The Roadway to Partial Petroleum Replacement with Biomass-Derived Fuels-A Report Along the Way

George J. Antos

National Science Foundation

MIT-Endicott House Symposium

August 24, 2010

Justification for Biomass Conversion Programs

Over the next 20 years, U.S. energy consumption is projected to rise by 30 percent while domestic energy production increases by 25 percent, intensifying the potential for energy imports. Petroleum imports now serve for more than 55 percent of U.S. energy needs and that share could increase to more than 68 percent by 2025. This increased reliance on imported energy threatens our national security, economic health, and future global competitiveness. In addition, the U.S. transportation sector is responsible for one-third of our country's carbon dioxide (CO2) emissions, the principal greenhouse gas contributing to global warming.

Organization of Presentation

- Government Funding of Biomass Research
- Co-ordination, with initial problems
- From Ethanol to Hydrocarbons
- Some Real Science
- Current Approach and Issues
- Final Thought on the Ultimate Biofuel Approach.

Staff Offices

- Office of Management and Budget
- Science Advisor, Office of Science and Technology Policy
- Other Boards and Councils

Major Departments

- Homeland Security
- Agriculture
- Commerce
- Defense
- Energy
- Health and Human Services
- Interior
- Transportation

Independent Agencies

- National Science Foundation (NSF)
- National Aeronautic and Space Administration
- Environmental Protection Agency
- Nuclear Regulatory Commission
- Smithsonian Institution
- Other Agencies

History of Public Efforts in Biomass RD&D

Efforts in bioenergy were initiated by the National Science Foundation (NSF) and subsequently transferred to DOE in the late 1970s.

Early projects focused on biofuels and biomass energy systems.

From the 1970s to the present, approximately $3.5 billion (including $800 million in ARRA funds) has been invested in a variety of RD&D programs covering biofuels (particularly ethanol), biopower, feedstocks, municipal wastes, and a variety of biobased products, including ones from forest products and agricultural processing industries.

Biomass R&D Board: The Biomass R&D Act of 2000 authorized the creation of the Biomass R&D Board, which coordinates R&D across federal agencies to promote the use of bio-based fuels and products, maximize benefits from federal grants and assistance, and bring coherence to federal strategic planning. Co-chaired by DOE and USDA, the Board is comprised of senior level representatives from the Environmental Protection Agency; the National Science Foundation; the Departments of Interior, Commerce, Defense, Transportation and Treasury; the Office of Science and Technology Policy; the Office of Management and Budget; and the Office of the Federal Environmental Executive.

