Biorefineries in the United States – Scenarios in the global context

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Golden, Colorado, USA

1st Brazilian
National Refinery
Symposium (SNBr)
At EMBRAPA
Brasilia, DF, Brazil

September 29, 2011

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Key Publications

Integrated Biorefineries

The Biomass Program's investment in integrated biorefineries at the pilot, demonstration, and commercial scale constitute a cornerstone of the program. Our projects employ various combinations of feedstocks and conversion technologies to produce a variety of biofuels, as well as by- or co- products that include chemicals, heat, and power. The March 2010 overview document, "Economy Through Product Diversity: Integrated Biorefineries", provides information on project locations and details such as feedstocks and technologies used as well as the products IBRs intend to generate.

Biofuels, Biopower, and Bioproducts: Integrated Biorefineries	An overview of integrated biorefineries and Biomass Program efforts to develop, build, operate, and validate integrated biorefineries on various scales. A crucial step in developing this industry is to establish integrated biorefineries capable of efficiently converting a broad range of biomass feedstocks into affordable biofuels, biopower, and other bioproducts.	November 2010
Economy Through Product Diversity: Integrated Biorefineries	A summary of the integrated biorefinery concept, the Biomass Program's related activities and challenges, and specific biorefinery projects funded through the Program.	March 2010

Biomass 2011: Replace the Whole Barrel, Supply the Whole Market

U.S. DEPARTMENT OF ENERGY BIOMASS 2011

The New Horizons of Bioenergy

http://www1.eere.energy.gov/biomass/biomass_2011.html

Program Priorities and Goals

"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 catalysts
  - Engineering of new microorganisms

Clean, Secure Energy

- Developing & demonstrating cellulosic and advanced biofuels, biorefineries and systems to support the Renewable Fuel Standard

Economic Prosperity

- Creating 50 to 75 jobs per new biorefinery
- Reinvigorating rural economies

Climate Change

- Reducing GHG emissions by 60% for cellulosic biofuels and 50% with advanced biofuels (relative to gasoline)

From N. Rossmeissl, 2011 IBR Peer Review, http://obpreview2011.govtools.us/IBR/

Sustainable Biofuels, Biopower, and Bioproducts

The Biomass Program is working to advance biomass technologies in support of DOE's mission to strengthen America's energy security, environmental quality, and economic vitality through:

Feedstocks

Developing lower cost feedstock logistics systems

Conversion technologies

Improving conversion efficiencies and costs

Integrated biorefineries

Systematically validating and deploying technology at first-of-a-kind facilities

Infrastructure

Evaluating vehicle emissions, performance, and deployment options

Biopower

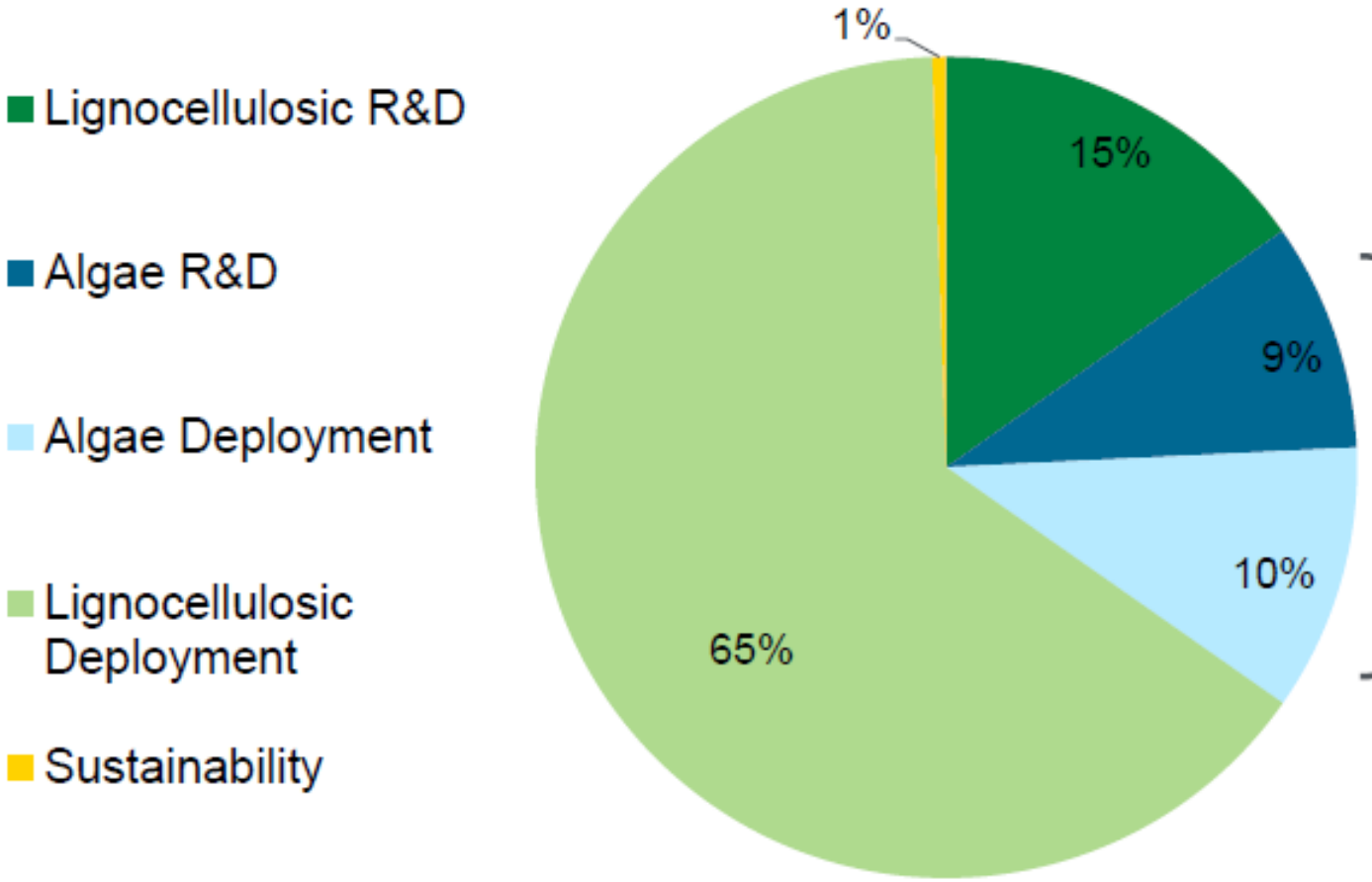
Providing a clean, domestic, dispatchable renewable source of power

Advanced biofuels

Expanding portfolio beyond cellulosic ethanol to hydrocarbon fuels

Biomass Program Budget

OBP 2010 Investment* $938M



The 2010 investment in algae totals more than $180M and includes:

- $35M for algae R&D, as directed by Congress
- $49M for the NAABB consortium
- $50M for the Sapphire to deploy open pond algal biofuel system
- $25M for the Algenol to pilot an photobioreactor algal biofuel system
- $22M for Solazymes to pilot a heterotrophic algal biofuel system

*Includes regular FY2010 appropriations and 2009 ARRA funds

Conceptual Framework: Supply Chain Parallels

Sustainability and Analysis

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








Integrated Biorefinery Description

The Program is currently investing in 27 IBR projects

Pilot Scale (12 projects)

Twelve exciting new technologies yet to be demonstrated ranging from $18 to $25 million in Recovery Act funding across 10 states

Feedstocks: Algae, CO_2, woody biomass, sweet sorghum, corn stover, switchgrass, energy sorghum, ag and forestry residue, and hybrid poplar
Fuels: Ethanol, cellulosic ethanol, renewable diesel, jet fuel, and renewable gasoline

Demonstration Scale (10 projects)

Working with projects to verify technologies from a technical and an economic perspective at a scale sufficient for a commercial facility

