NSF Funding Directions for Biofuels from Biomass

Oklahoma EPSCoR Annual State Conference
Norman, OK

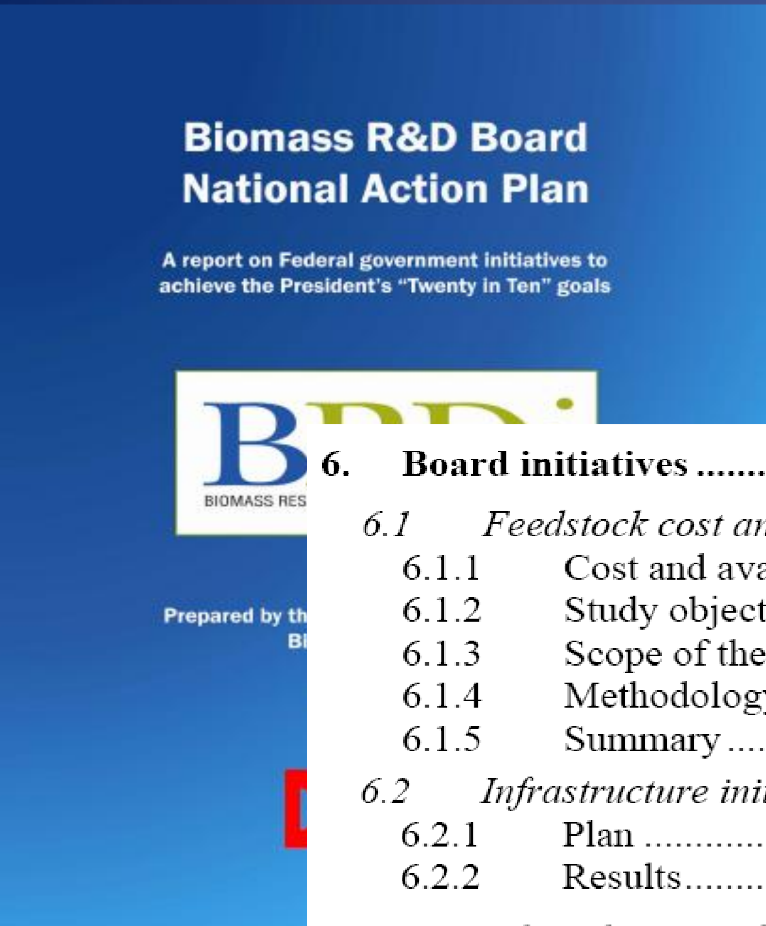
George J. Antos
Catalysis and Biocatalysis Program
Directorate for Engineering
National Science Foundation

29 April, 2010

Outline

- Motivation for HC Biofuels
- Evolution of Federal Research Outlook
- Roadmap to HC Fuels
  - Biochemistry
  - Inorganic catalysis
- Technology Issues
  - NSF Funded Projects
- Future for Biomass-Derived Fuels

Biomass R&D Board
National Action Plan
Early 2007 status


Biomass R&D Board
National Action Plan

A report on Federal government initiatives to achieve the President's "Twenty in Ten" goals

Current Situation in Biofuels

- Energy Independence and Security Act of 2007
  - 36 billion gallons of renewable fuel by 2022
  - 15 billion cap on corn ethanol
  - Increase average gas mileage from 25 to 35 MPG
    - Flex fuel: 25 MPG $\rightarrow$ 18 MPG
    - Renewable fuels must be exempted from CAFE increase

Challenge:
How to produce a renewable biofuel without incurring a loss in gas mileage.

Challenge :
Avoid Land Use Change Penalty

- Land use change creates a large CO_2 debt
- Payback can be very slow

Fargione et al. (Science Express, March 2008):
"biofuels made from waste biomass… or grown on abandoned… lands planted with perennials incur little or no carbon debt…

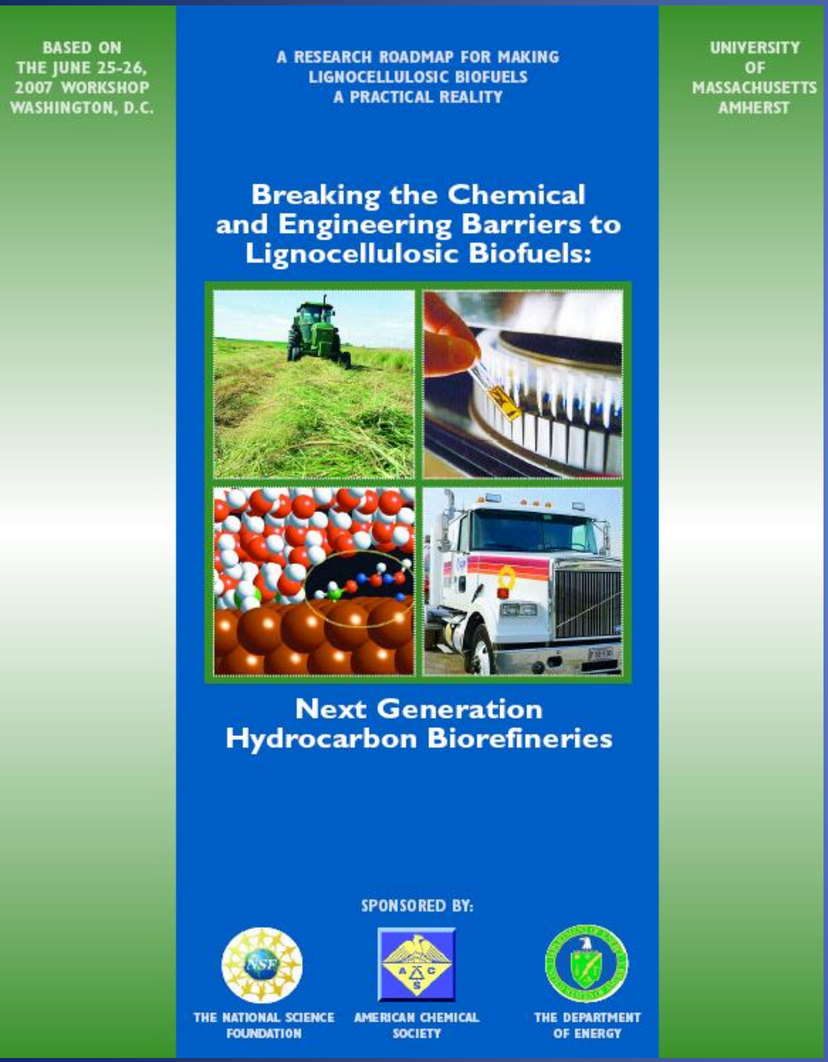
Challenge for Biofuels:

- Mass produce a renewable biofuel which incurs penalties in neither gas mileage or lifecycle greenhouse gas emissions.
- Utilization of existing fuel infrastructure (pipelines, refineries, engines) would be advantageous

The Solution:

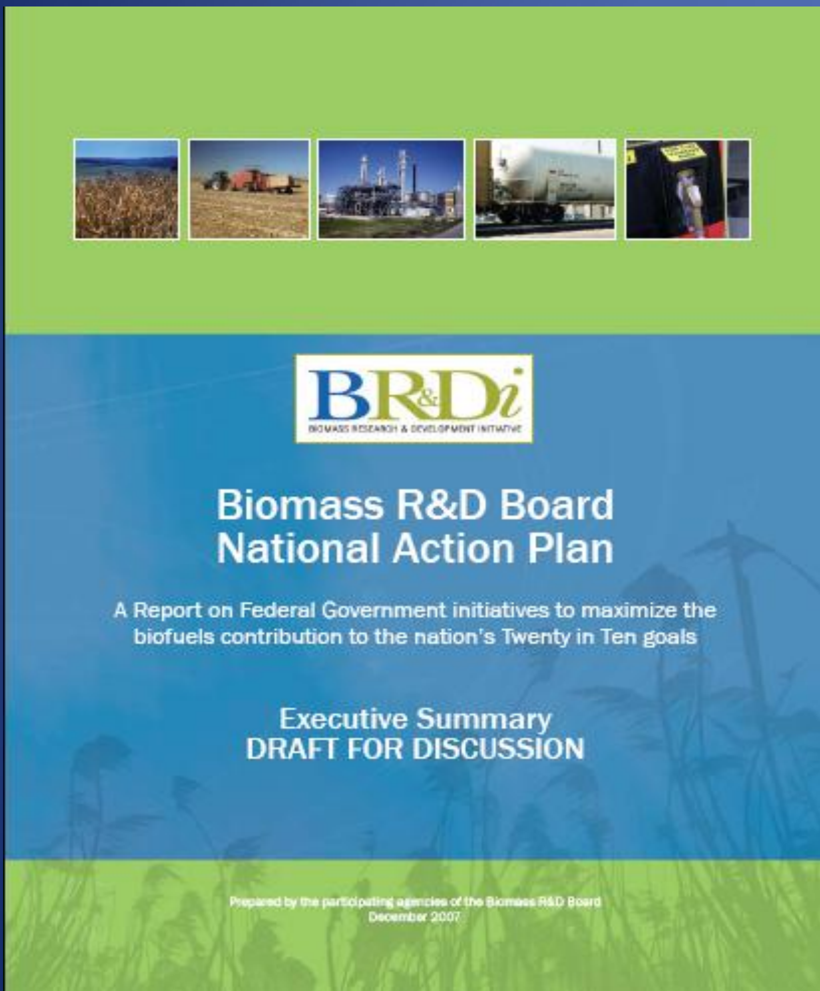
- Produce hydrocarbons from lignocellulose grown with minimal land use change

Roadmap for Hydrocarbon Production, June 2007

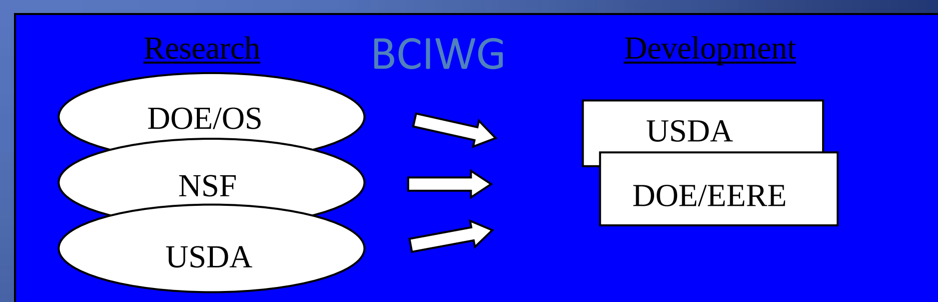


- 2007 NSF/ENG and DOE/EERE Cosponsors
- Workshop participants:
  - 71 invited participants
  - 27 academics from 24 universities
  - 19 companies, small and large
  - 13 representatives from 5 national labs
  - 10 program managers (NSF, DOE, USDA)
- Workshops Goals:
  - Articulate the role of chemistry and catalysis in the mass production of green gasoline, diesel and jet fuel from lignocellulose.
  - Understand the key chemical and engineering challenges.
  - Develop a roadmap for the mass production of next generation hydrocarbon biofuels.
- Final Report Released April 1, 2008
  - www.ecs.umass.edu/biofuels/roadmap.htm
- Input for Interagency Working Group on Biomass Conversion

Timeline: December, 2007



- Arden Bement (NSF) proposed to the Biomass R&D Board
  - revision of NBAP to include "next generation hydrocarbon biofuels"
  - creation of interagency working group to address hydrocarbon biofuels (BCIWG)
- Unanimously approved at December, 2007 Board meeting



