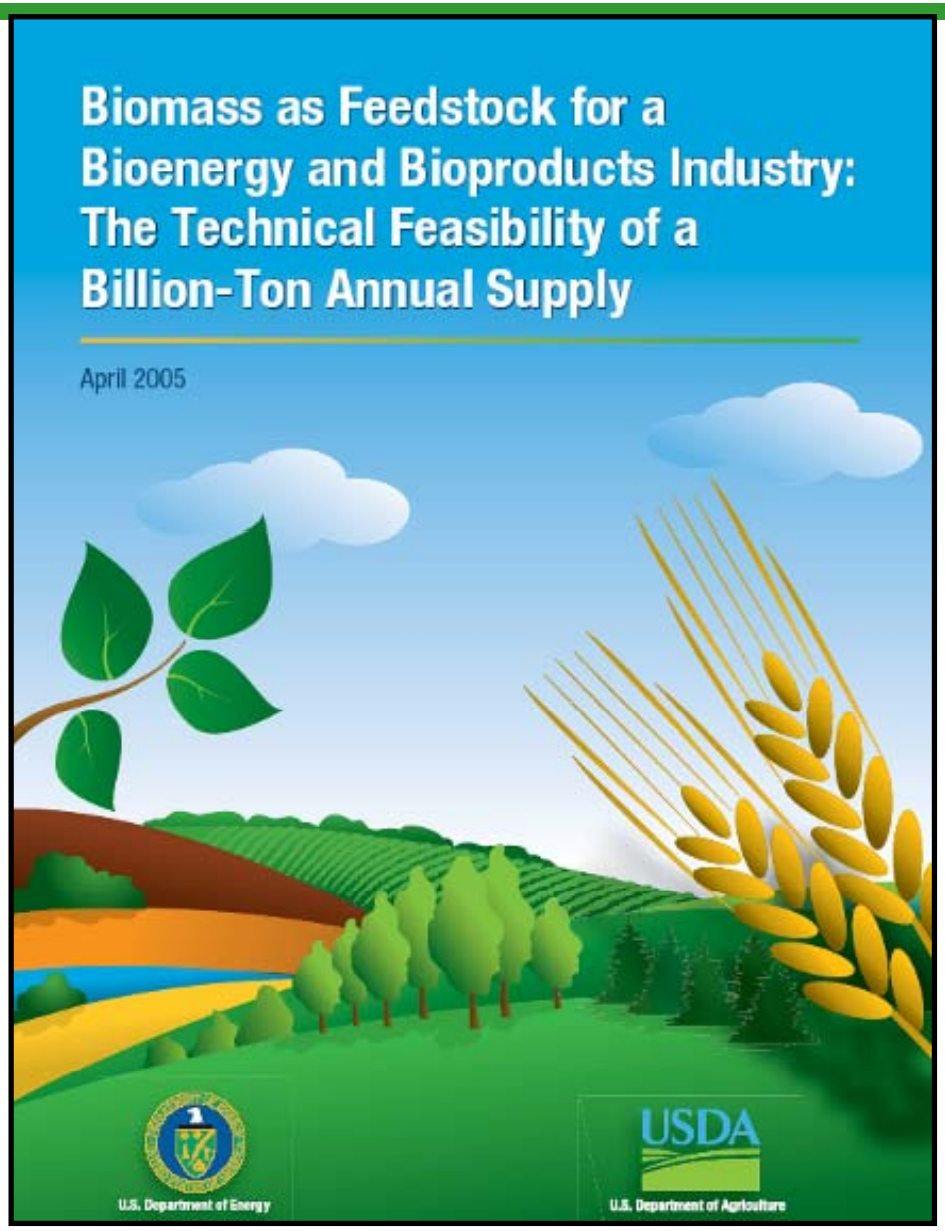
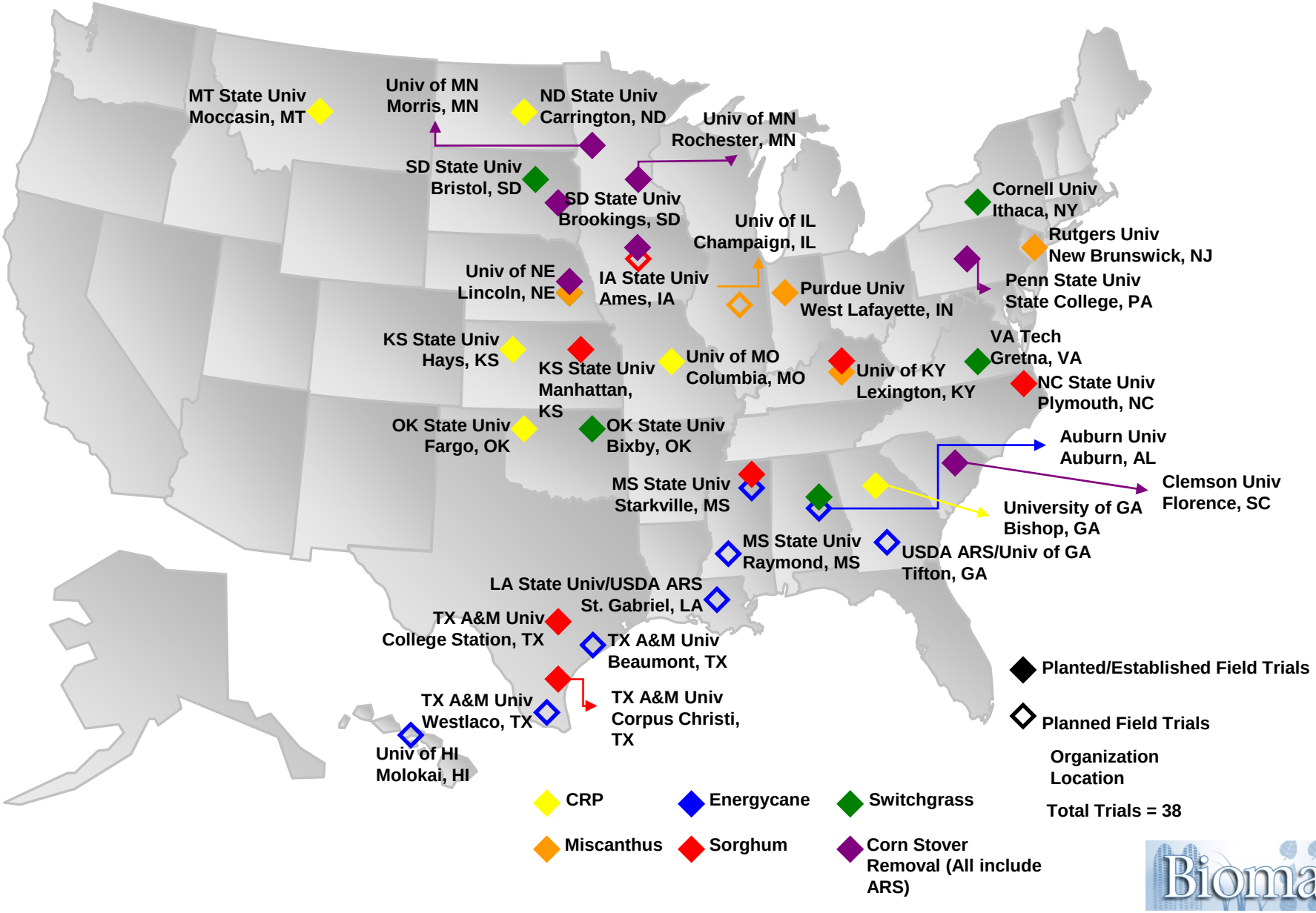
Biomass Resources Adequate to Meet RFS