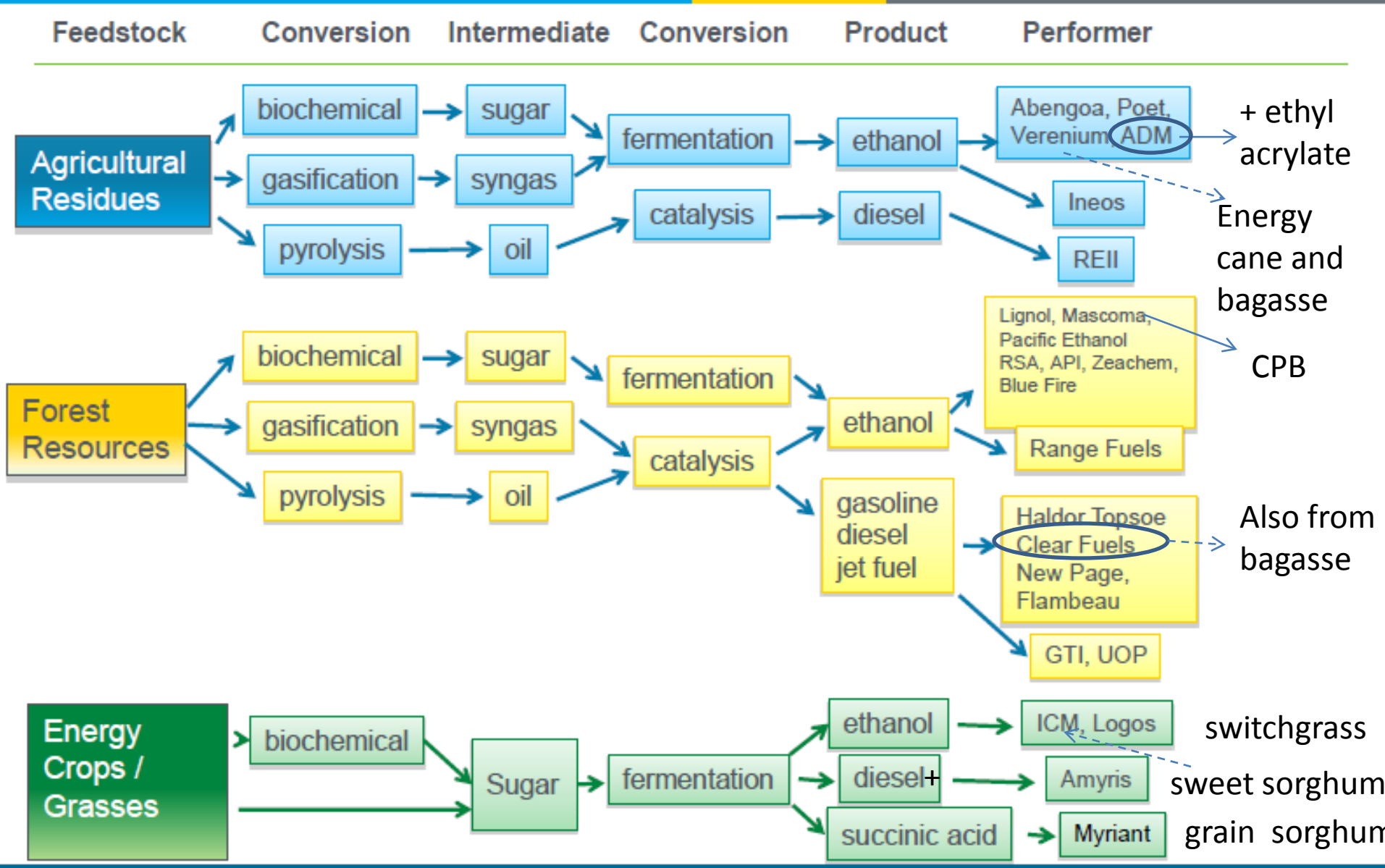
Feedstocks: Wheat straw, corn stover, poplar residues, woody biomass, algae, mill residues, msw, ag and forestry residues
Fuels: Cellulosic ethanol, renewable sulfur-free diesel fuel, renewable hydrocarbon based fuel, renewable gasoline, renewable diesel, jet fuel

Commercial Scale (5 projects)

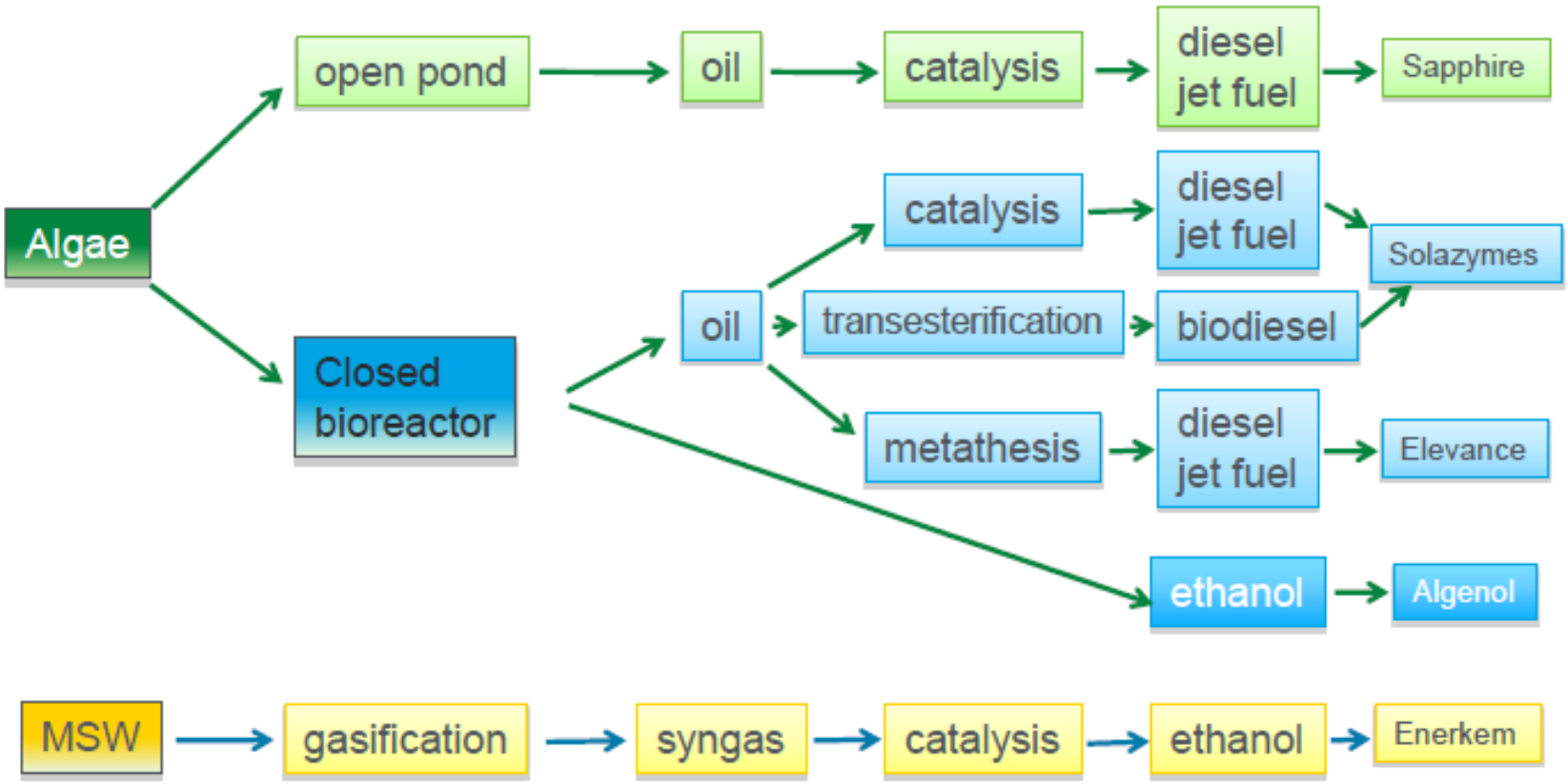
Up to 80 million gallons of cellulosic biofuel annually by 2014

Feedstocks: Lignocellulosic biomass, corn cobs, woody biomass, mill waste, sorted msw
Fuels: Cellulosic ethanol, ethanol, methanol

