Environmental and Sustainability Factors Associated With Next-Generation Biofuels in the United States: What Do We Really Know?

Pamela R.D. Williams

Presentation at the Metropolitan Water Reclamation District of
Greater Chicago, Monitoring and Research Department
February 26, 2010. Chicago, Illinois

E RISKSCIENCES
ANALYSIS & TOOLS FOR DECISION-MAKING

Outline

- Background information
  - Legislative history
  - Conventional biofuels
  - Next-generation biofuels
- Study purpose and methods
- Key findings and conclusions
- Data gaps and research needs

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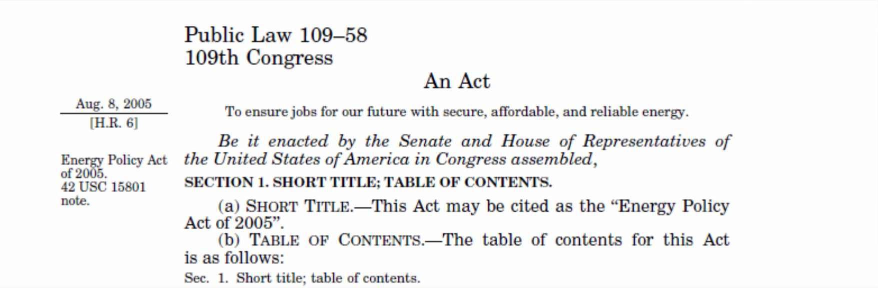
Background

- Biofuels are renewable liquid fuels derived from biomass (organic material from plants and animals)
- The production of biofuels has been promoted in the United States for more than a decade
- Potential benefits of national interest
  - Energy independence and security
  - Healthier rural economies
  - Improved environmental quality
  - Near-zero net greenhouse gas (GHG) emissions
  - Technology export
  - Diverse and sustainable resource supply

Legislative History

- Biomass Research and Development Act of 2000
- Farm Security and Rural Investment Act of 2002
- Energy Policy Act of 2005
- Energy and Independence Security Act of 2007
- Food, Conservation, and Energy Act of 2008



Public Law 109–58
109th Congress

An Act

Aug. 8, 2005
[H.R. 6]

To ensure jobs for our future with secure, affordable, and reliable energy.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

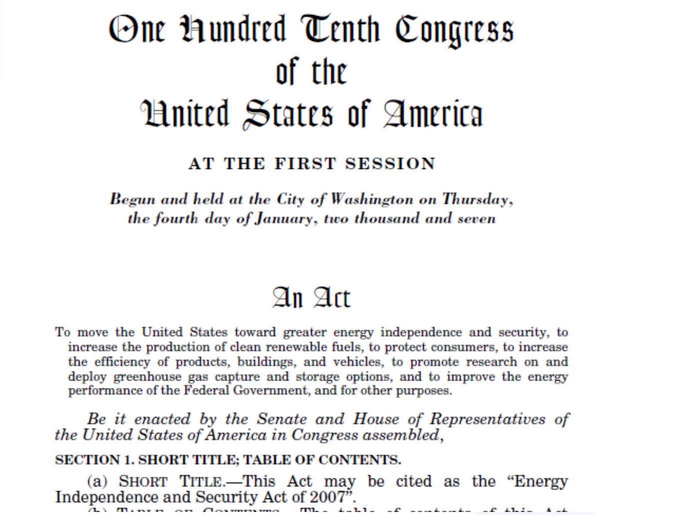
Energy Policy Act of 2005.
42 USC 15801 note.

SECTION 1. SHORT TITLE; TABLE OF CONTENTS.

(a) SHORT TITLE.—This Act may be cited as the "Energy Policy Act of 2005".

(b) TABLE OF CONTENTS.—The table of contents for this Act is as follows:

Sec. 1. Short title; table of contents.