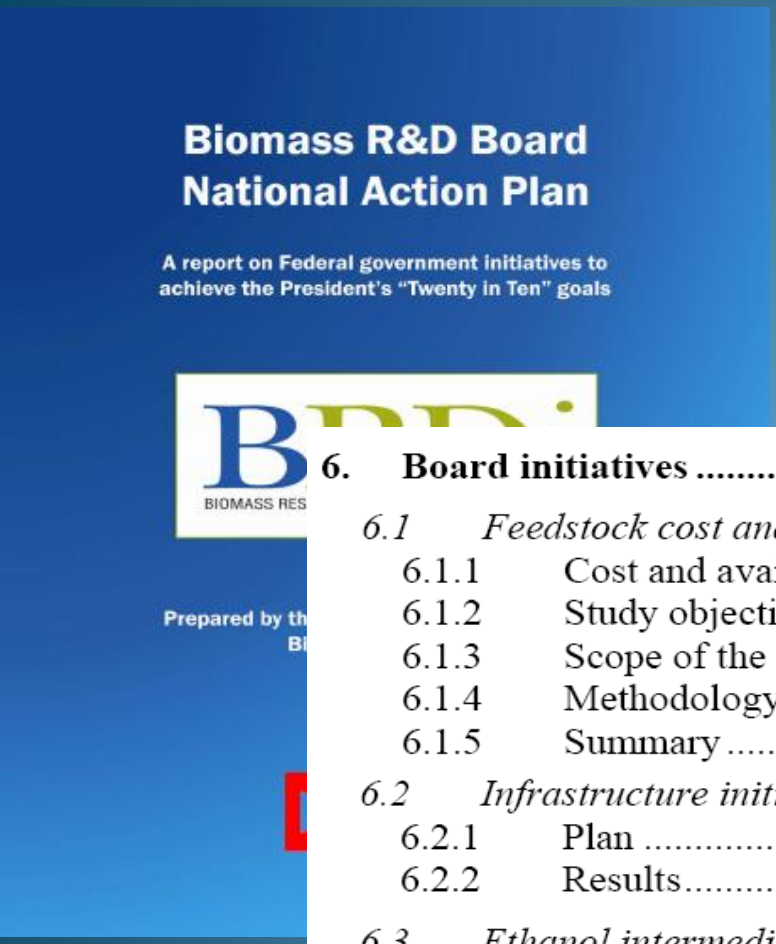
Coordination of Federal Activities

Coordination with other government offices involved in bioenergy is essential to avoid duplication, leverage limited resources, optimize the federal investment, ensure a consistent message to all of its stakeholders, and meet the national energy goals.

Biofuels Interagency Working Group co-chaired by the Secretaries of
Agriculture and Energy, and the Administrator of the Environmental Protection Agency,
Biomass Research and Development Board with multiple agency representation and Biomass
R&D Technical Advisory Committee.

National Action Plan.

Biomass R&D Board
National Action Plan
Early 2007 status



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 → 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 lignocellulosic biomass grown with minimal land use change.
- How to change the paradigm?

LS9, INC.

THE BEST REPLACEMENT FOR PETROLEUM IS PETROLEUM

RENEWABLE.

OUR FOUNDERS ASKED:

"If you removed all constraints, what would the ideal biofuel be?"

THEIR ANSWER: petroleum.

A biological, fermentation-based process starting from renewable sugars offers the most compelling economics. However, petroleum products could not be made in this way. Until now.

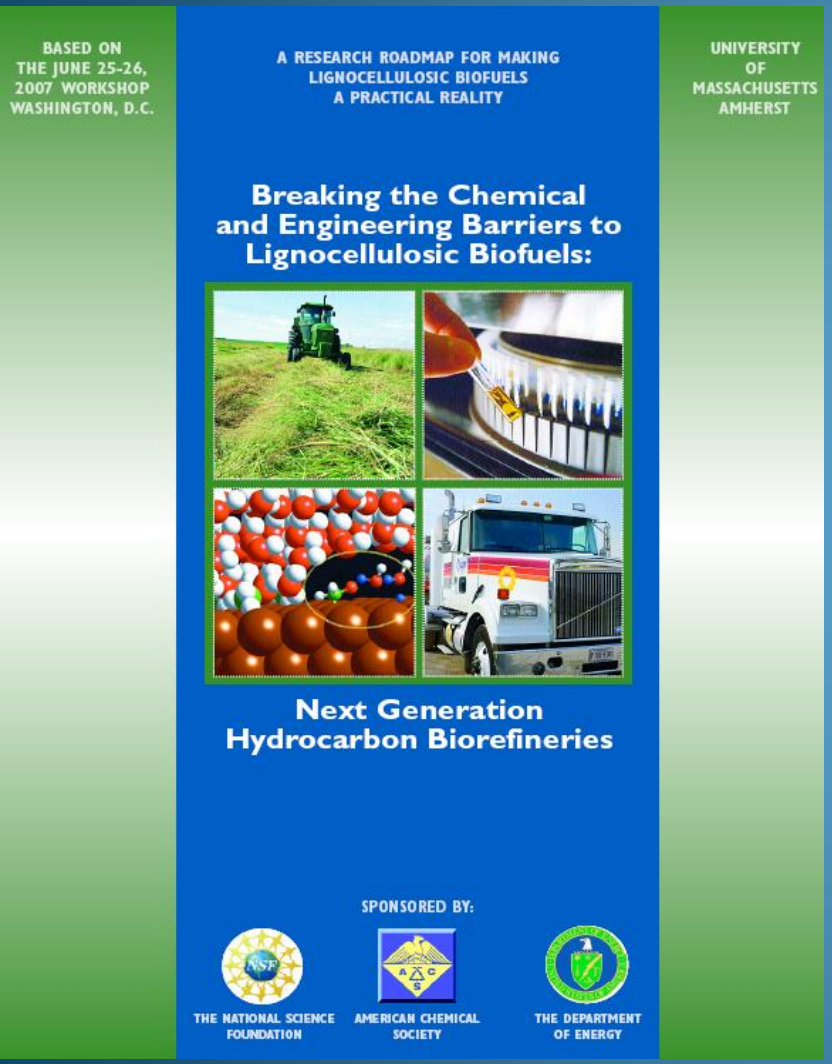
LS9 Renewable Petroleum™ technology enables the rapid and widespread adoption of renewable transportation fuels. Patent-pending DesignerBiofuels™ products are custom engineered to have higher energetic content than ethanol or butanol; to have fuel properties that are essentially indistinguishable from those of gasoline, diesel, and jet fuel; and to be distributed in existing pipeline infrastructure and run in any vehicle. Learn more about LS9