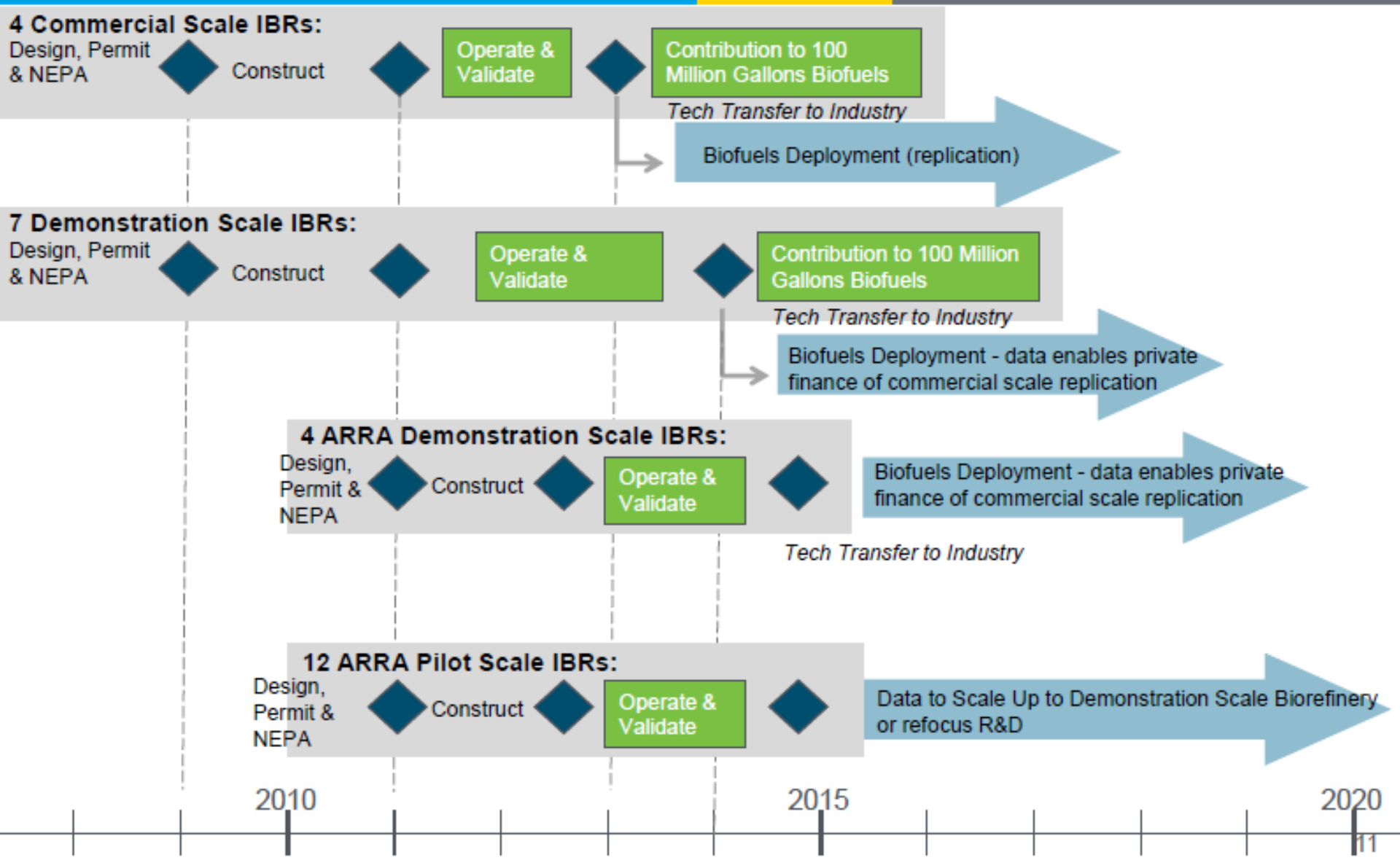
Integrated Biorefineries



Integrated Biorefineries

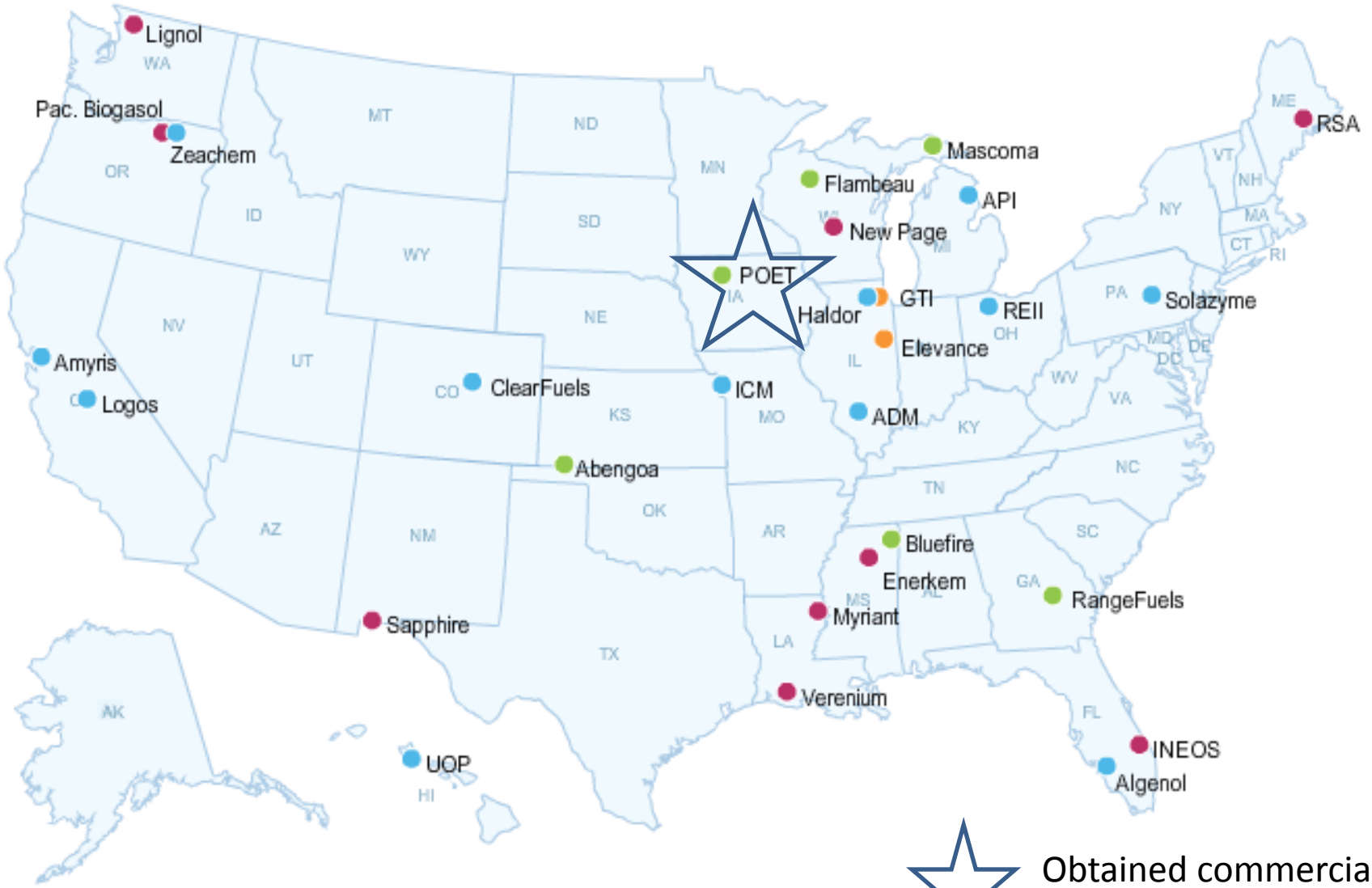


Demonstration & Deployment Timeline



Integrated Biorefinery Project Map

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



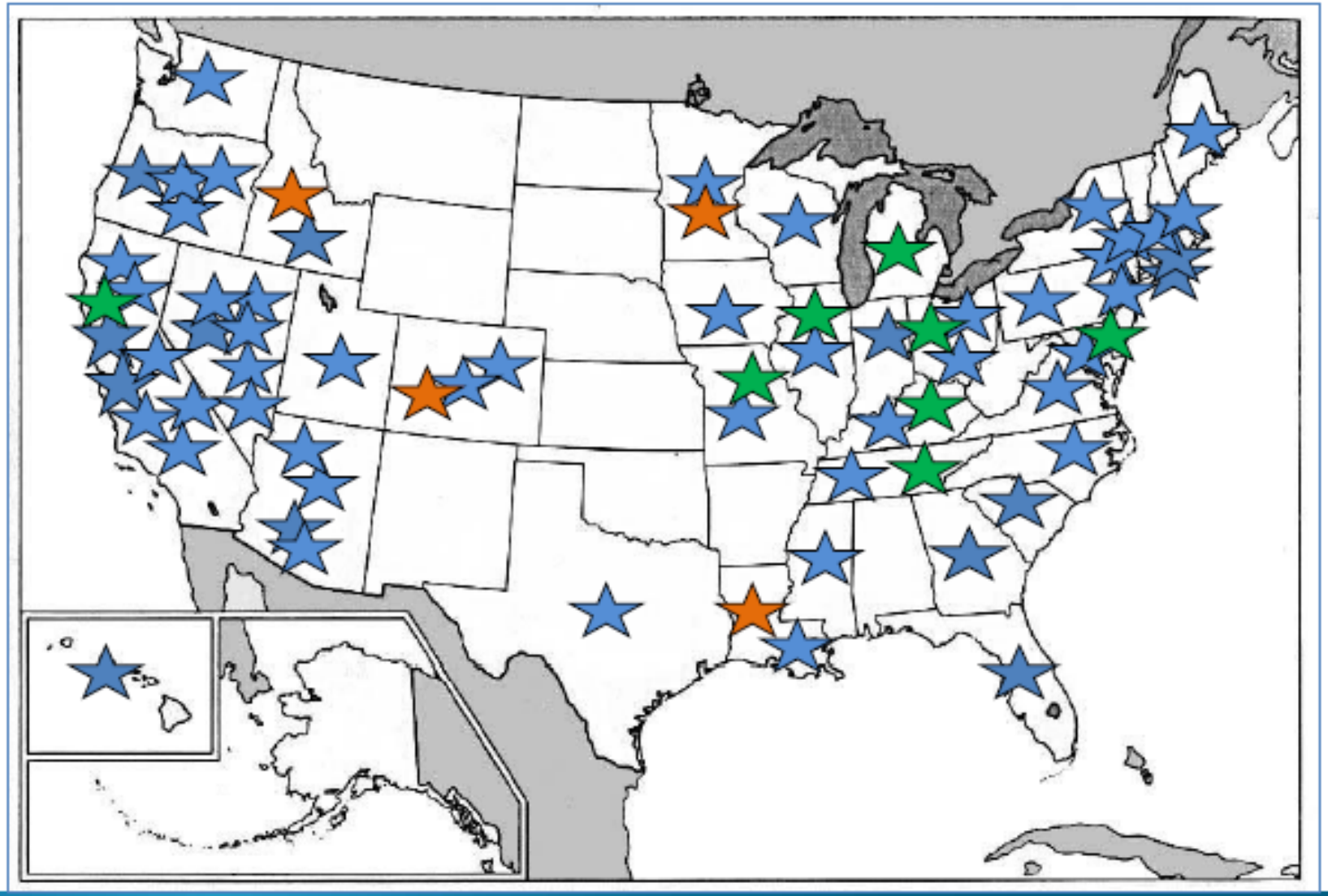
http://www.eere.energy.gov/biomass/integrated_biorefineries.html