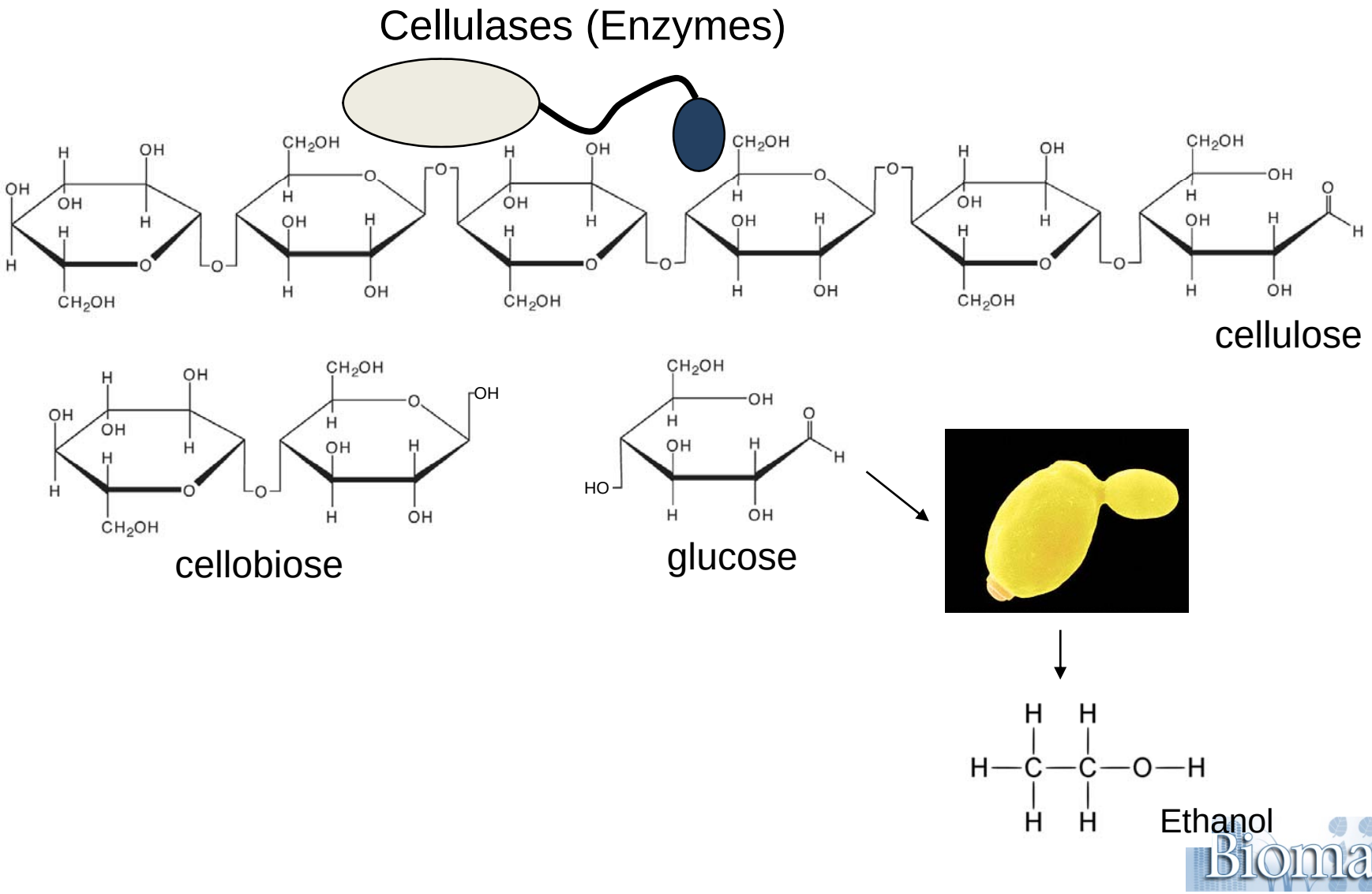
Conclusion:
By 2017, forest and cropland resources can yield 20-30 billion gallons of cellulosic biofuels.