One Hundred Tenth Congress
of the
United States of America

AT THE FIRST SESSION

Begun and held at the City of Washington on Thursday, the fourth day of January, two thousand and seven

An Act

To move the United States toward greater energy independence and security, to increase the production of clean renewable fuels, to protect consumers, to increase the efficiency of products, buildings, and vehicles, to promote research on and deploy greenhouse gas capture and storage options, and to improve the energy performance of the Federal Government, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE; TABLE OF CONTENTS.

(a) SHORT TITLE.—This Act may be cited as the "Energy Independence and Security Act of 2007".

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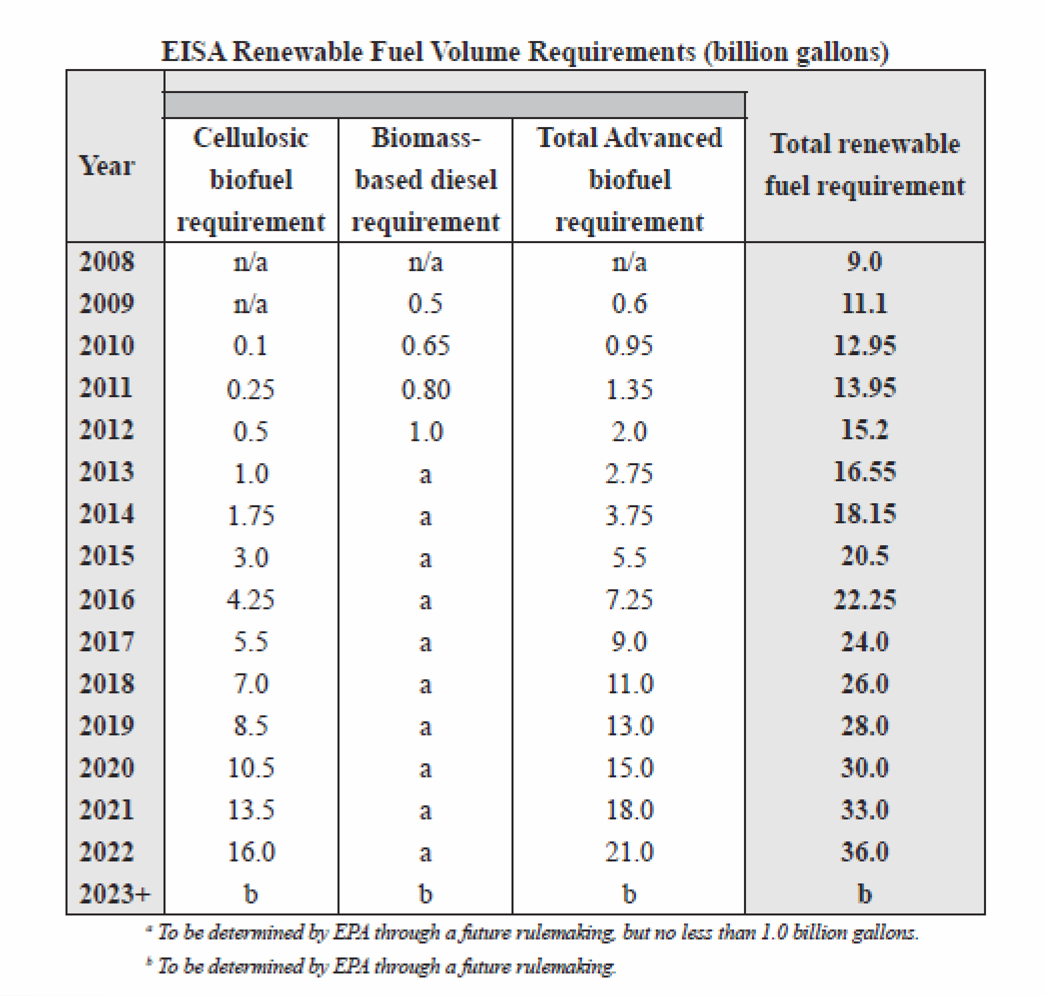
Renewable Fuel Standard (EISA 2007)