Obtained commercial project loan guarantee

Current Project Footprint

LPO has already supported projects in 38 states plus the District of Columbia

http://www1.eere.energy.gov/biomass/pdfs/bio2011_tobin_3-4.pdf

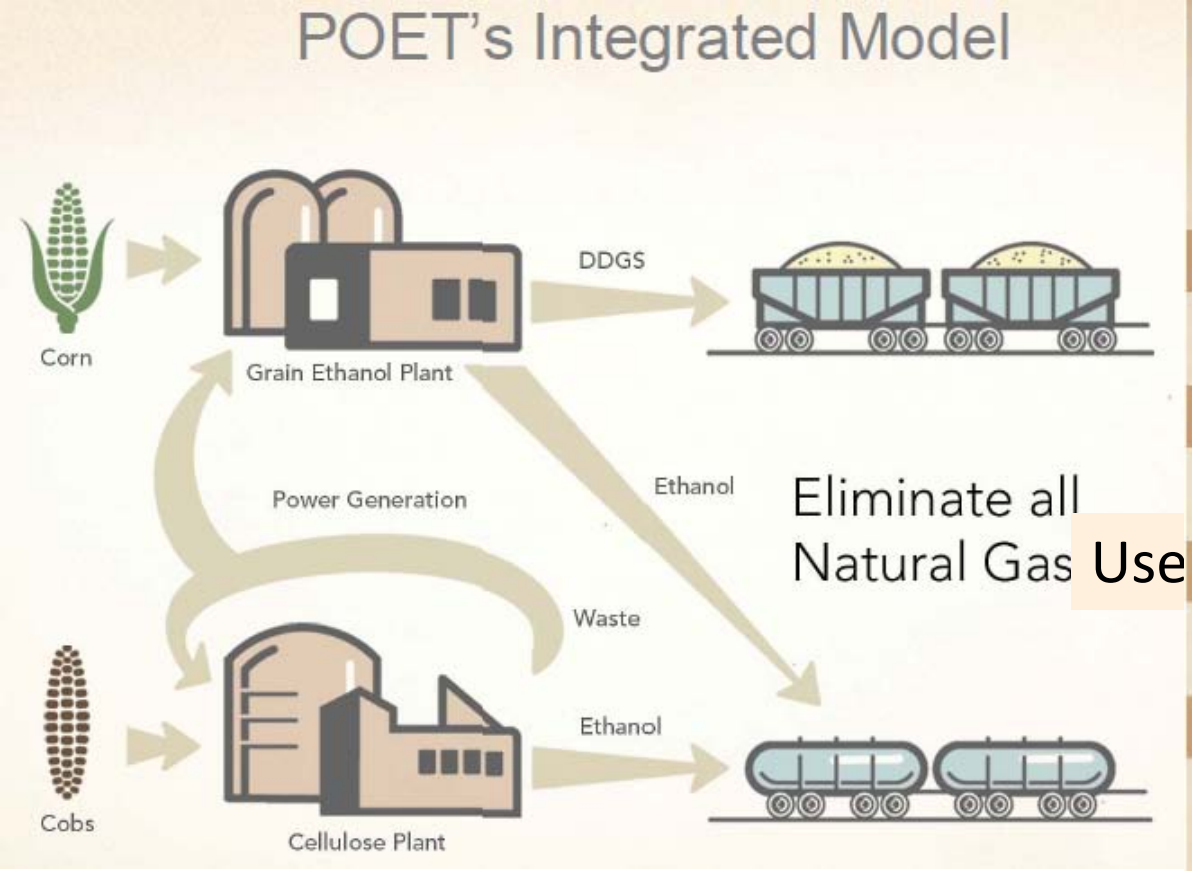


Innovative technology at scale

1705 Approved Mature

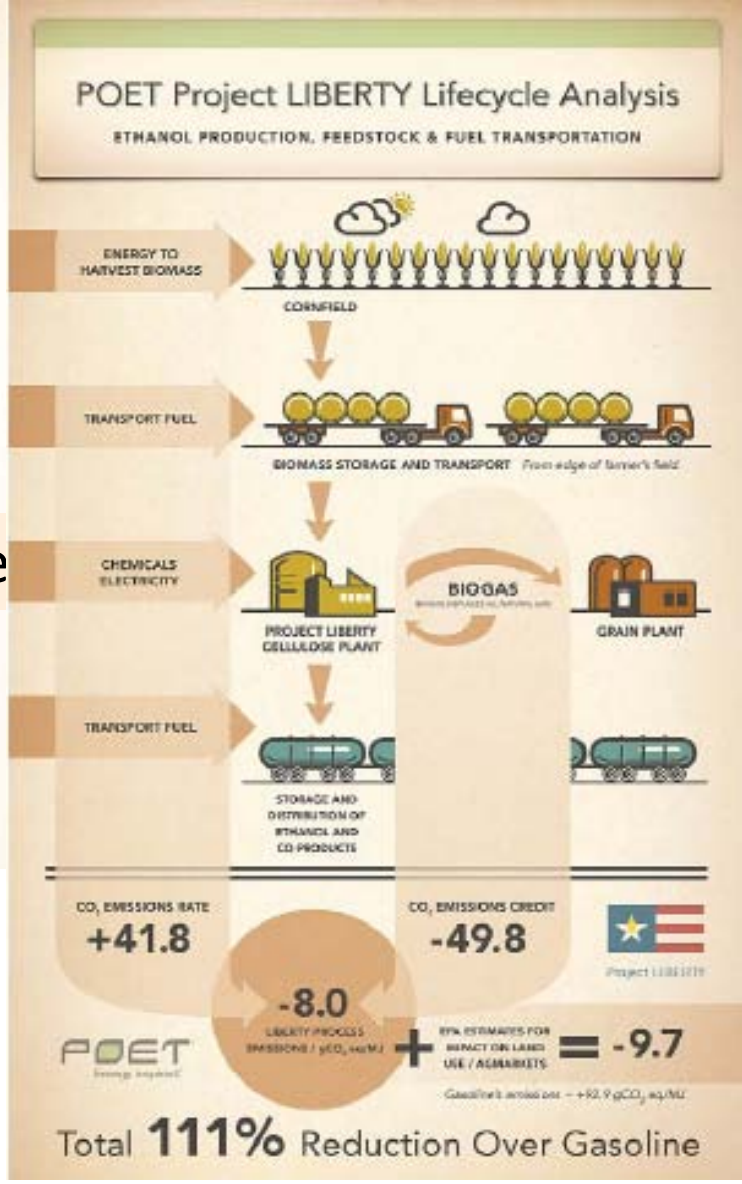
1703 Approved

ATVM Approved Advanced technology vehicle & components

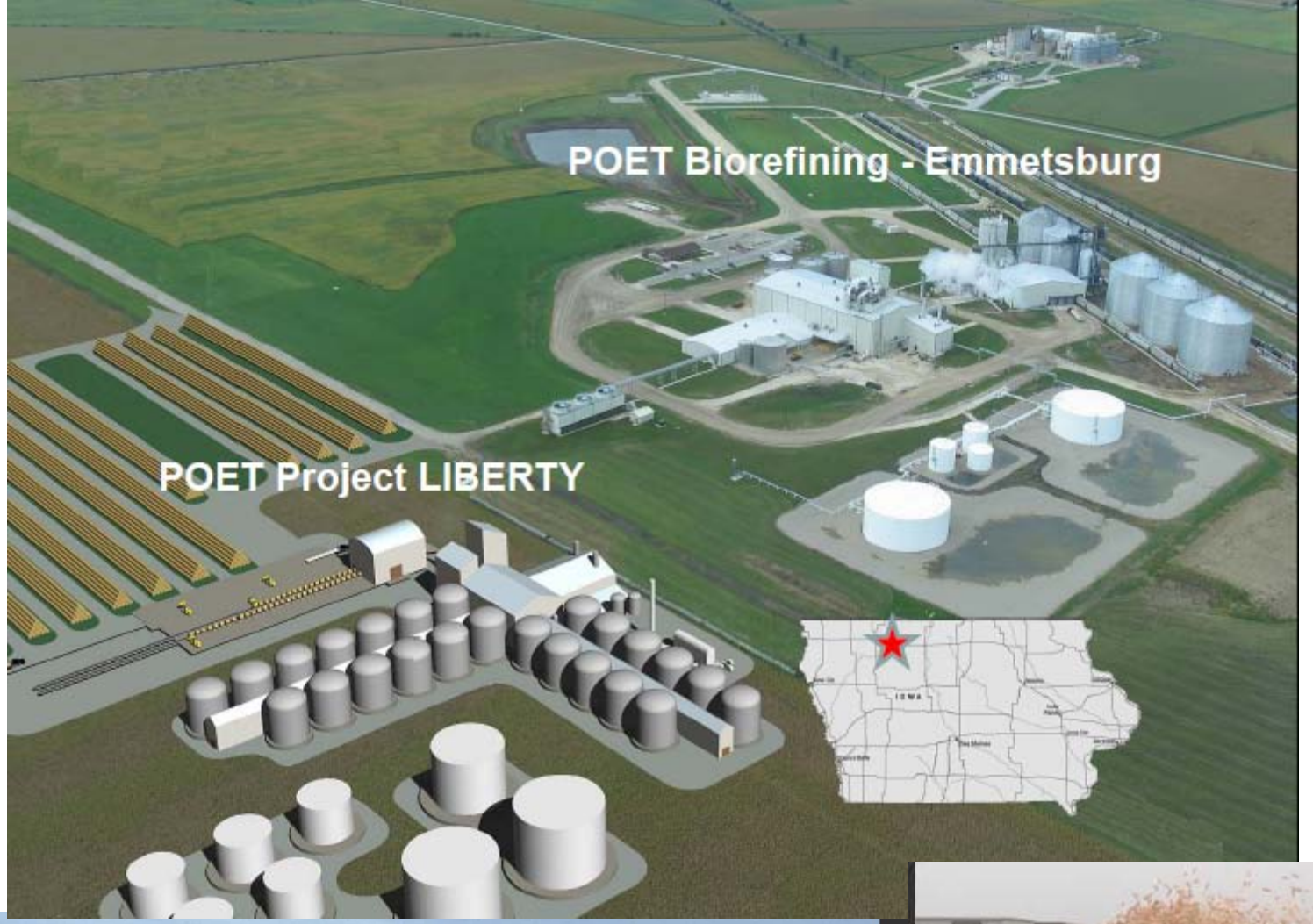


Or stover

Storage



http://obpreview2011.govtools.us/IBR/
see Poet's presentation by J.A. Sturdevant


POET Biorefining - Emmetsburg
POET Project LIBERTY

Approach

- Management Approach
  - Stage Gate Management, Stage 4
  - POET's vertically integrated business model reduces risk
- Risk Mitigation Monitored Regularly
  - Risk register categories: Financing, Technology, Operations, Schedule
- Feedstock
  - Biomass supply chain operations with farmers and OEMs for over four years
  - Constructed and operating the commercial-scale biomass storage area
  - Working with experts on agronomic impacts and biomass storage
- Technology and Engineering
  - POET-funded cellulosic ethanol pilot plant in SD operating for over two years
  - 1,000 – 2,000 hour technology validation
  - LIBERTY design package in 12/09; IE design review in 3/10
  - POET's capital delivery process
- Go/No Go Decision Points
  - Economics updated monthly
  - All construction permits secured
  - Federal loan guarantee required

At presentation; awarded in September

Beyond Gasoline: Renewable Jet Fuel, Diesel, and Chemicals Using Rentech's Technologies

Clear Fuels and Rentech Project

$150 Million Fully Integrated Biomass Synthetic Fuels, Power and Chemicals Facility

http://obpreview2011.govtools.us/IBR/
see Rentech's presentation by H. Wright, CTO

Low Cost Inputs to High Value Outputs

Bagasse

Ag Waste

Grass

Energy Crops

Wood / Timber

Other Biomass

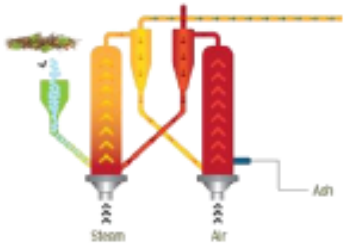
Coal

Natural Gas

Pet Coke

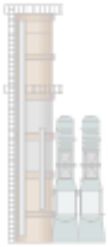
Rentech - ClearFuels
Biomass Reforming

Rentech-SilvaGas
Biomass Gasification System



Licensed Third Party
Fossil Fuel Gasification System

Rentech Fischer-Tropsch
Process and UOP Upgrading



RENTECH

UOP

Commercially-Available
Combined Cycle Power Block

Diesel or Jet Fuel

RenDiesel®
RenJet®

Naphtha

Renchem®
Naphtha

Clean Power

Biofuels Consortia

Consortia Objectives