Perlack *et al*., 2005

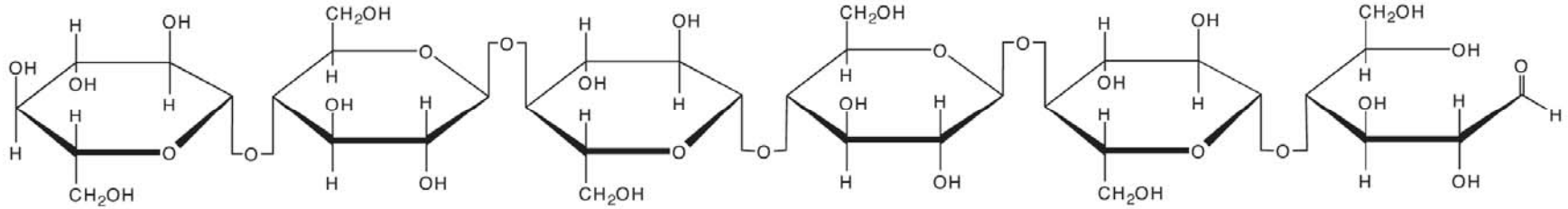
Regional Biomass Energy Feedstock Partnership



Biochemical Conversion of Cellulose

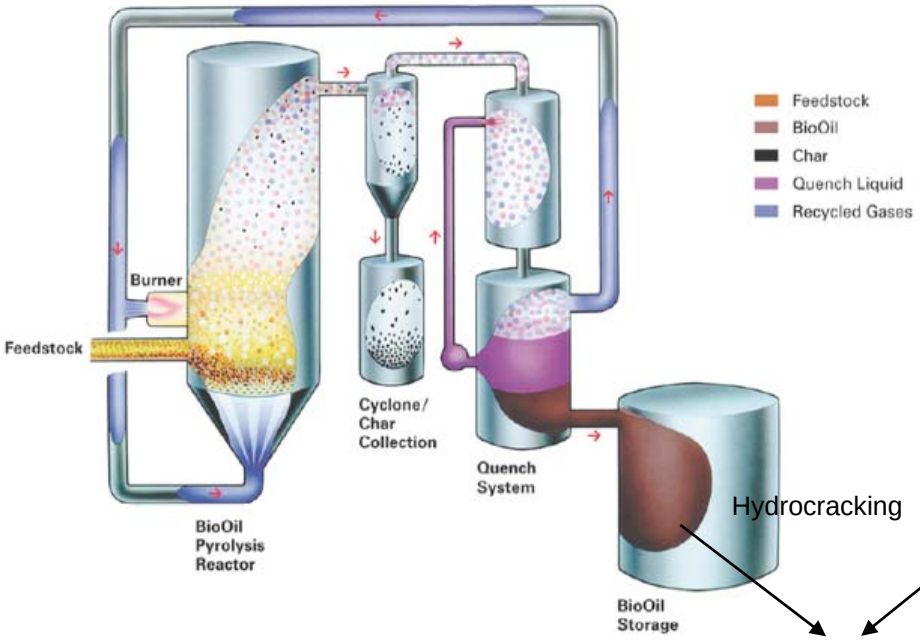


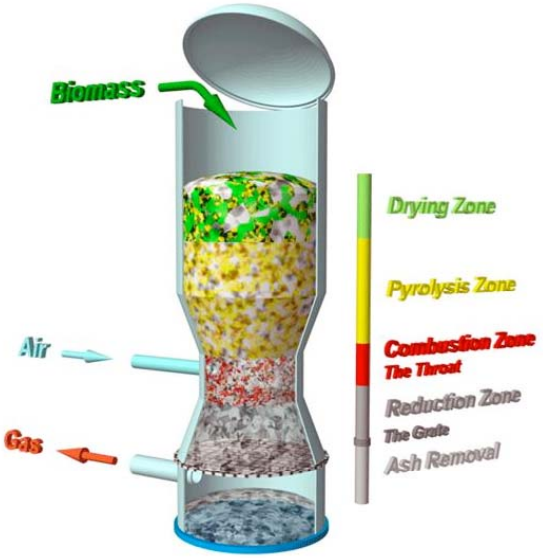
Thermochemical Conversion of Cellulose



pyrolysis

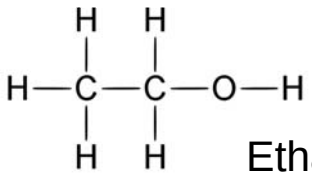
gasification





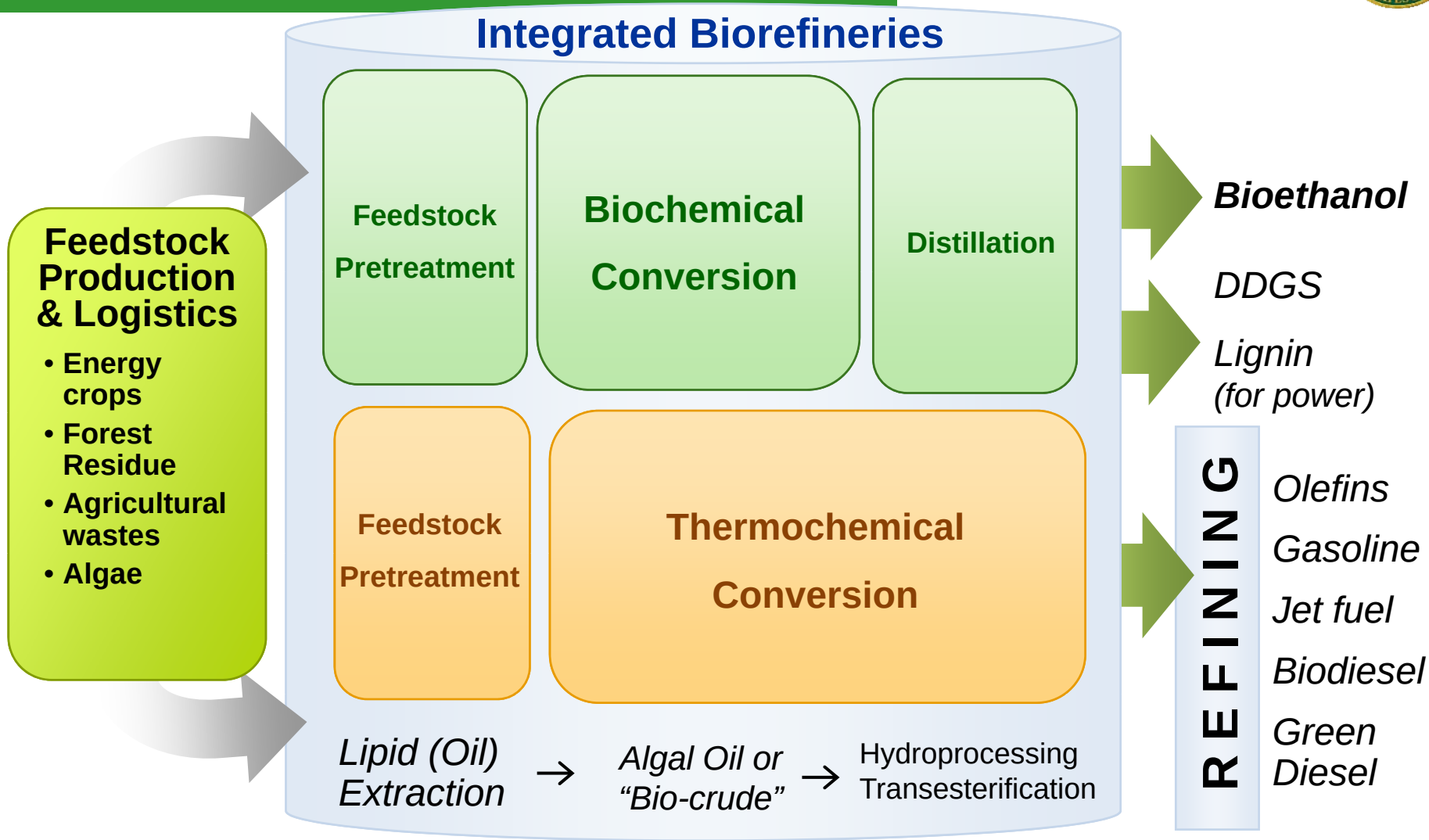
Hydrocracking

Fischer-Tropsch/
Alcohol Synthesis



Ethanol

Exploring Routes to Convert Biomass