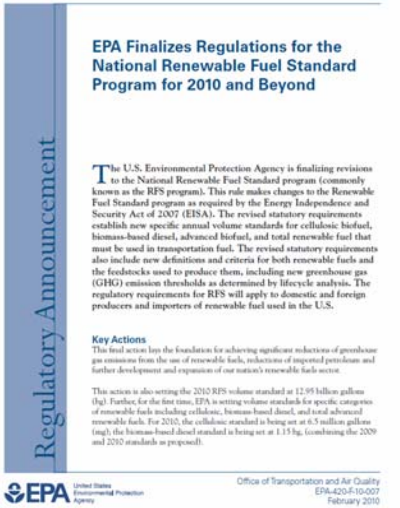


EISA Renewable Fuel Volume Requirements (billion gallons)

Year	Cellulosic biofuel requirement	Biomass-based diesel requirement	Total Advanced biofuel requirement	Total renewable fuel requirement
2008	n/a	n/a	n/a	9.0
2009	n/a	0.5	0.6	11.1
2010	0.1	0.65	0.95	12.95
2011	0.25	0.80	1.35	13.95
2012	0.5	1.0	2.0	15.2
2013	1.0	a	2.75	16.55
2014	1.75	a	3.75	18.15
2015	3.0	a	5.5	20.5
2016	4.25	a	7.25	22.25
2017	5.5	a	9.0	24.0
2018	7.0	a	11.0	26.0
2019	8.5	a	13.0	28.0
2020	10.5	a	15.0	30.0
2021	13.5	a	18.0	33.0
2022	16.0	a	21.0	36.0
2023+	b	b	b	b

[a] *To be determined by EPA through a future rulemaking, but no less than 1.0 billion gallons.*

[b] *To be determined by EPA through a future rulemaking.*



Regulatory Announcement

EPA Finalizes Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond

The U.S. Environmental Protection Agency is finalizing revisions to the National Renewable Fuel Standard program (commonly known as the RFS program). This rule makes changes to the Renewable Fuel Standard program as required by the Energy Independence and Security Act of 2007 (EISA). The revised statutory requirements establish new specific annual volume standards for cellulosic biofuel, biomass-based diesel, advanced biofuel, and total renewable fuel that must be used in transportation fuel. The revised statutory requirements also include new definitions and criteria for both renewable fuels and the feedstocks used to produce them, including new greenhouse gas (GHG) emission thresholds as determined by lifecycle analysis. The regulatory requirements for RFS will apply to domestic and foreign producers and importers of renewable fuel used in the U.S.

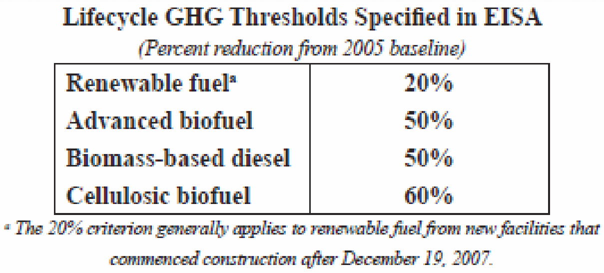
Key Actions

This final action lays the foundation for achieving significant reductions of greenhouse gas emissions from the use of renewable fuels, reductions of imported petroleum and further development and expansion of our nation's renewable fuels sector.

This action is also setting the 2010 RFS volume standard at 12.95 billion gallons (bg). Further, for the first time, EPA is setting volume standards for specific categories of renewable fuels including cellulosic, biomass-based diesel, and total advanced renewable fuels. For 2010, the cellulosic standard is being set at 6.5 million gallons (mg); the biomass-based diesel standard is being set at 1.15 bg, (combining the 2009 and 2010 standards as proposed).