– Break down critical barriers to the commercialization of algae-based and other advanced biofuels such as green aviation fuels, diesel, and gasoline that can be transported and sold using today's existing fueling infrastructure.

National Alliance for Advanced Biofuels and Bioproducts (NAABB) ($49 million)

- Led by the Donald Danforth Plant Science Center
- Will develop a systems approach for sustainable commercialization of algal biofuel and bioproducts
- Will develop and demonstrate the science and technology necessary to:
  - significantly increase production of algal biomass and lipids
  - efficiently harvest and extract algae and algal products
  - establish valuable certified co-products that scale with renewable fuel production.
- Multiple test sites will cover diverse environmental regions to facilitate broad deployment.

National Advanced Biofuels Consortium (NABC) ($35 million)

- Led by the National Renewable Energy Laboratory and Pacific Northwest National Laboratory
- Will conduct cutting-edge research to develop infrastructure compatible, biomass-based hydrocarbon fuels
  - Result will be a sustainable, cost-effective production process that maximizes the use of existing refining and distribution infrastructure.
- Plans to develop strategies to deliver a pilot-ready process, with full lifecycle analysis to measure the environmental benefits.

NABC
National Advanced Biofuels Consortium

NABC Developing Technologies Towards Advanced Infrastructure

Consortium Leads
National Renewable Energy Laboratory*
Pacific Northwest National Laboratory

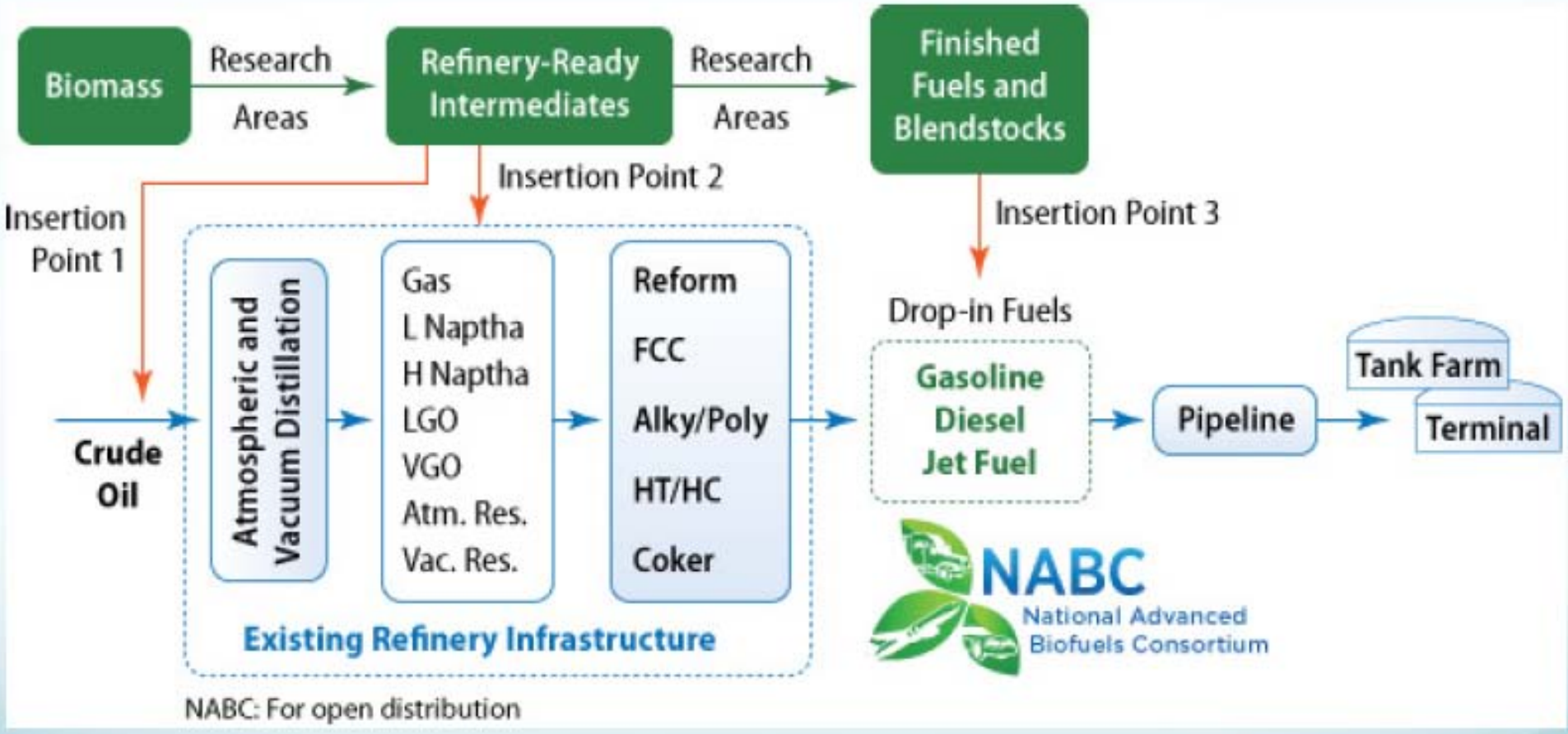
Consortium Partners
Albemarle Corporation
Amyris Biotechnologies
Argonne National Laboratory
BP Products North America Inc.
Catchlight Energy, LLC
Colorado School of Mines
Iowa State University
Los Alamos National Laboratory
Pall Corporation
RTI International
Tesoro Companies Inc.
University of California,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

Project Objective: to develop cost-effective technologies that supplement petroleum-derived fuels with advanced "drop-in" biofuels that are compatible with today's transportation infrastructure and are produced in a sustainable manner.

*Tom Foust, NREL Co-director, Tom.Foust@nrel.gov
see: http://www1.eere.energy.gov/biomass/pdfs/nabc_webinar.pdf

NABC
National Advanced Biofuels Consortium

How can biomass fit into the petroleum infrastructure?