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Need for 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 and diesel fuels.

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

- Green gasoline
- Cellulosic biobutanol
- Algae-based biofuels

Hydrocarbon-Compatible (Infrastructure-Compatible) Advanced Biofuels

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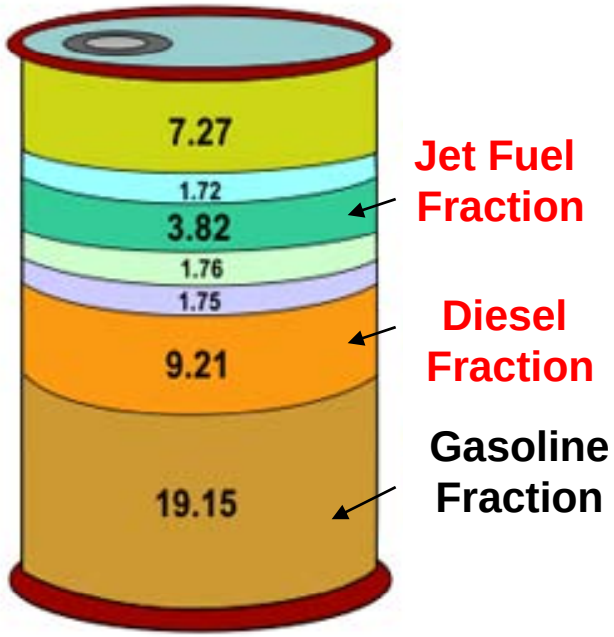
Why Advanced Biofuels? Demand