EPA United States Environmental Protection Agency

Office of Transportation and Air Quality
EPA-420-F-10-007
February 2010



Lifecycle GHG Thresholds Specified in EISA

(Percent reduction from 2005 baseline)

Renewable fuel[a]	20%
Advanced biofuel	50%
Biomass-based diesel	50%
Cellulosic biofuel	60%

[a] *The 20% criterion generally applies to renewable fuel from new facilities that commenced construction after December 19, 2007.*

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Conventional Biofuels

- First-generation (“conventional”) biofuels produced from major commercial crops
  - Corn-grain ethanol
  - Soybean biodiesel
- Many concerns raised about increased production of conventional biofuels
  - Net energy balance
  - Food vs. fuel
  - GHG emissions
  - Water impacts

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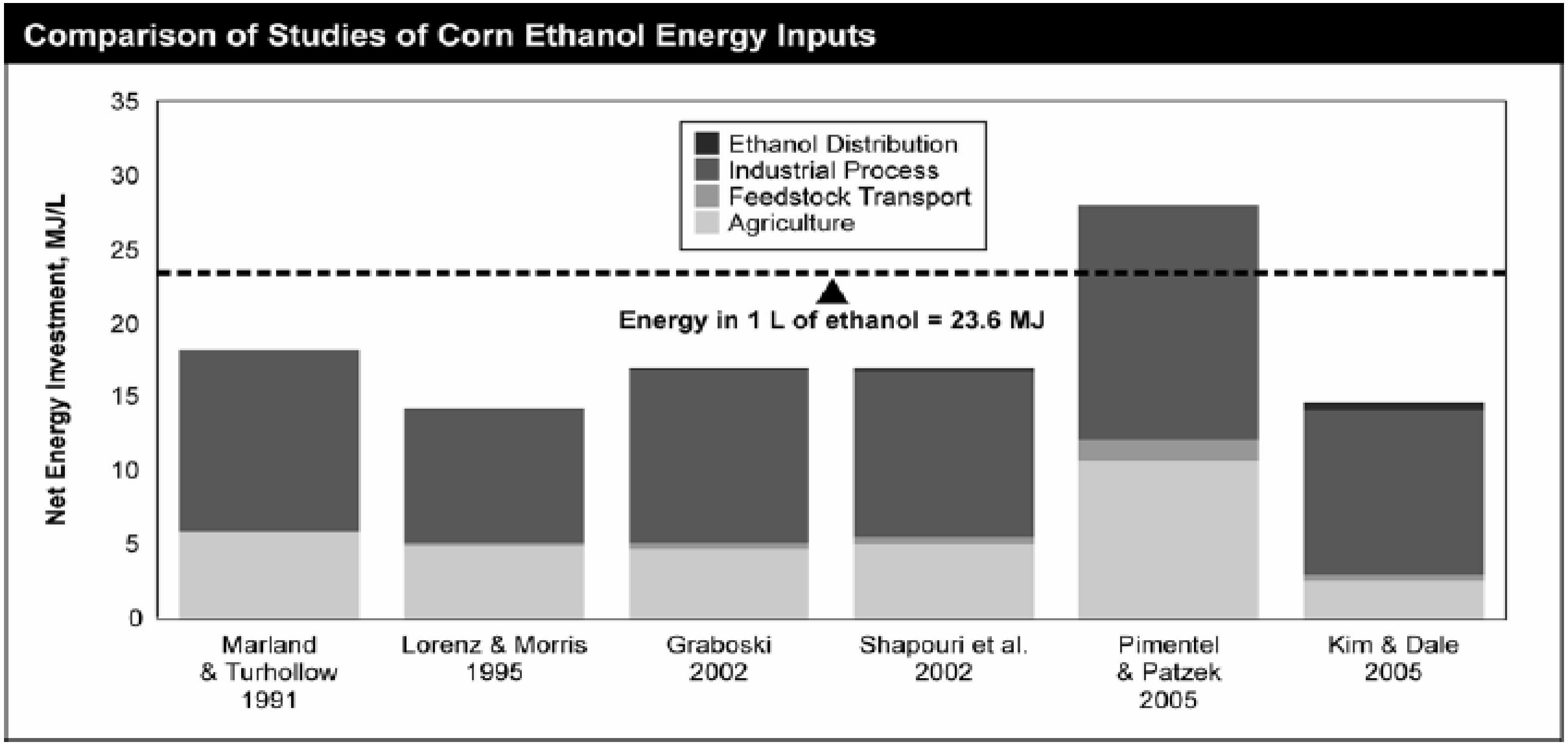
Net Energy Balance of Corn Ethanol



NRDC. 2006. Ethanol: Energy Well Spent. A Survey of Studies Published Since 1990.