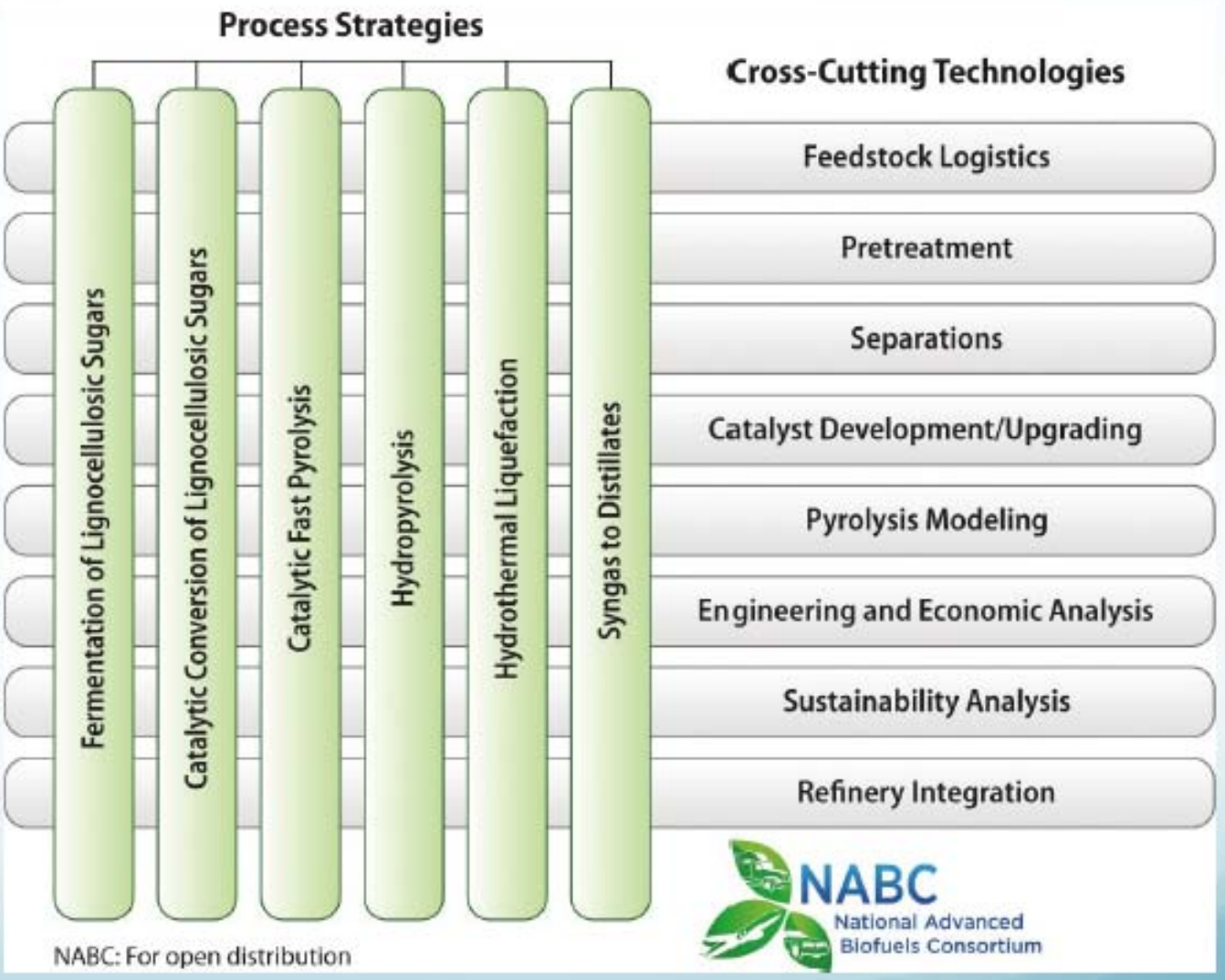


- Three possible insertion points
- Develop new technologies that use today's infrastructure

NABC
National Advanced Biofuels Consortium

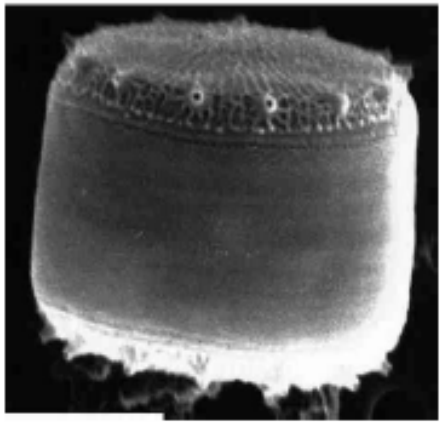
Strategies and Technologies

- Converting biomass into infrastructure-compatible materials



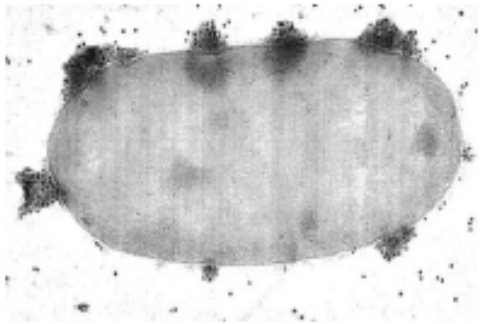
Nature's solutions to energy challenges

Thalassiosira pseudonana



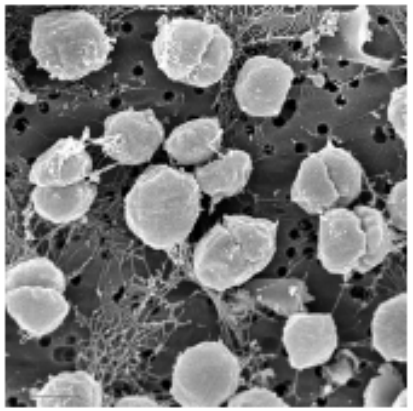
Ocean carbon pumping

Microbulbifer 2-40



Biomass conversion

Methanococcus jannaschii

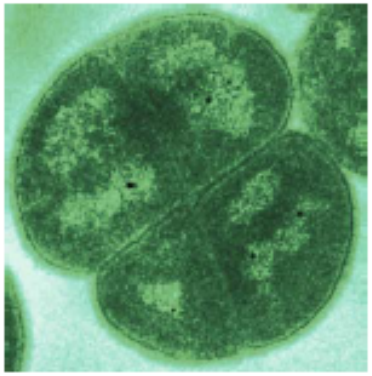


Methane production

Rhodopseudomonas palustris

Hydrogen production / Carbon sequestration

Deinococcus radiodurans



Radiation resistance - bioremediation

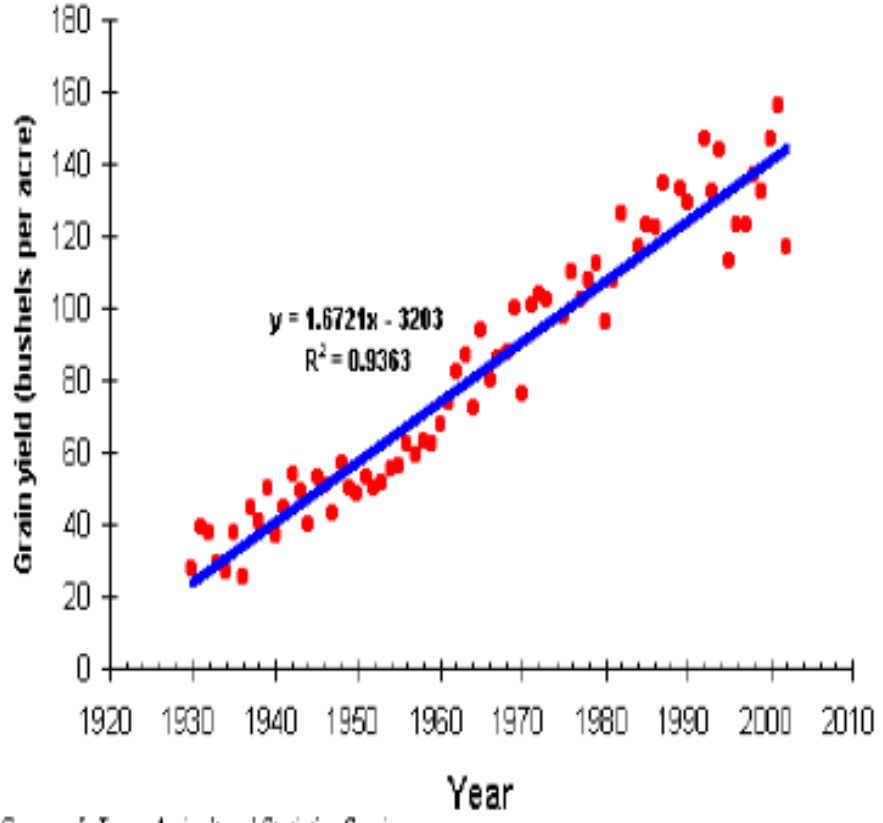
Office of Science

U.S. DEPARTMENT OF ENERGY

High-leverage technologies that can contribute to useful change

- Biology/biotech
  - Esp plant, microbial
- Materials science
  - Simulation, synthesis, characterization
- Data & understanding
  - Physical, societal
  - Diagnosis, management, prediction

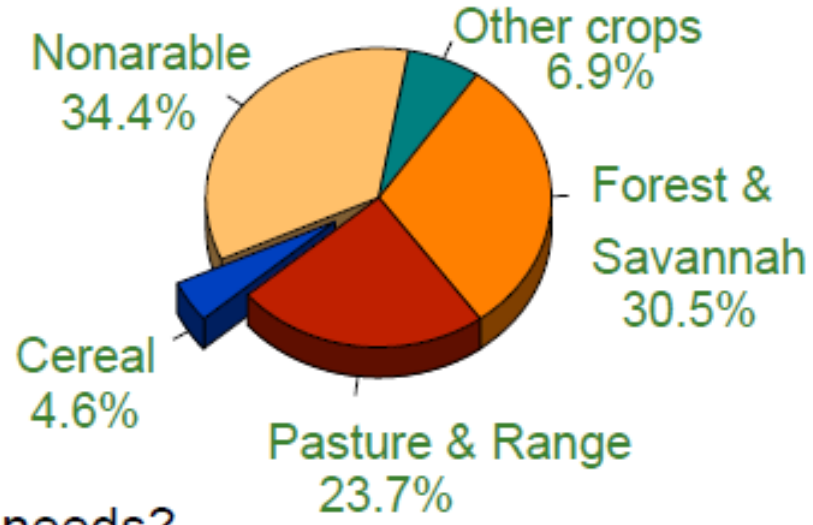
Average Indiana corn yield dramatically increased



Data Source: Indiana Agricultural Statistics Service

U.S. DEPARTMENT OF ENERGY

Biofuel Questions



- **Costs**
  - Biofuel production costs
  - Infrastructure & vehicle costs
- **Materiality**
  - Is there sufficient land after food needs?
  - Are plant yields sufficiently high?
  - Optimized plant traits?
- **Environmental sustainability**
  - Field-to-tank CO2 emissions relative to business as usual?
  - Agricultural practice – water, nitrogen, ecosystem diversity and robustness, sustainability, food impact
- **Energy balance**
  - More energy out than in?
  - Does it matter?