Source: Energy Information Administration

U.S. Diesel Outlook
(EIA FY2008 Reference Case for 2030)

- 75 billion gal/yr
  - < 0.5 billion gal/yr biodiesel production (2007)
  - 13 billion gal/yr if the entire U.S. soybean crop utilized

U.S. Jet Fuel Outlook
(EIA FY2008 Reference Case for 2030)

- 35 billion gal/yr

Cellulosic Ethanol displaces light duty gasoline fraction only.
Need heavy duty/diesel substitutes to displace entire barrel.

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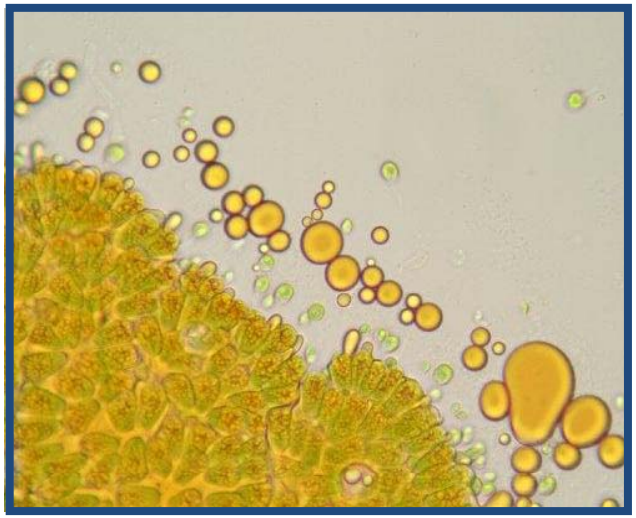
Why Algae? Supply



- 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

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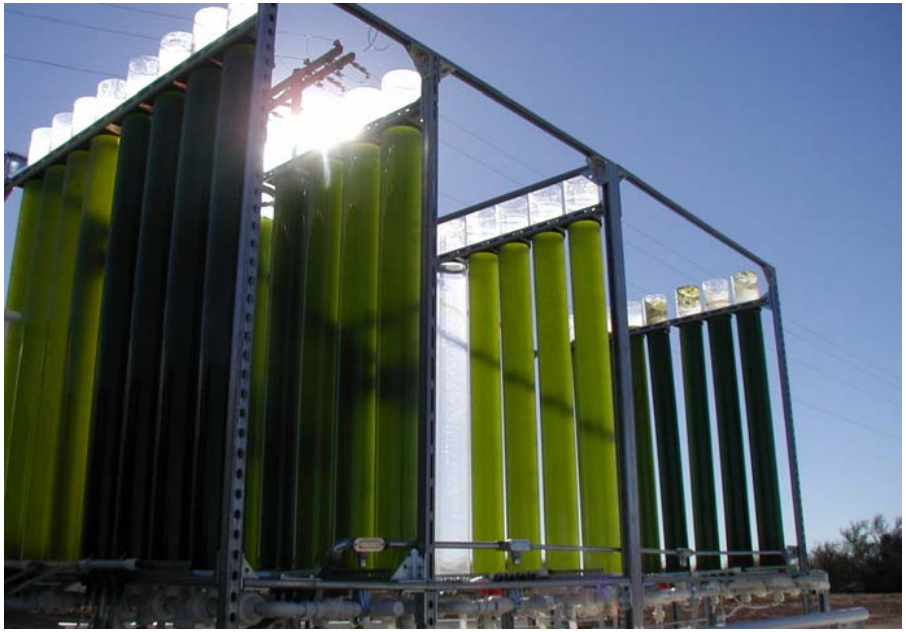
Commercial-Scale Cultivation

Raceway Ponds
Cyanotech, Hawaii



Outdoor Photobioreactor
Arizona State University

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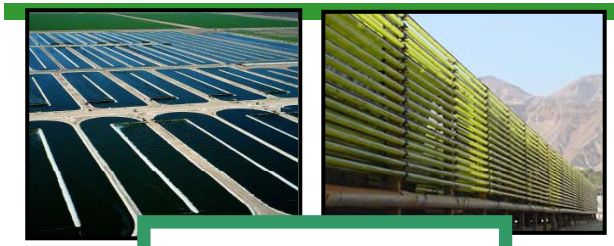
Technical Barriers



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)

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U.S. Congressional Interest

FY08 DOE Appropriation Language

Biomass and Biorefinery Systems R&D.— Funding under this heading in the amended bill includes $200,000,000 for integrated research and development on biomass and biorefinery systems, an increase of $20,737,000 over the budget request for additional biomass research solicitations. The Department is directed to include algae as a potential feedstock in its biomass research and development.