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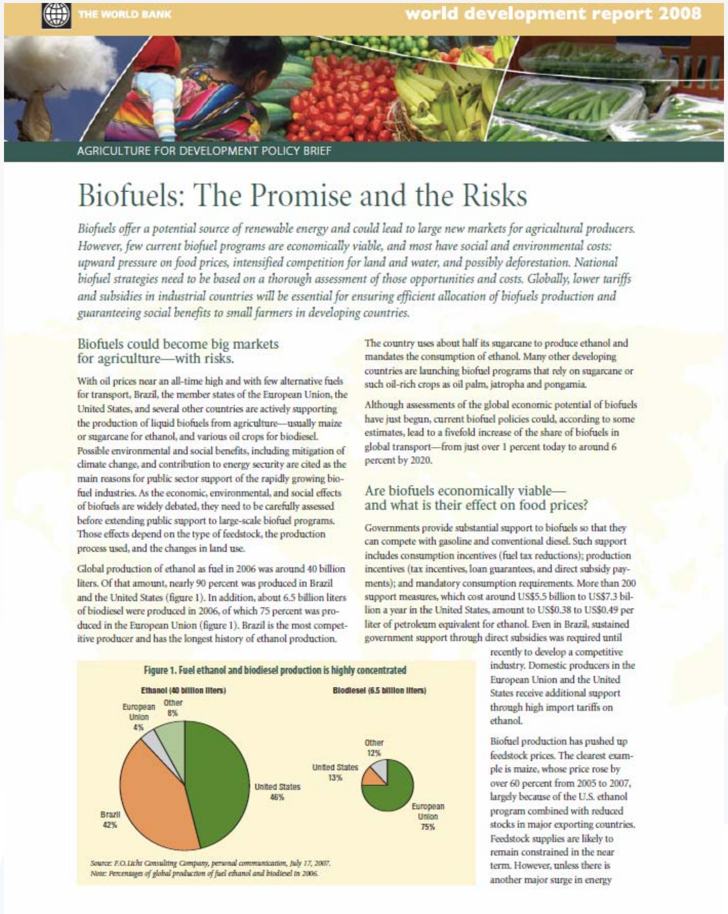
Food vs. Fuel Debate



THE WORLD BANK world development report 2008

AGRICULTURE FOR DEVELOPMENT POLICY BRIEF

Biofuels: The Promise and the Risks

Biofuels offer a potential source of renewable energy and could lead to large new markets for agricultural producers. However, few current biofuel programs are economically viable, and most have social and environmental costs: upward pressure on food prices, intensified competition for land and water, and possibly deforestation. National biofuel strategies need to be based on a thorough assessment of those opportunities and costs. Globally, lower tariffs and subsidies in industrial countries will be essential for ensuring efficient allocation of biofuels production and guaranteeing social benefits to small farmers in developing countries.

Biofuels could become big markets for agriculture—with risks.

With oil prices near an all-time high and with few alternative fuels for transport, Brazil, the member states of the European Union, the United States, and several other countries are actively supporting the production of liquid biofuels from agriculture—usually maize or sugarcane for ethanol, and various oil crops for biodiesel. Possible environmental and social benefits, including mitigation of climate change, and contribution to energy security are cited as the main reasons for public sector support of the rapidly growing biofuel industries. As the economic, environmental, and social effects of biofuels are widely debated, they need to be carefully assessed before extending public support to large-scale biofuel programs. Those effects depend on the type of feedstock, the production process used, and the changes in land use.

Global production of ethanol as fuel in 2006 was around 40 billion liters. Of that amount, nearly 90 percent was produced in Brazil and the United States (figure 1). In addition, about 6.5 billion liters of biodiesel were produced in 2006, of which 75 percent was produced in the European Union (figure 1). Brazil is the most competitive producer and has the longest history of ethanol production. The country uses about half its sugarcane to produce ethanol and mandates the consumption of ethanol. Many other developing countries are launching biofuel programs that rely on sugarcane or such oil-rich crops as oil palm, jatropha and pongamia.