National Action Plan revised draft, early 2008

Biomass Research and Development Board

Leading the U.S. Government's Federal Interagency Biomass R&D Initiative

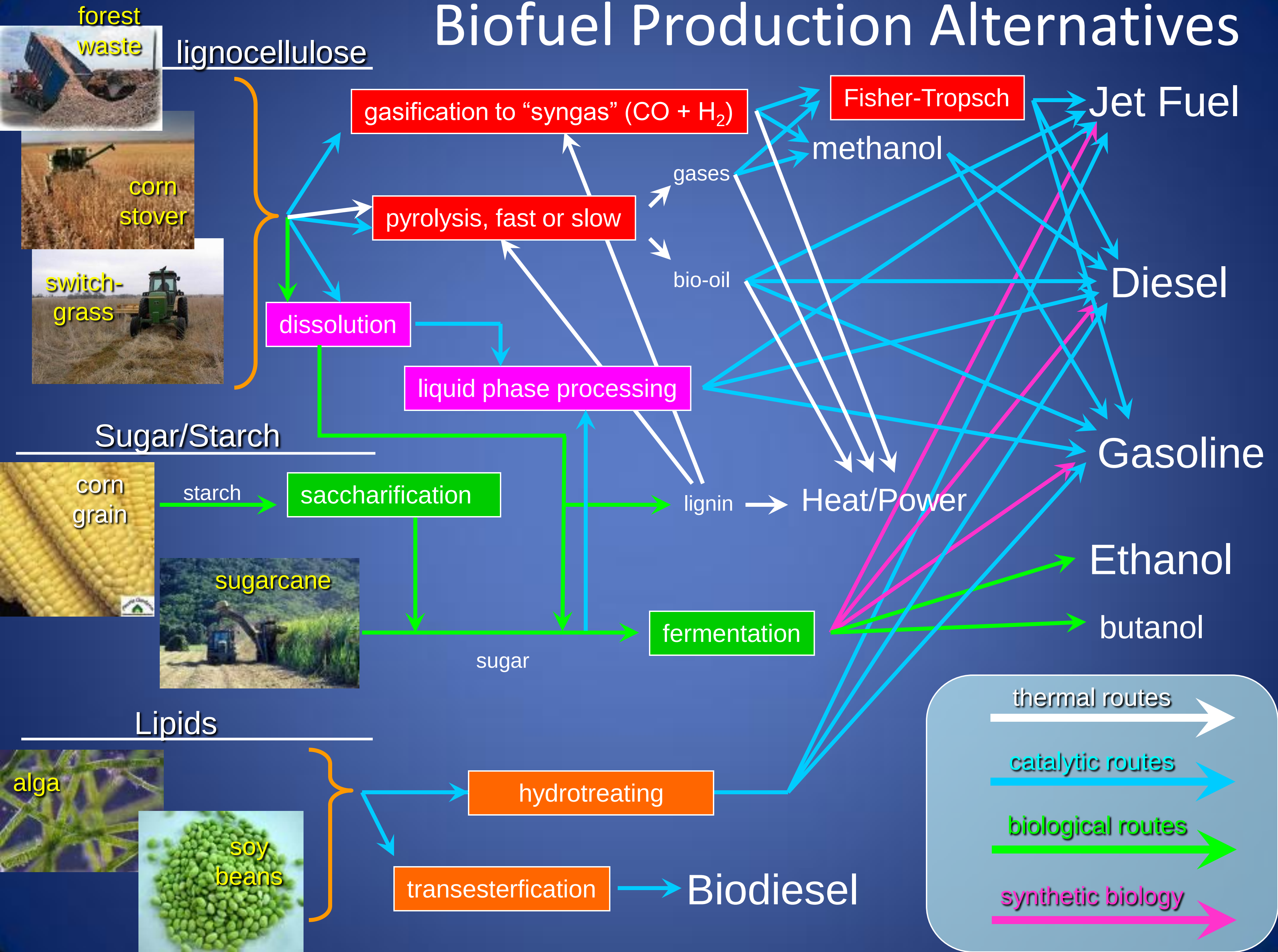
In October 2008 the Biomass Board released a National Biofuels Action Plan (PDF 4.2 MB) which outlines the areas in which Federal interagency cooperation will help evolve biofuel production technologies from promising ideas to competitive solutions.

- About Us
- Sustainability
- Feedstock Production
- Feedstock Logistics
- Conversion Science and Technology
- Distribution Infrastructure
- Environment Health Safety
- Intermediate Ethanol Blending