2007 Energy Independence and Security Act (EISA)

- Section 228 Required the DOE to present a report to Congress on the feasibility of microalgae as a feedstock for biofuels production

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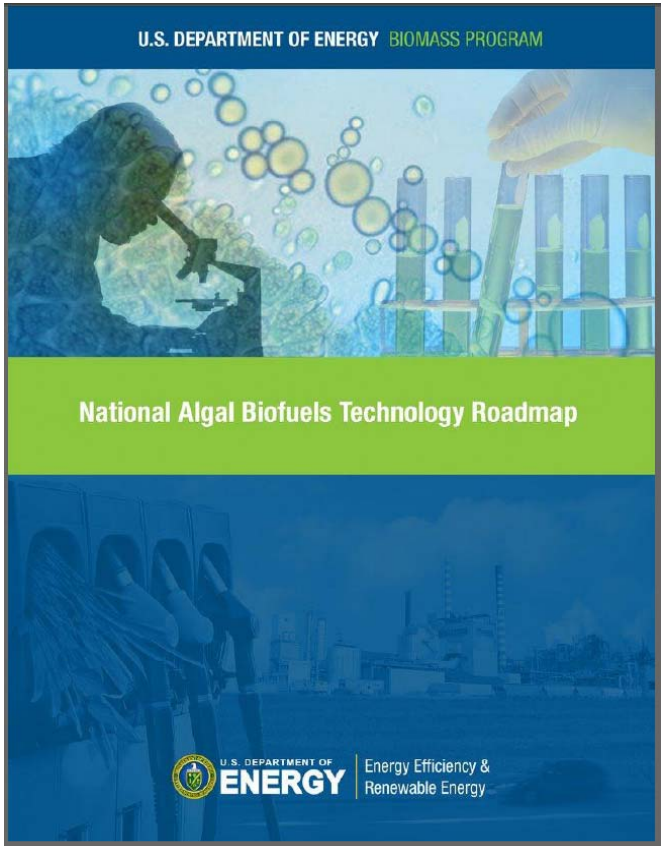
Recent Biomass Program Algae Activities

- Algal Biofuels Technology Roadmap Workshop December 2008
  - *Public comment on rough draft ended 08/03/09
  - *Workshop Proceedings
    - http://www.orau.gov/algae2008pro/

- 3 University-based algae projects
  - *U. Georgia – livestock waste as algae nutrient
  - *Montana State & Utah State- extremophilic algae
  - *Scripps Oceanographic Institute- diatom lipids

- Analyses
  - *Techno-economic modeling (Sandia and NREL)
  - *Resource assessment (Pacific Northwest National Lab)

- Algal Biofuels Consortium FY10



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Algal Biofuels Consortium Announcement

- Release Date: July 15, 2009

- Funding Opportunity Number (Grants.gov): DE-FOA-0000123

- Close date: September 14, 2009

- Consortium Composition: “appropriate mix of U.S. industry, academia, and government and/or non-government laboratories, and could include foreign entities with the appropriate skill sets”.

- R&D areas:
    - Feedstock Supply- Strain development and cultivation
    - Feedstock Logistics- Harvesting and extraction
    - Conversion/Production - Accumulation of Intermediates and Synthesis of Fuels and Co-products

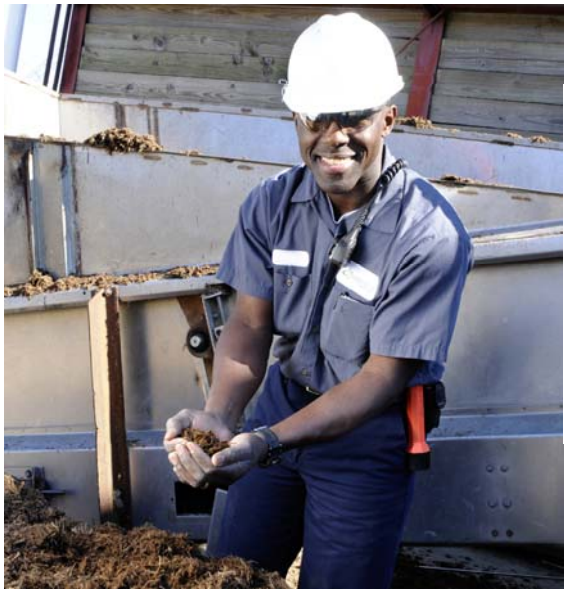
Integrated Biorefineries
&
Biofuels Infrastructure Compatibility

Biorefinery Demonstrations

Expediting Commercialization

Commercial-Scale Biorefineries (up to $272 M)

- Four cost-shared, integrated biorefinery demonstrations to produce 98 million gallons of cellulosic ethanol in 5 years with variety of conversion technologies and cellulosic feedstocks



10%-Scale Biorefinery Validation (up to $210 M)

- Cost-shared, integrated biorefinery demonstrations using cellulosic feedstocks to produce renewable fuels at one-tenth of commercial scale
- Eight projects now in progress

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Commercial-Scale Biorefinery Demonstrations

DOE investments in cellulosic biofuels will accelerate commercialization and help create a biofuels market based on non-food feedstocks.