Although assessments of the global economic potential of biofuels have just begun, current biofuel policies could, according to some estimates, lead to a fivefold increase of the share of biofuels in global transport—from just over 1 percent today to around 6 percent by 2020.

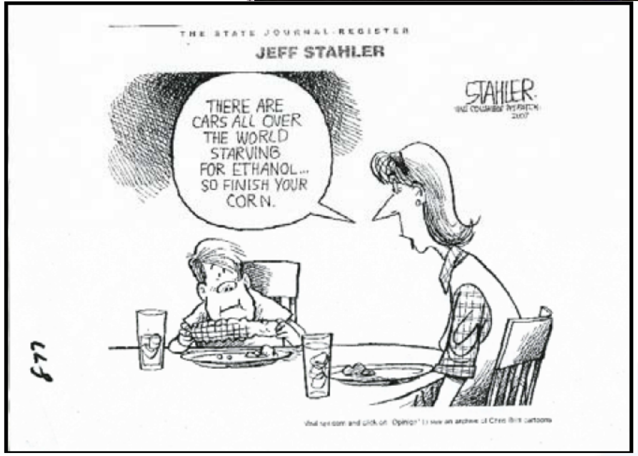
Are biofuels economically viable—and what is their effect on food prices?

Governments provide substantial support to biofuels so that they can compete with gasoline and conventional diesel. Such support includes consumption incentives (fuel tax reductions); production incentives (tax incentives, loan guarantees, and direct subsidy payments); and mandatory consumption requirements. More than 200 support measures, which cost around US$5.5 billion to US$7.3 billion a year in the United States, amount to US$0.38 to US$0.49 per liter of petroleum equivalent for ethanol. Even in Brazil, sustained government support through direct subsidies was required until recently to develop a competitive industry. Domestic producers in the European Union and the United States receive additional support through high import tariffs on ethanol.

Biofuel production has pushed up feedstock prices. The clearest example is maize, whose price rose by over 60 percent from 2005 to 2007, largely because of the U.S. ethanol program combined with reduced stocks in major exporting countries. Feedstock supplies are likely to remain constrained in the near term. However, unless there is another major surge in energy

Figure 1. Fuel ethanol and biodiesel production is highly concentrated

Source: F.O.Licht Consulting Company, personal communication, July 17, 2007.
Note: Percentages of global production of fuel ethanol and biodiesel in 2006.



World Bank. 2008. Biofuels: The Promise and the Risks. World Development Report

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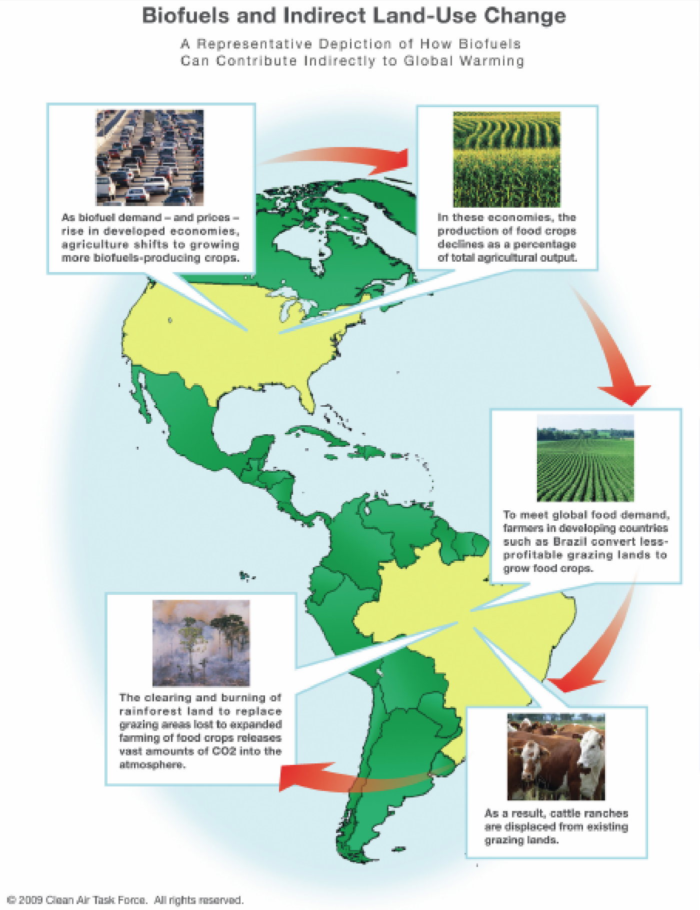
GHG Emissions from Land-Use Changes