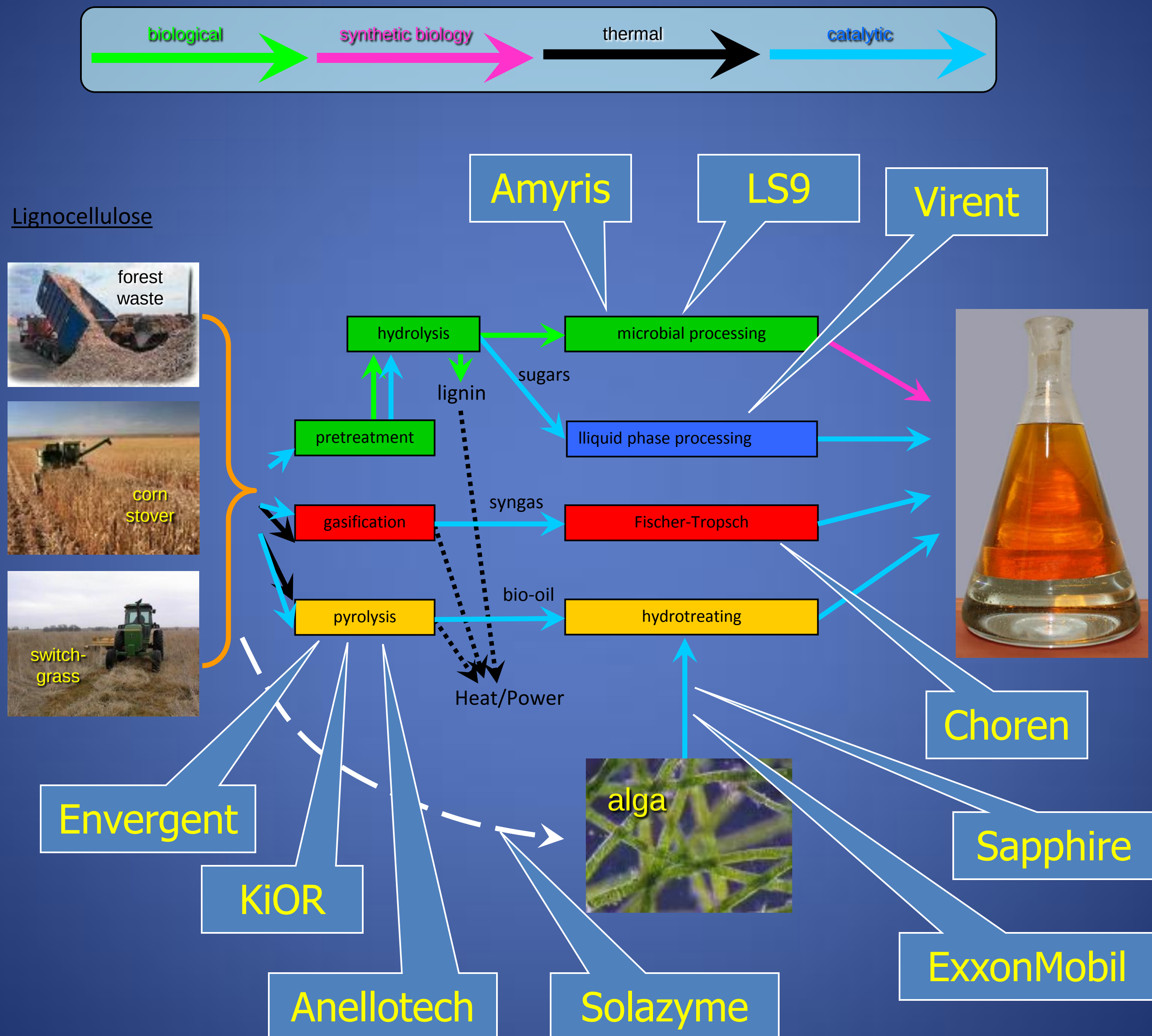
Revised NBAP issued Oct. 2008

BR&Di

Biofuel Production Alternatives



Pathways to Hydrocarbons



Summary of Advantages and Disadvantages

Process	Potential advantages	Key present shortcoming
Gasification	- feedstock agnostic - utilizes lignin - autothermal - no or little water required	- small scale FTS (or MTG) will be difficult to develop, expensive
Pyrolysis/ Liquefaction	- feedstock agnostic - utilizes lignin - autothermal - water positive - provides fungible intermediate	- process to stabilize pyrolysis oil must be developed
Aqueous phase processing	- uses concentrated sugar solutions - does not need pure sugar substrate - water positive - eliminates most distillation	- uses only solubilized sugars (no lignin)
Synthetic biology	- eliminates distillation - microbes not poisoned by fermentation product	- microbes are specific to sugar feedstock - does not utilize lignin - very slow rates wrt catalysis
Algae	- tremendous inherent growth rates - easy to convert lipids	- cost of production is sky high

Potentially Transformative Research

- Emerging Frontiers of Research and Innovation
- Interdisciplinary research
- Disciplinary research

Growing microalgae for renewable fuel. *Credit: Phillip Savage, Univ. of Michigan*

An anatomically correct testbed hand. *Credit: Ellen Garvens, University of Washington*

Engineers examine the scoured trench behind the concrete floodwall next to the catastrophic levee breach at the west end of the Lower Ninth Ward of New Orleans. *Credit: Rune Storesund*

Emerging Frontiers in Research and Innovation (EFRI)

- Supports higher-risk, higher-payoff opportunities that:
  - Are potentially transformative
  - Address a national need or grand challenge
- One Topic Area for FY 2009 was:
  - Hydrocarbons from Biomass (HyBi)
- $16M investment for 4-year awards at ~$500K per year
- EFRI Web site: www.nsf.gov/eng/efri

EFRI
Sohi Rastegar
Prog. Dir.
George Antos

EFRI-HyBi Proposal (University of Kentucky):

PI: R Andrews

Co-PIs: M. Crocker, S. DeBolt, M. Meier, S. Morton

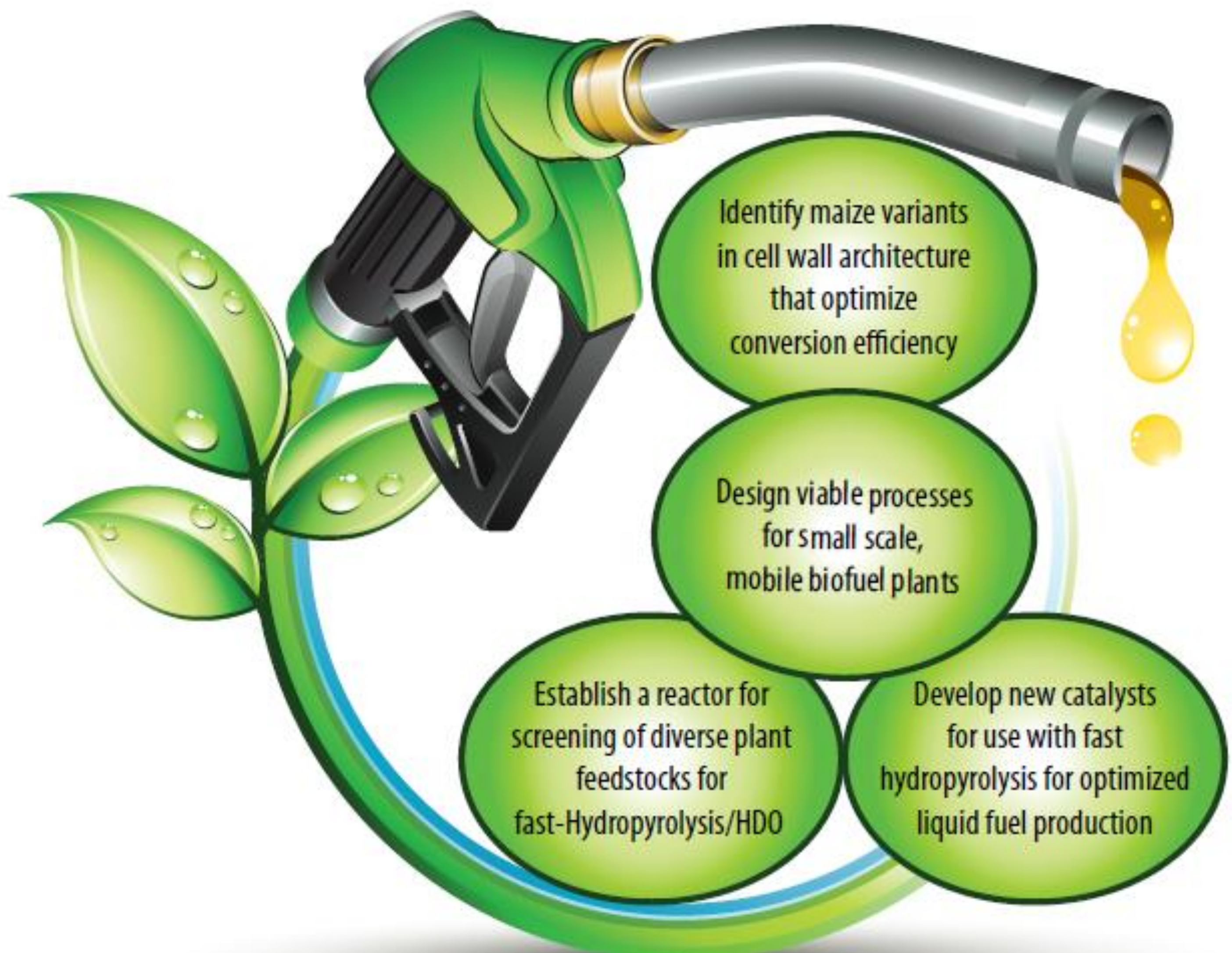
Lignin Deconstruction for the Production of Liquid Fuels