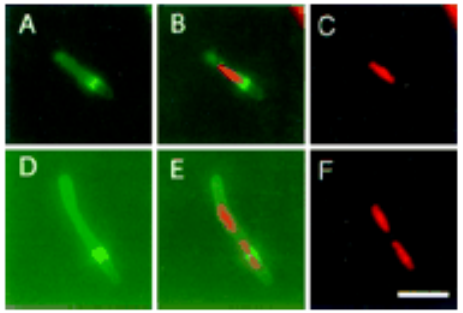
U.S. DEPARTMENT OF ENERGY

Systems biology research at DOE

From Molecules to Cells to Ecosystems

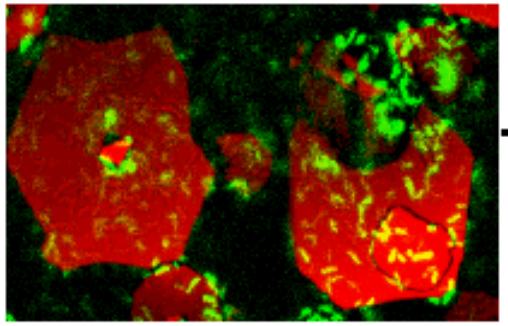
Obtaining a Predictive Understanding of Biological Systems

Subcellular



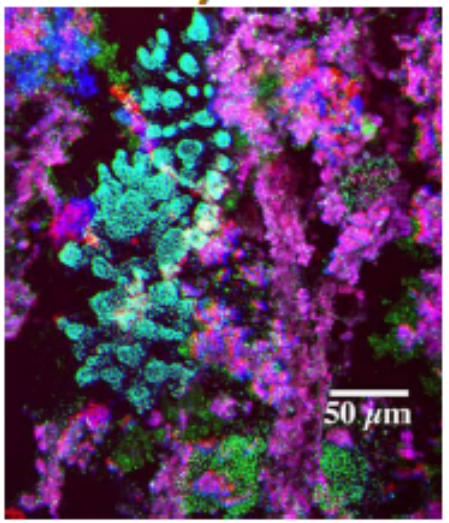
Identification, subcellular location, and dynamics of molecular machines

Cellular



Regulation of gene expression in individual cells

Ecosystems



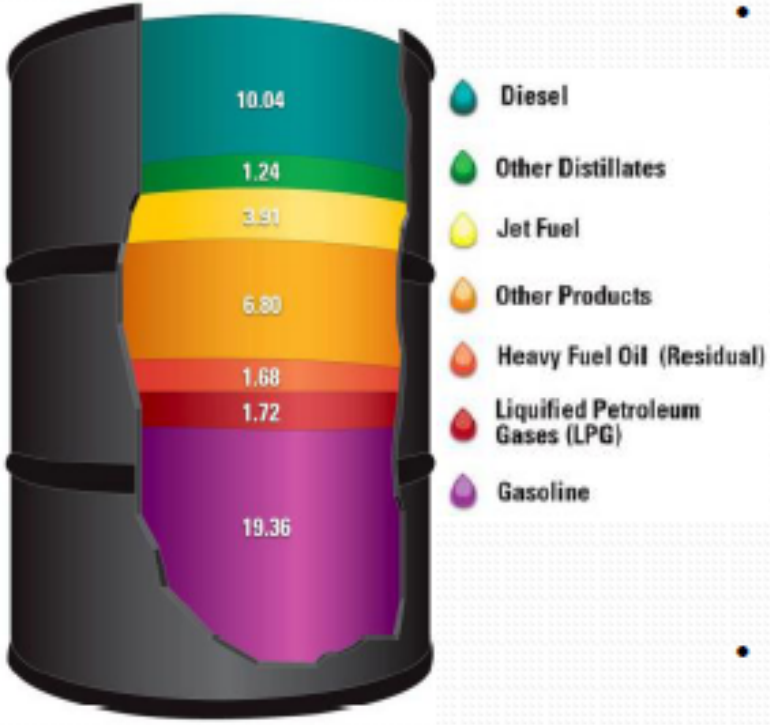
Who is expressing what, when, where, and under what conditions? How do they work together?

DOE GENOMICS:GTL
ACCELERATING DISCOVERY FOR ENERGY AND ENVIRONMENT
OFFICE OF SCIENCE U.S. DEPARTMENT OF ENERGY

U.S. DEPARTMENT OF ENERGY

Replacing the Whole Barrel

Products Made from a Barrel of Crude Oil (Gallons)
(2009)

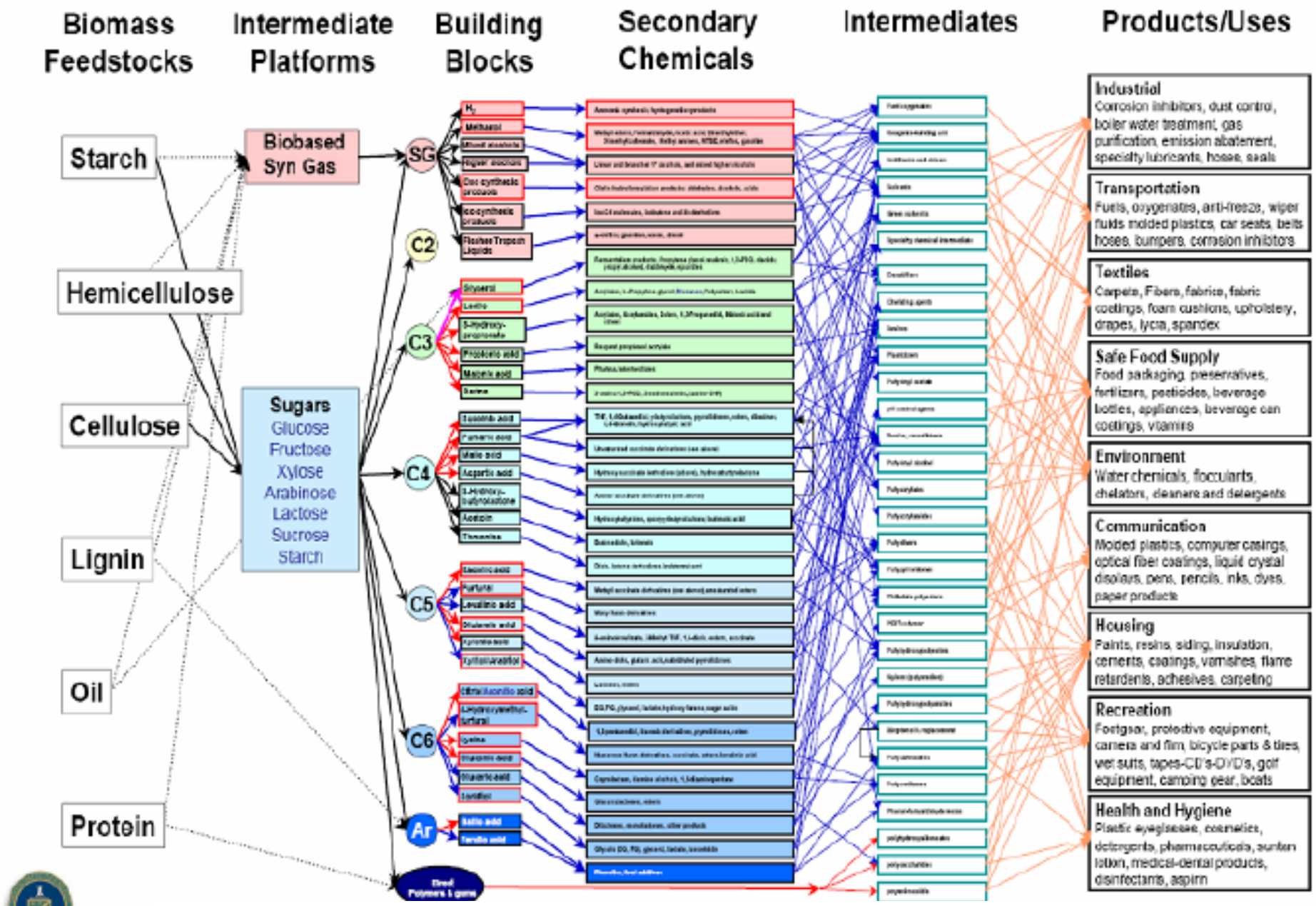


- Greater focus needed on research, development, demonstration, and deployment of a range of technologies to displace the entire barrel of petroleum crude
- Reducing dependence on oil will require developing technologies to replace other components of the barrel, such as diesel, jet, heavy distillates, and a range of chemicals and products

  Cellulosic ethanol displaces light duty gasoline fraction only and only 40% of a barrel of crude is used to produce light duty gasoline.