What is Renewable Petroleum™ Technology?

Learn about our DesignerBiofuels™ Products

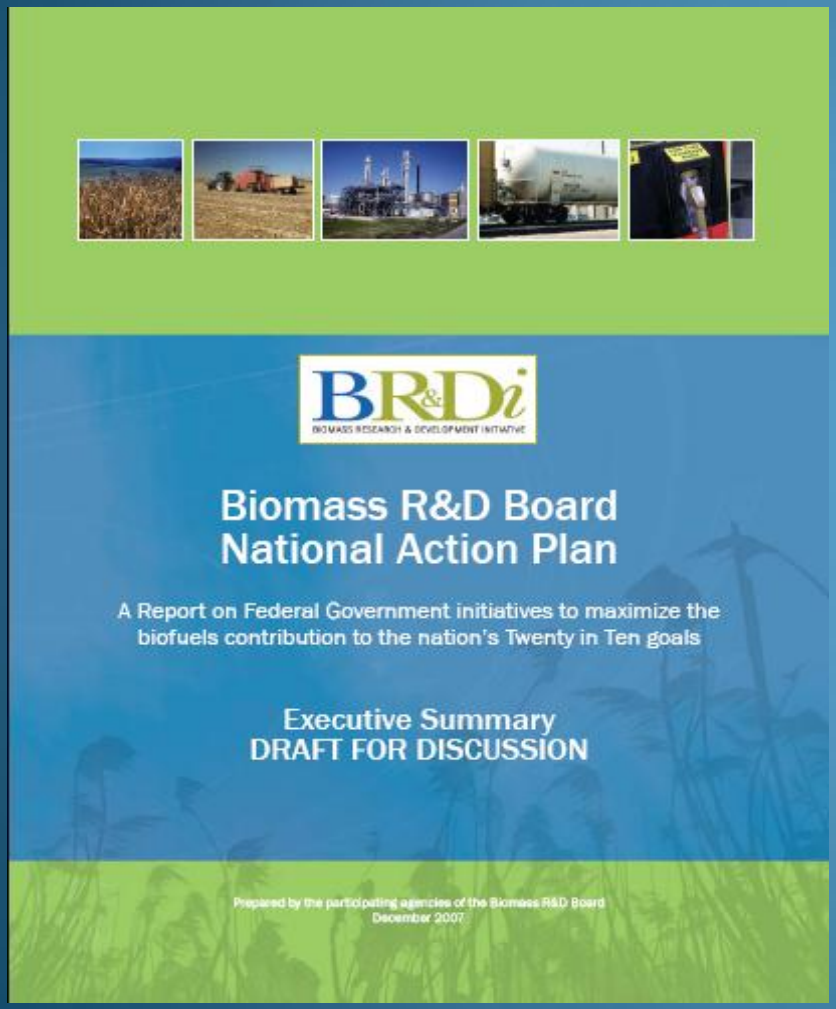
Join Our Team!