<u>Project Vision</u>

- Goal: develop new processes for the utilization of lignin
- Proposed project requires integration of bio-engineering, chemistry and chemical engineering
- Specific objectives:
  - modify chemical composition of plant lignin for easier processing to liquid fuels and chemicals
  - improve understanding of lignin deconstruction at the molecular level (emphasis on thermolysis and oxidation chemistry)
  - based on chemical insights, develop improved catalytic processes for lignin upgrading
  - promote cross fertilization of ideas across disciplines
  - expose students to multi-disciplinary research environment

AGRAWAL–MAXIMIZING CONVERSION OF BIOMASS CARBON TO LIQUID FUEL

ENGINEERING CHEMISTRY BIOLOGY



EFRI-HyBi Proposal: Algal Oils to 'Drop-in' Replacements for Petroleum-Derived Transportation Fuels

PI: W. L. Roberts – CoPis: J. Burkholder, H. Lamb, H. Sederoff, L. Stikeleather

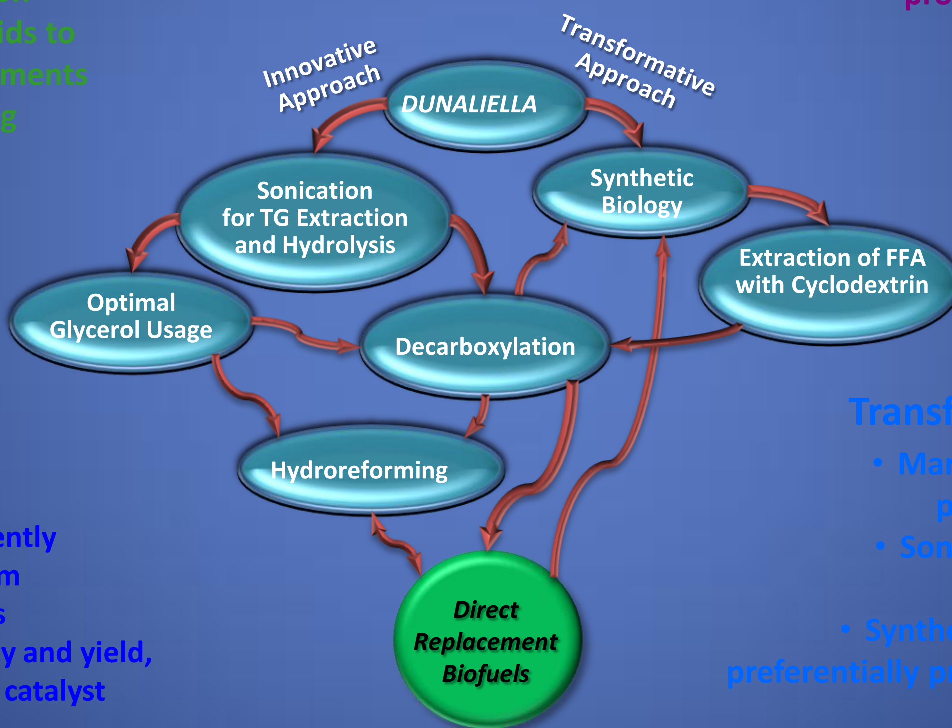
Vision

- Use synthetic biology to modify marine microalgae for maximum lipid/FFA production
- Develop innovative and transformative lipid/FFA extraction from microalgae
- Optimize catalysts for decarboxylation and isomerization/aromatization
- Optimize conversion of lipids to drop-in petroleum replacements using multi-step biorefining

Impacts

- Multi-step catalytic approach to produce biofuels with physical and chemical characteristics similar to petroleum fuels
- Successful biorefinery architecture implementation will provide significant progress in making algal oil-based biofuels truly competitive

Approach



Biofuels Challenges

- Mass-culturing, harvesting, and extracting lipids from microalgae efficiently
- Separating wanted lipids from undesirable/poisonous lipids
- Optimizing catalyst selectivity and yield, while mitigating/minimizing catalyst deactivation
- Biorefinery architecture optimization, demonstration of scalability and economic viability

Innovative & Transformational Technologies

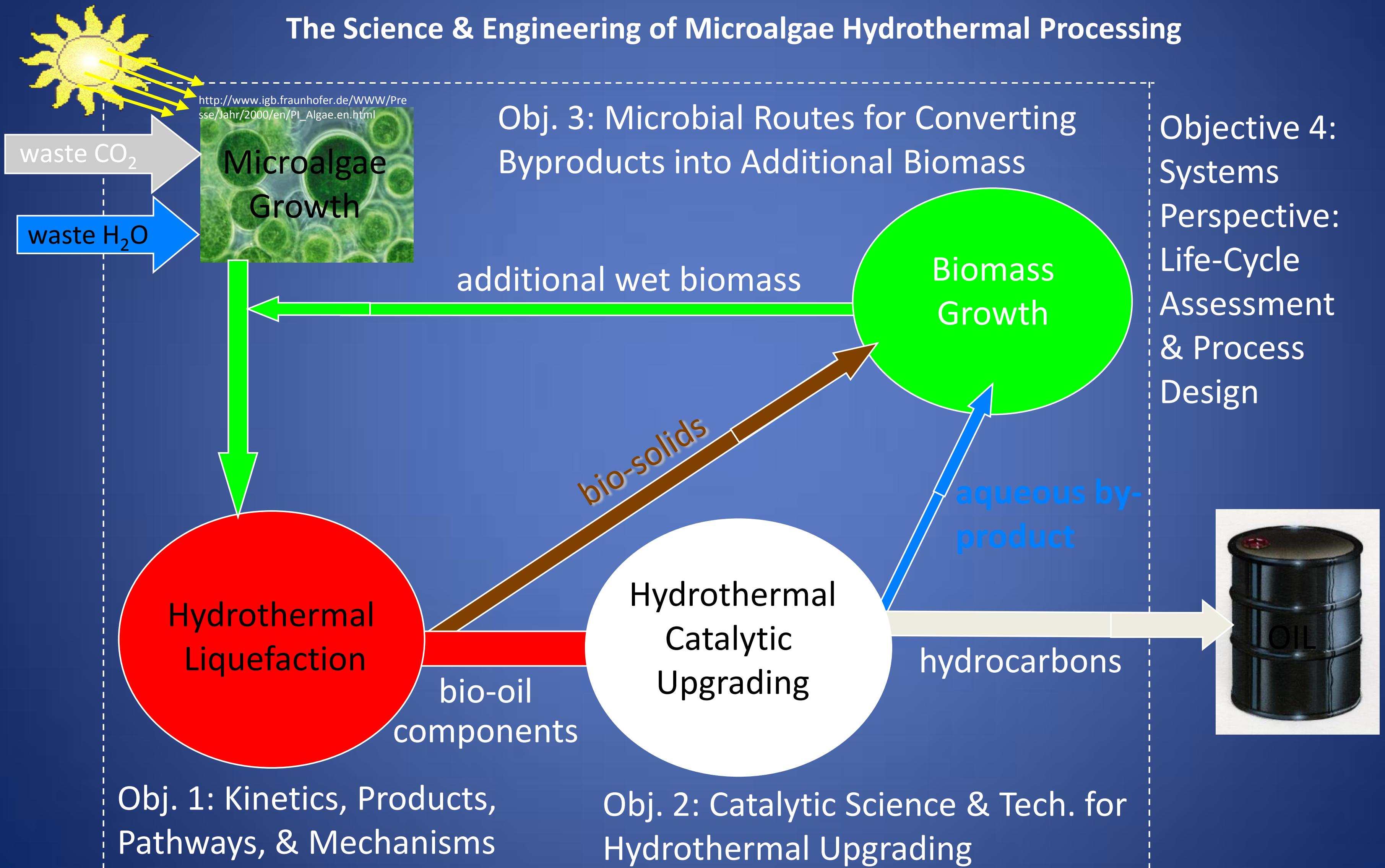
- Marine microalgae as feedstock to produce 2nd generation biofuels
- Sonication with unique harvesting and concentration techniques
- Synthetic and extremophile genes to preferentially produce lauric acid and increase overall lipid production
- Continuous extraction of fatty acids through cell membrane with cyclodextrin