  Oil accounts for 94% of transportation fuel use (EIA), accounting for over 70% of total U.S. oil consumption.
- Nearly 22.3 million barrels of oil are required **every day** to fuel ~247 million light-duty vehicles on the road [www.api.org]

DOE, OBP, Rossmeissl, http://www1.eere.energy.gov/biomass/pdfs/bio2011_rossmeissl_2-3.pdf



Biobased Products from Biomass Feedstocks and their Applications

Substitution and New Products Possible. Entering the Market

Organized, Focused, Meeting Challenges

FAA
AIA CAAFI ATA
ACI-NA

www.caafi.org

"I'm directing the Navy and the Departments of Energy and Agriculture to work with the Private sector to **create advanced biofuels that can power** ..not just fighters..but trucks and **commercial airliners**."

..... *U.S. President Barack Obama, March 30, 2011*

Airlines Support of Alternative Fuels Development

http://www1.eere.energy.gov/biomass/pdfs/bio2011_barker_3-5.pdf

Fischer-Tropsch-2009

- CTL
- BTL
- GTL

HEFA-Hydroprocessed Esters and Fatty Acids -2011

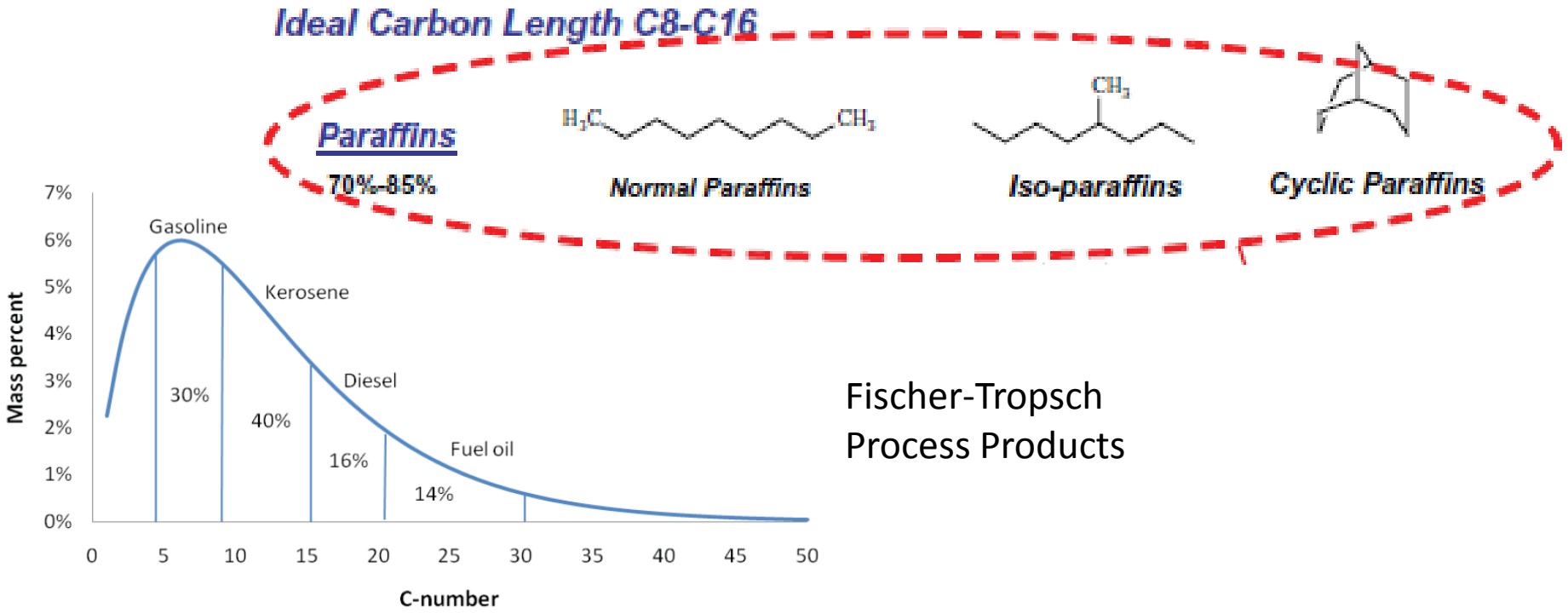
- Plant and Animal Oils/Tallow

Alcohol/Fermentation Derived Fuels

International Context

International Air Transport Association

IATA (2009). *Report on Alternative Fuels.* Montreal, Canada, 92 pp.

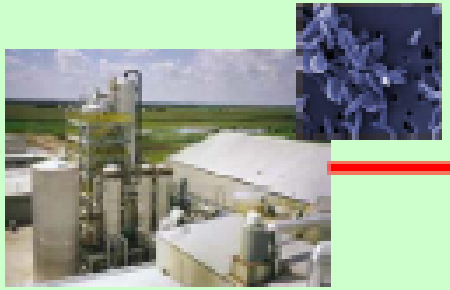


Fischer-Tropsch Process Products

Figure 3: Typical product distribution of Fischer-Tropsch synthesis. Kerosene typically contains between 9 and 15 carbons.

Advanced Process Paths To Increase Supply

Advanced Fermentation



Genetically Engineered Microbes

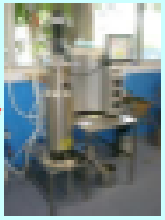
Fermentation

Jet Fuel

Sugar

Alcohol Oligomerization

Fermentation



Dehydration

Olefins

Conventional Refinery Processes

Polymerization

Lignocellulose

Pyrolysis

Pyrolysis

Bio-Crude

Hydroprocessing

Jet Fuel

Some Lessons Learned

- Technology development in conjunction with appropriate business models and financing mechanisms from government and private sector in partnership can create new and expand existing companies, generate economic growth, diversify fuels and energy sources, decrease fossil fuel reliance in transport, while caring for the environment.
- Supportive (and constant) policies have been essential including for RD&D, support through the Valley of Death of technologies and into first of a kind commercialization of replicable projects.
- Sustainability needs to be addressed throughout the stages of development. Impacts across project, region, national and global level and at different times make analyses of impacts difficult. Multiple government organizations and stakeholders are involved.
- Integration of feedstock development, logistics, conversion to products and their use essential. Many failures and delays resulted from underestimated difficulty of the whole supply chain all the way to products and their use.
- Balancing different markets/volumes/and quality requirements of feedstocks is a challenge and an opportunity for biorefineries.

Information Resources and DOE Programs Highlighted *

- Office of Biomass Program - http://www.eere.energy.gov/biomass/ *
- EERE Info Center - http://www.eere.energy.gov/informationcenter
- Alternative Fuels Data Center - http://www.eere.energy.gov/afdc/fuels/ethanol.html
- ARPA-E - http://arpa-e.energy.gov/ *
- Bioenergy Feedstock Information Network - http://bioenergy.ornl.gov
- Biomass R&D Initiative - http://www.biomass.govtools.us
- Grant Solicitations - http://www.grants.gov
- Office of Science - http://www.er.doe.gov *
- Loan Guarantee Program Office - http://www.lgprogram.energy.gov *
- Loan Guarantee Final Rule - http://www.lgprogram.energy.govlgfinalrule.pdf

Integrated Biorefineries

- Recovery Act - Active
  - ADM Recovery Act Biorefinery Project
  - Algenol Recovery Act Biorefinery Project
  - Amyris Recovery Act Biorefinery Project
  - API Recovery Act Biorefinery Project
  - Bluefire Recovery Act Biorefinery Project
  - Clear Fuels Recovery Act Biorefinery Project
  - Elevance Recovery Act Biorefinery Project
  - Enerkem Recovery Act Biorefinery Project
  - GTI Recovery Act Biorefinery Project
  - Haldor Topsoe Recovery Act Biorefinery Project
  - ICM Recovery Act Biorefinery Project
  - INEOS Bio Recovery Act Biorefinery Project
  - Logos Recovery Act Biorefinery Project
  - Myriant Recovery Act Biorefinery Project
  - REII Recovery Act Biorefinery Project
  - Sapphire Recovery Act Biorefinery Project
  - Solazyme Recovery Act Biorefinery Project
  - UOP Recovery Act Biorefinery Project
  - ZeaChem Recovery Act Biorefinery Project
- Active
  - Abengoa Commercial Scale Biorefinery
  - Poet Commercial Scale Biorefinery
  - Range Fuels Commercial Scale Biorefinery
  - Flambeau River Biofuels LLC Demonstration Scale Biorefinery
  - Lignol Innovations, Inc Demonstration Scale Biorefinery
  - Mascoma Demonstration Scale Biorefinery
  - NewPage Corp. Demonstration Scale Biorefinery
  - Pacific Ethanol, Inc. Demonstration Scale Biorefinery
  - RSA Demonstration Scale Biorefinery
  - Verenium Biofuels Corporation Demonstration Scale Biorefinery