Roadmap for Hydrocarbon Production, June 2007

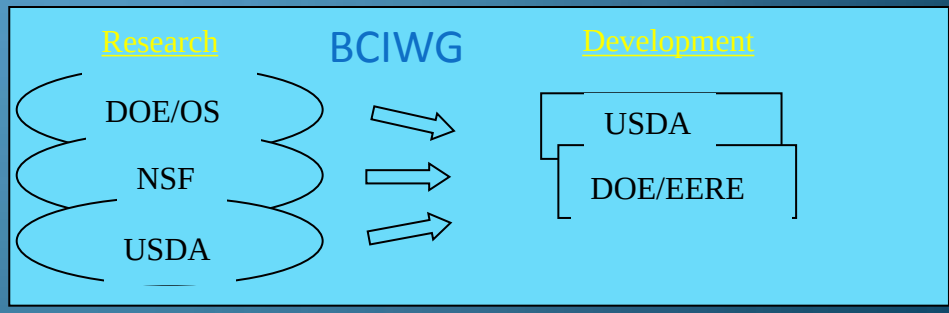


- 2007 NSF/ENG and DOE/EERE Cosponsors
- Workshop participants:
  - 71 invited participants
  - 27 academics from 24 universities
  - 19 companies, small and large
  - 13 representatives from 5 national labs
  - 10 program managers (NSF, DOE, USDA)
- Workshops Goals:
  - Articulate the role of chemistry 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.

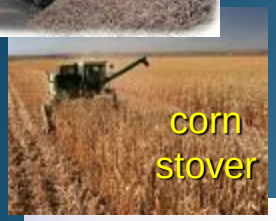
- About Us
- Sustainability
- Feedstock Production
- Feedstock Logistics
- Conversion Science and Technology
- Distribution Infrastructure
- Environment Health Safety
- Intermediate Ethanol Blending

Revised NBAP issued Oct. 2008

BRDi

Biofuel Production Alternatives

lignocellulose



gasification to “syngas” ($CO + H_2$)

pyrolysis, fast or slow

gases

bio-oil

dissolution

liquid phase processing

Fisher-Tropsch

methanol

Jet Fuel

Diesel

Gasoline

Sugar/Starch

starch

saccharification

lignin → Heat/Power

sugar

fermentation

Ethanol

butanol

Lipids

hydrotreating

transesterfication → Biodiesel

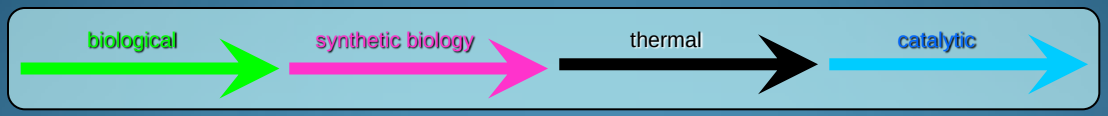
thermal routes

catalytic routes

biological routes

synthetic biology

Pathways to Hydrocarbons



Lignocellulose

hydrolysis
microbial processing
sugars
lignin
pretreatment
lliquid phase processing
syngas
gasification
Fischer-Tropsch
bio-oil
pyrolysis
hydrotreating
Heat/Power

Amyris
LS9
Virent
Choren
Sapphire
ExxonMobil
Solazyme
Anellotech
KiOR
Envergent

HyBi Proposals

- Lignocellulosics conversion is still not a commercial reality.
- There are many gaps in the fundamental understanding of the conversion pathways.
- Potential advantages to bio-engineering of the biomass feedstock.
- Algae utilization has many current limitations.
- New catalysts are needed everywhere.

HyBi Projects

- **Algae Feedstocks**
  - **Algal Oils to 'Drop-in' Replacements for Petroleum-Derived Transportation Fuels**
  - **The Science & Engineering of Microalgae Hydrothermal Processing**
- **Bio-engineering**
  - **Fungal Processes for *Direct* Bioconversion of Cellulose to Hydrocarbons**
  - **Bioengineering a system for the direct production of biological hydrocarbons for biofuels**
- **Bio-engineering and Catalysis**
  - **Lignin Deconstruction for the Production of Liquid Fuels**
  - **Maximizing Conversion of Biomass Carbon to Liquid Fuels**
- **Catalytic Conversion Processes**
  - **Green Aromatics by Catalytic Fast Pyrolysis of Lignocellulosic Biomass**
  - **Conversion of Biomass to Fuels using Molecular Sieve Catalysts and Millisecond Contact Time Reactors**

Coordination of Federal Activities

Coordination with other government offices involved in bioenergy is essential to avoid duplication, leverage limited resources, optimize the federal investment, ensure a consistent message to all of its stakeholders, and meet the national energy goals.