NC STATE UNIVERSITY

PI: P. Savage

CoPIs: G. Keoleian, Z. Lin, S. Linic, A. Matzger

The Science & Engineering of Microalgae Hydrothermal Processing



Cartoon-level Simplified Process Overview for Algae Hydrothermal Liquefaction

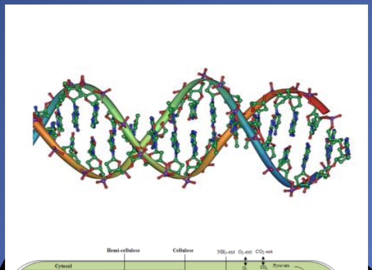
EFRI-HyBi: PI- B. Peyton

CoPIs: R. Carlson, M. Smooke, G. Strobel, S. Strobel

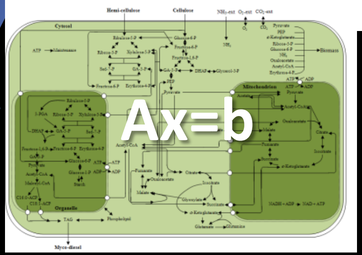
Fungal Processes for *Direct* Bioconversion of Cellulose to Hydrocarbons

Gliocladium roseum

Combustion tests and modeling (Task 4) provides feedback to optimize metabolic engineering and bioreactor growth efforts (Tasks 2 and 3)

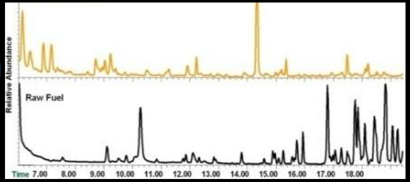


Task 1. Molecular Basis of Direct Biosynthetic Hydrocarbon Production – Genome annotation.



Task 2. Detailed Metabolic Flux Analysis Modeling - Elementary mode and metabolic flux analysis to map experimentally measured myco-diesel fluxes onto intracellular reactions.

Task 3. Kinetic Parameters to Optimize Fungal Growth and Hydrocarbon Production – Fermentation experiments to quantitatively describe key metabolic rates and yields for scale-up.



Task 4. Hydrocarbon Composition Analysis and Fuel Combustion Properties - Detailed model of myco-diesel flame structures and combustion testing for fuel.

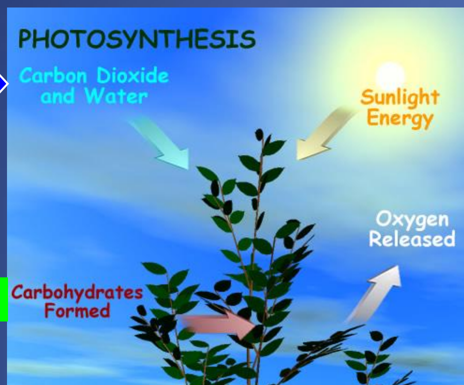
A collaboration of Montana State University and Yale University

Project Vision - Develop fundamental engineering bioprocess knowledge for *direct* conversion of waste cellulose to produce a range of usable fuel hydrocarbons

PI: J. Shanks
Co-PIs: T. Bobik, G. Nadathur, B. Nikolau, G. Wolfe

EFRI-HyBi: Bioengineering a system for the direct production of biological hydrocarbons for biofuels

CO_2

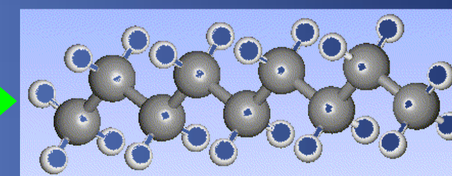


acetyl-CoA

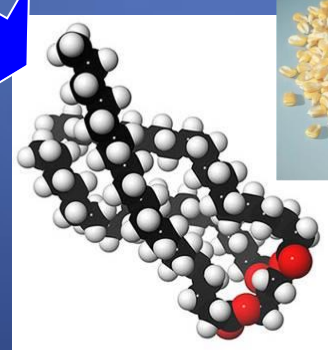
Reducing carbon, capturing solar energy

"Green hydrocarbon biofuel"

Goal of this project is to isolate, characterize and bioengineer a biocatalyst for generating a biological source of linear hydrocarbons



Hydrocarbon
"Green hydrocarbon biofuel"