Performers	Feedstock Type	Conversion Technology	Status of Project
Abengoa	Agricultural Residue	Biochemical	Phase 1-Cooperative Agreement signed Sept. 2007
Bluefire	MSW	Biochemical	Phase 1-Cooperative Agreement signed Sept. 2007.
Poet	Corncobs Corn Fiber	Biochemical	Phase 2-Technology Investment Agreement – Signed Oct. 2008
Range Fuels	Woody Waste	Gasification + Mixed Alcohol synthesis	Phase 2-Technology Investment Agreement – Signed Nov. 2007 Ground Breaking Nov. 2007

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Small-Scale (10% of Commercial Scale) Biorefinery Demonstrations

Performers	Feedstock Type	Conversion Technology
Alltech Envirofine, LLC	Wood Residue	Biochemical
Flambeau River	Wood Residue	Thermochemical
Lignol Innovations	Wood Residue	Biochem-organosolv
NewPage Corporation	Wood Waste	Thermochemical
Mascoma	Switchgrass & hardwoods	Biochemical
Pacific Ethanol	Agricultural & Forest Residue	Biochemical
RSE Pulp & Chemical	Wood chips (mixed hardwood)	Biochemical
Verenium Biofuels	Bagasse, Agricultural & Wood Residue	Biochemical

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Impacts of Intermediate Ethanol Blends

Preliminary Report Issued Oct. 7, 2008

- DOE studying intermediate ethanol blends (allocated $2.1 million in FY07 and $12.5 million in FY08).
- The DOE test program is evaluating --
  - Vehicle exhaust and evaporative emissions
  - Catalyst durability and aging
  - Cold-start operation and drivability
  - Fuel-system and catalyst materials compatibility
- DOE is also evaluating impacts of higher ethanol blends on small engines
  - Testing leaf blowers, line trimmers, pressure washers, and small generators
  - Expanded test plan for marine engines, all-terrain vehicles, and motorcycles in summer 2008 with input from industry.
- Additional durability testing is required

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The Biomass Program Yesterday,Today, and Tomorrow

A Billion-Dollar Investment in Biofuels

Since early 2007, DOE has announced investments of *more than* $1 billion for the RD&D of new biofuels technology, with a focus on non-food, cellulosic feedstocks.

- Cellulosic Ethanol Biorefinery Demonstrations at commercial and 10%-scale
- World-class Bioenergy Research Centers (Office of Science)
- University Research projects (including Advanced Biofuels)
- New and Improved Enzymes and Micro-organism R&D
- Thermochemical Processes R&D (Pyrolysis, Gasification)
- Annual USDA/DOE Joint Solicitation
- Field Trials under the Regional Biomass Energy Feedstock Partnership
- Biofuels Sustainability Studies and Modeling (Knowledge Discovery Framework)
- Joint EPA/DOE Ethanol Blend Studies

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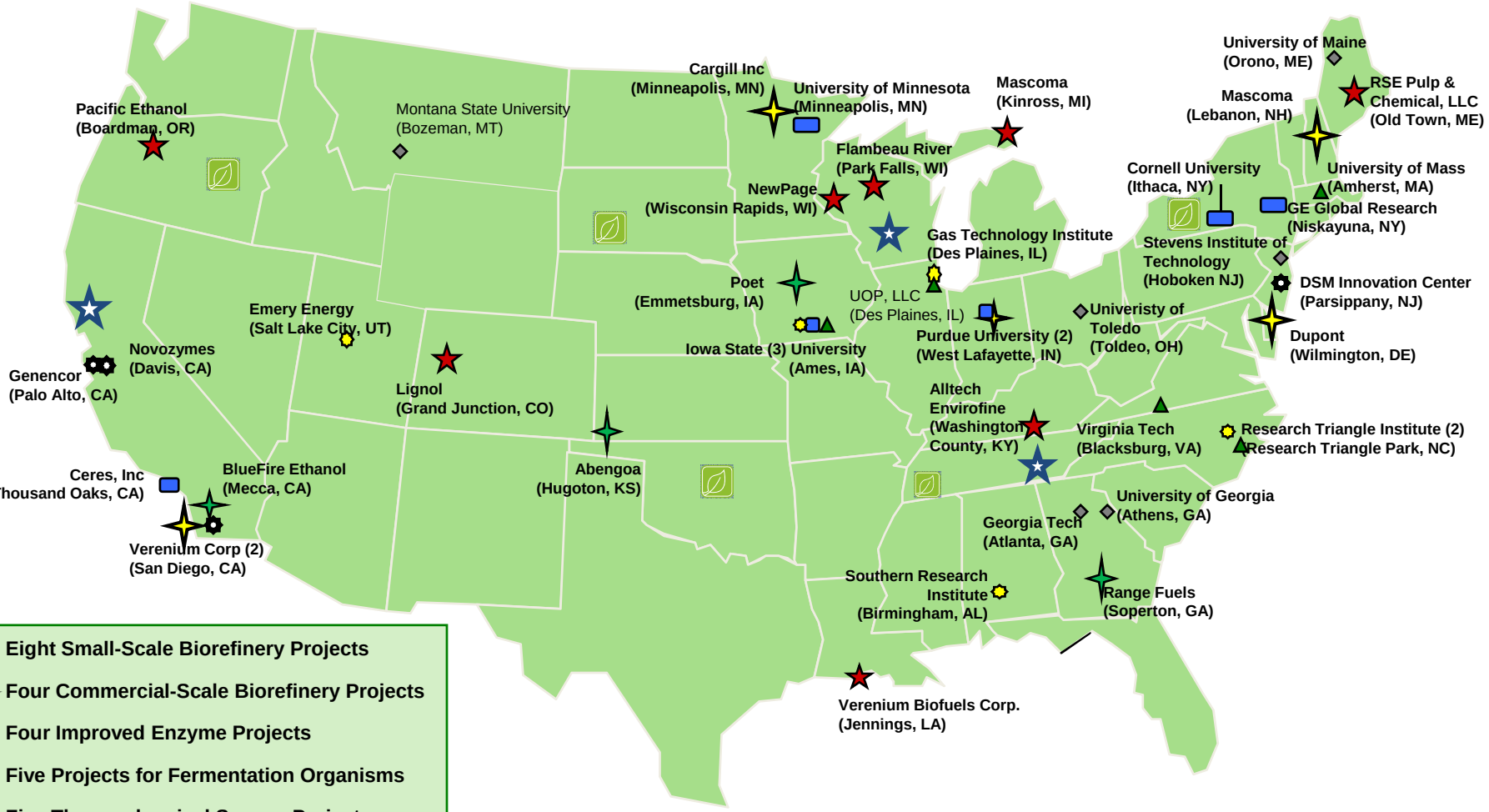
Major DOE Biofuels Project Locations