Biofuels Interagency Working Group co-chaired by the Secretaries of
Agriculture and Energy, and the Administrator of the Environmental Protection Agency,
Biomass Research and Development Board with multiple agency representation and Biomass
R&D Technical Advisory Committee.

National Action Plan.

Current Situation

- Next versions of Boards (new Administration) are in place and beginning to conduct business.
- Policy issues under consideration by BIWG.
- BRDi establishes Operations Committee and establishes new Working Groups to continue technical RD&D, and address new issues not previously developed.
- Environmental issues now being evaluated.
- Life cycle analysis best practices under evaluation.
- DOE Biomass Program an excellent source for issues.

Issues for the Current BIWG and BRDi Boards

- The national RFS legislated by Energy Policy Act of 2005 (EPAct 2005) provides a reliable market for biofuels of at least 7.5 billion gallons by 2012.
- Historically, when the blender's tax credit is subtracted from wholesale prices, biofuels are price competitive with petroleum fuels on a volumetric basis.
- Blender's tax credits for ethanol and biodiesel have helped to ensure biofuels can compete with gasoline.
- To incentivize, or not?
- Cellulosic technology may not be as competitive and could require policy supports and regulatory mandates to drive the market.

Issues for the Current BIWG and BRDi Boards

- The industry assumes considerable market risk when only limited feedstock types are available.
- For example, the heightened demand for corn – which comprises 70% of the cost of ethanol – has driven the price of that commodity from $2.32/bu in 2002 to over $4.25/bu in 2007.
- The differential between the cost of the corn feedstock and the open market value of ethanol has declined precipitously.
- What to do about ethanol plant investments?
- Feedstock diversity and regionalization complicate conversion strategies.
- Conversion technologies may be feedstock dependent, may influence transport and collection strategies.
- Optimization strategies may limit flexibility.

Issues for the Current BIWG and BRDi Boards

- The feedstocks used to produce biofuels are located at the end of a long agricultural supply chain.
- The markets for biofuels, biofuel co-products (e.g., animal feed, corn oil and meal), and crop commodities are linked and susceptible to volatility in the price and availability of crops.
- Surging demand for biofuel feedstocks is likely to continue to exert upward price pressure on corn and soybean commodities and influence export, food, and industrial feedstock markets, particularly in the short term.
- Will food and fuel prices be elevated or at least volatile? Negative impact on consumers will affect political approach.

Issues for the Current BIWG and BRDi Boards

- Limited rail and truck capacity may complicate the delivery of biofuels, contributing to regional supply shortages and price spikes.
- Retail distribution continues to be an issue. Stations equipped for dispensing biodiesel and E85 fuels only accounted for about 1 percent of fueling stations.
- Some station owners may be averse to carrying B20 or E85, because the unique physical properties of the blends may require costly retrofits to storage and dispensing equipment.
- Independent station owners may also be uncomfortable with novel biofuels and the regulatory environment that surrounds their use and distribution at retail locations.

Issues for the Current BIWG and BRDi Boards

- Co-products of biofuels production, such as corn gluten feed and meal, corn oil, glycerin, and other feed products, also increase with biofuel production.
- At higher levels of biofuel production in the future, co-products may be oversupplied, resulting in depressed prices for the co-products and lower revenues from their sale to offset fuel production costs.

Issues for the Current BIWG and BRDi Boards

- Consumer behavior will play an increasingly important role in determining demand for biofuels.
- Consumer attitudes about fuel prices, relative fuel performance, biofuel-capable vehicles, and the environment will affect the volume and type of biofuels sold.
- Price, availability, and familiarity are the primary attributes by which many consumers judge the value of biofuels. E85 and B20, for example, are much less common in the United States than are petroleum-rich blends (E10).
- Consumers who are generally unfamiliar with biofuels have been hesitant to use them, even where they are available.
- What about those State and Local Political Climates and resulting legislation or regulations?

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, but longer term
    - Feedstock production costs still too high; conversion is cheap
  - Recent indications: commercial production of hydrocarbon biofuels is likely in several years, likely from wood sources

- 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