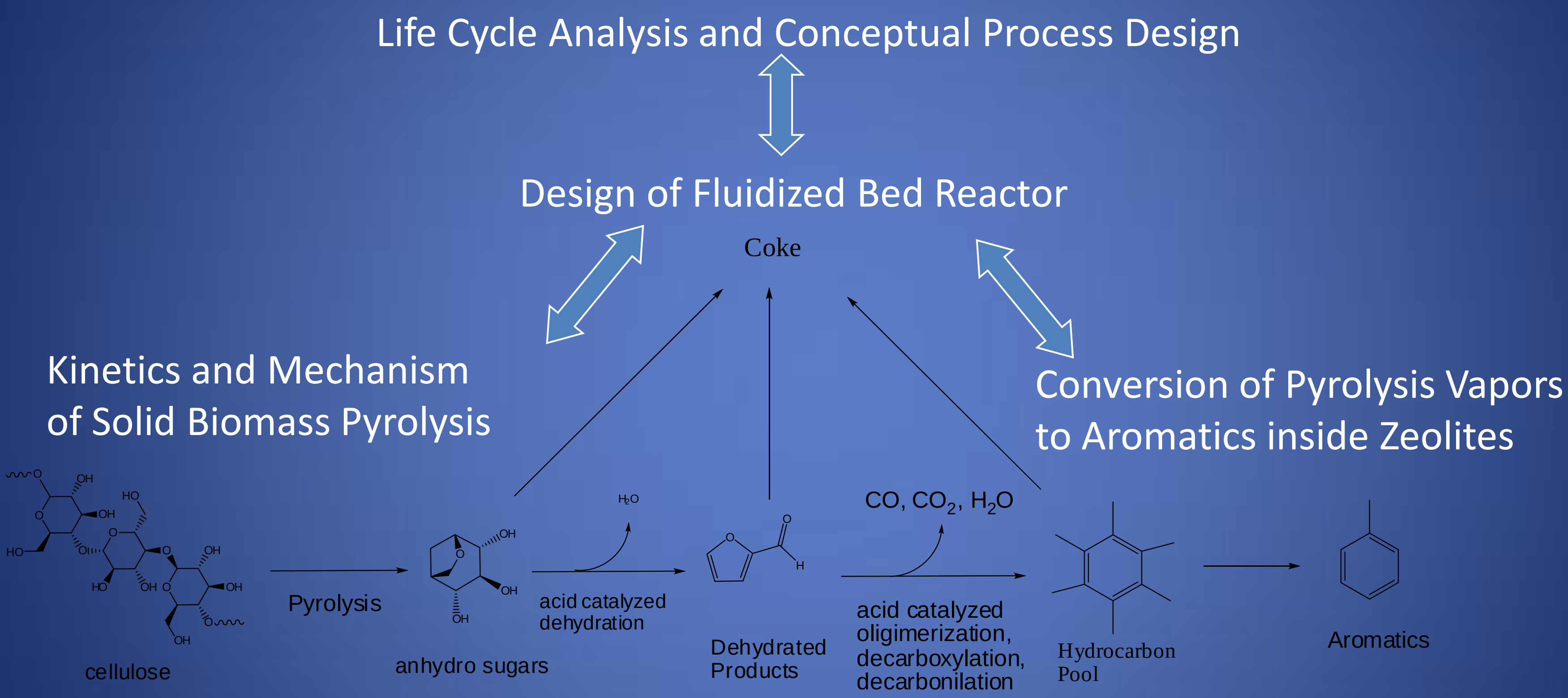


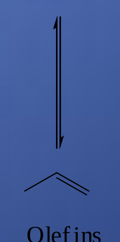
Fats and oils

PI: **Huber**

CoPI: S. Auerbach, W. Conner, S. deBruyn Kops, T Mountziaris

EFRI: Green Aromatics by Catalytic Fast Pyrolysis of Lignocellulosic Biomass



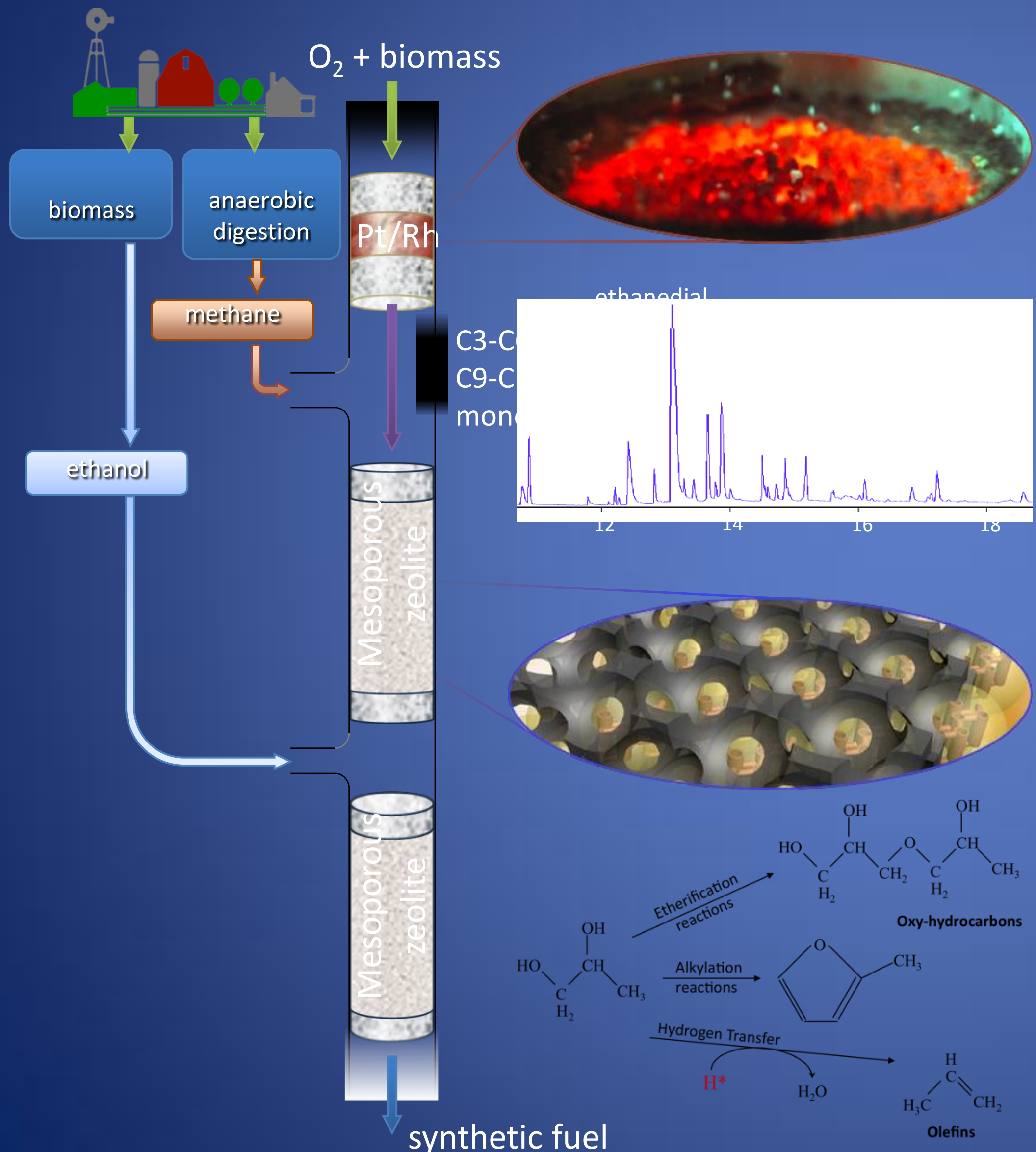


Interdisciplinary Research: Catalysis, Reaction Engineering, Theoretical Chemistry, Fluid Mechanics, Heat Transfer, Cogeneration, Life Cycle Analysis, Conceptual Process Design.