- Eight Small-Scale Biorefinery Projects
- Four Commercial-Scale Biorefinery Projects
- Four Improved Enzyme Projects
- Five Projects for Fermentation Organisms
- Five Thermochemical Syngas Projects
- DOE Joint Solicitation Biomass Projects
- Five Thermochemical Bio-Oil Projects
- Six University Conversion Projects

Office of Science Bioenergy Centers
DOE Great Lakes, Madison, WI
DOE Joint Bioenergy Institute, Berkeley, CA
DOE Bioenergy Science Center, Oak Ridge, TN

Regional Partnerships
South Dakota State Univ., Brookings, SD
Cornell University, Ithaca, NY
Univ. of Tennessee, Knoxville, TN
Oklahoma State Univ., Stillwater, OK
Oregon State Univ., Corvallis, OR

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2009 Program Priorities and Goals

Advancing Presidential Objectives

Science & Discovery

- Connecting basic and applied bioscience
- Conducting R&D at universities and national labs to achieve transformational breakthroughs:
  - 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 up to 90% with advanced biofuels (compared to gasoline)

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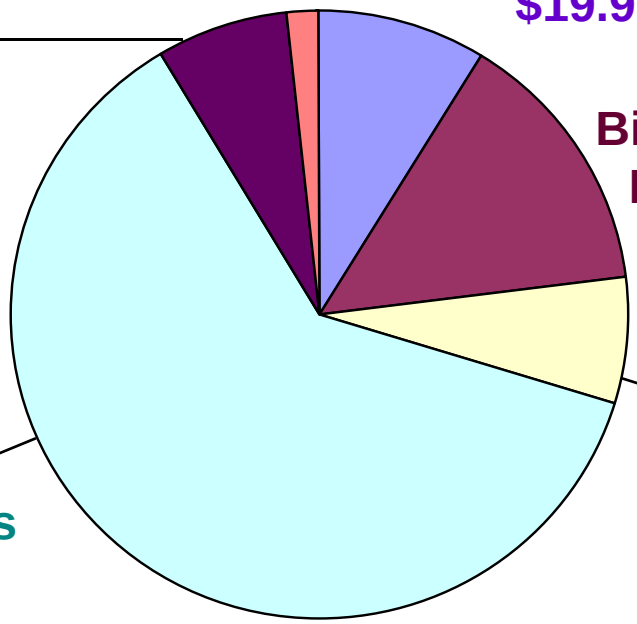
Program Plan for FY 2009

Biomass Budget by Technology Area



SBIR/STTR
$3.8M

Thermochemical Platform R&D
$19.9M

Syngas & Bio-oil Production
- Gasification & Gas Clean-up
- Pyrolysis & Oil Stabilization

Products Development
$15.7M
- Fuels
- Chemicals
- Materials
- Other Products

Bioconversion Platform R&D
$32.1M

Low-Cost Sugars
- Pretreatment
- Enzymes
- Fermentation

Feedstock Infrastructure
$15.1M

Low-Cost Biomass
- Production
- Harvesting
- Collection & Storage
- Sustainability

Biorefinery Demonstrations
$138.4M
- Small commercial scale
- Demonstration scale
- Pilot Scale

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Recovery Act: Biomass Program

Recovery Act Funding for Biomass Projects

Secretary Chu Announces Nearly $800 Million from Recovery Act to Accelerate Biofuels Research and Commercialization – May 5, 2009

As part of the ongoing effort to increase the use of domestic renewable fuels, U.S. Secretary of Energy Steven Chu today announced plans to provide $786.5 million from the American Recovery and Reinvestment Act to accelerate advanced biofuels research and development and to provide additional funding for commercial-scale biorefinery demonstration projects.

- $480M Integrated pilot and demonstration biorefineries
- $176.5M Commercial-scale biorefineries
- $25M Process demonstration user facility
- $5M Sustainability efforts
- $50M Algal biofuels consortium
- $35M Advanced fungible biofuels technology consortium

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Biomass Program: The Impact

We are bringing a viable alternative to gasoline to the market, lowering greenhouse gas emissions in the transportation sector, and reducing the need for imported oil.

- In 2007 alone, the U.S. biofuels industry **--**
  - Added $48 billion to U.S. gross domestic product
  - Supported creation of 230,000 jobs
  - Displaced 228 million barrels of oil and saved Americans $16.5 billion
  - Displaced 3% of vehicle gasoline consumption
- Recent McKinsey study found that ethanol blending lowered gas prices by 17 cents per gallon in 2008

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Questions?

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