University of Massachusetts

PI: M.Tsapatsis
Co-PIs: A. Bhan, C. Floudas, L. Schmidt, D. Vlachos

EFRI-HyBi : Conversion of Biomass to Fuels using Molecular Sieve Catalysts and Millisecond Contact Time Reactors



Minnesota-Delaware-Princeton

Emerging interdisciplinary frontiers in heterogeneous catalysis, reaction engineering, materials design, systems integration, and energy are combined to develop a highly integrated, millisecond contact time reactor for the production of hydrocarbons from biomass feedstocks by rapidly and selectively reacting them to eliminate solid carbon formation and other undesired reactions.

Current Status of Hydrocarbon Biofuels in U.S.

- NBAP rewritten to include hydrocarbon biofuels
- Biomass Conversion Interagency WG → 10 Year RD&D Plan
- Sec. Chu has recently testified on priority of HC biofuels
- Federal Funding:
  - DOE/SC $20 MM EFRCs; 3 or 4 on hydrocarbon fuels
  - DOE/EERE/OBP: $800 MM, $480MM demonstration projects, $85 MM algae and thermochem. consortia
  - NSF: "Hydrocarbons from Biomass" FY 09 EFRI topic, $16 MM
  - USDA, DOD, etc.

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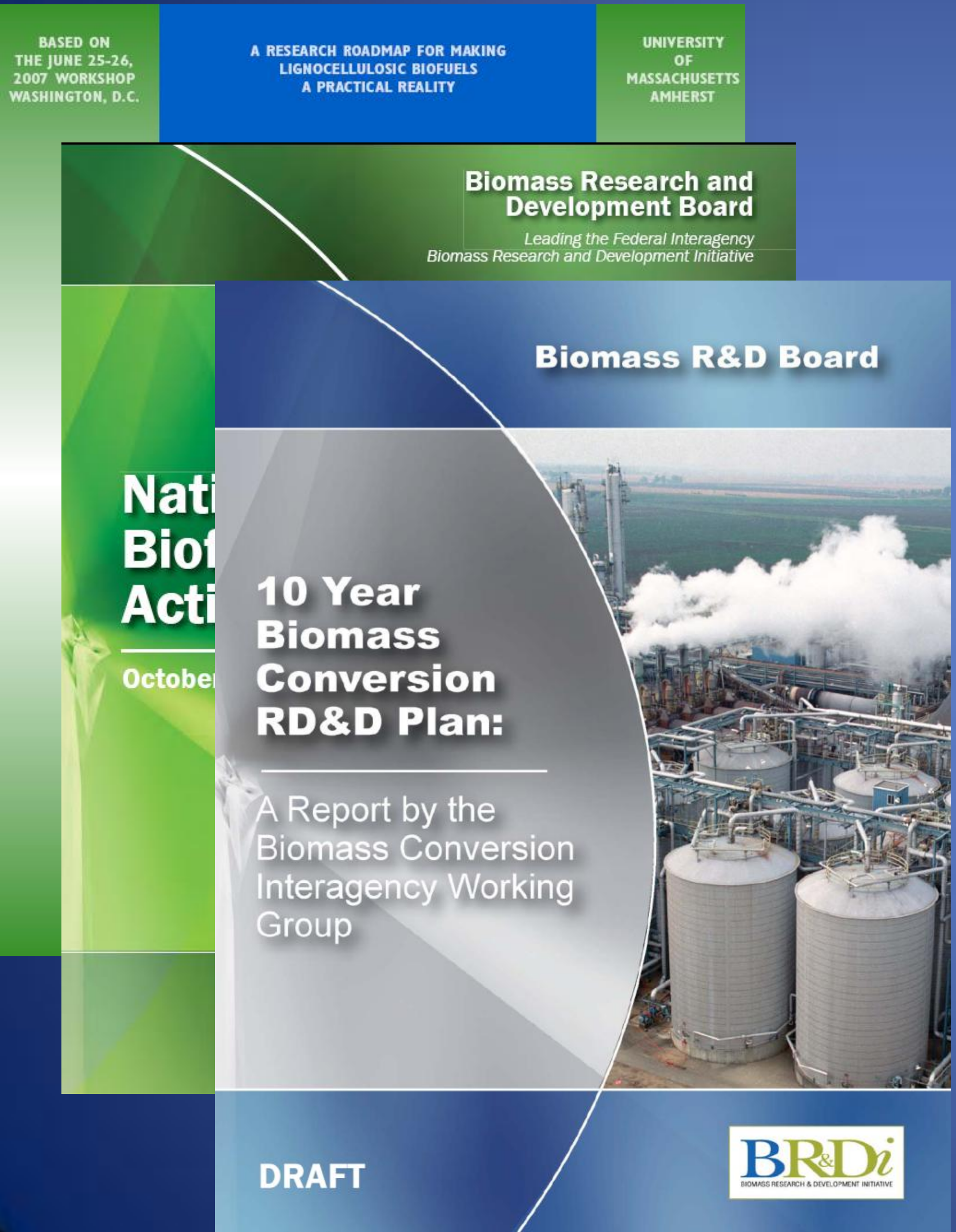

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Summary Thoughts

- Green Gasoline vision: "Cellulosic Gasoline"
  - Utilize existing corn EtOH plants for blending at E10 (15 billion gal/yr)
  - With lignocellulose, make green gasoline, diesel, jet
    - No need to remove the EtOH "blend wall"
  - Hydrocarbon biofuels from algae also possible
    - Feedstock production costs still too high; conversion is cheap
  - Recent indications: hydrocarbon biofuels are imminent

- Long range vision:
  - Light vehicles: electric or plug in hybrid (much less demand for gasoline)
  - Still need diesel and jet fuel for planes, trains, trucks, and boats
  - Use biomass for 100% of liquid transportation fuels