Biofuels and Indirect Land-Use Change

A Representative Depiction of How Biofuels Can Contribute Indirectly to Global Warming

As biofuel demand – and prices – rise in developed economies, agriculture shifts to growing more biofuels-producing crops.

In these economies, the production of food crops declines as a percentage of total agricultural output.

To meet global food demand, farmers in developing countries such as Brazil convert less-profitable grazing lands to grow food crops.

As a result, cattle ranches are displaced from existing grazing lands.

The clearing and burning of rainforest land to replace grazing areas lost to expanded farming of food crops releases vast amounts of CO2 into the atmosphere.

Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change

Timothy Searchinger,[1]* Ralph Heimlich,[2] R. A. Houghton,[3] Fengxia Dong,[4] Amani Elobeid,[4] Jacinto Fabiosa,[4] Simla Tokgoz,[4] Dermot Hayes,[4] Tun-Hsiang Yu[4]

Most prior studies have found that substituting biofuels for gasoline will reduce greenhouse gases because biofuels sequester carbon through the growth of the feedstock. These analyses have failed to count the carbon emissions that occur as farmers worldwide respond to higher prices and convert forest and grassland to new cropland to replace the grain (or cropland) diverted to biofuels. By using a worldwide agricultural model to estimate emissions from land-use change, we found that corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years. Biofuels from switchgrass, if grown on U.S. corn lands, increase emissions by 50%. This result raises concerns about large biofuel mandates and highlights the value of using waste products.

Most life-cycle studies have found that replacing gasoline with ethanol modestly reduces greenhouse gases (GHGs) if made from corn and substantially if made from cellulose or sugarcane (*1*–*7*). These studies compare emissions from the separate steps of growing or mining the feedstocks (such as corn or crude oil), refining them into fuel, and burning the fuel in the vehicle. In these stages alone (Table 1), corn and cellulosic ethanol emissions exceed or match those from fossil fuels and therefore produce no greenhouse benefits. But because growing biofuel feedstocks removes carbon dioxide from the atmosphere, biofuels can in theory reduce GHGs relative to fossil fuels. Studies assign biofuels a credit for this sequestration effect, which we call the feedstock carbon uptake credit. It is typically large enough that overall GHG emissions from biofuels are lower than those from fossil fuels, which do not receive such a credit because they take their carbon from the ground.

For most biofuels, growing the feedstock requires land, so the credit represents the carbon benefit of devoting land to biofuels. Unfortunately, by excluding emissions from land-use change, most previous accountings were one-sided because they counted the carbon benefits of using land for biofuels but not the carbon costs, the carbon storage and sequestration sacrificed by diverting land from its existing uses. Without biofuels, the extent of cropland reflects the demand for food and fiber. To produce biofuels, farmers can directly plow up more forest or grassland, which releases to the atmosphere much of the carbon previously stored in plants and soils through decomposition or fire. The loss of maturing forests and grasslands also foregoes ongoing carbon sequestration as plants grow each year, and this foregone sequestration is the equivalent of additional emissions. Alternatively, farmers can divert existing crops or croplands into biofuels, which causes similar emissions indirectly. The diversion triggers higher crop prices, and farmers around the world respond by clearing more forest and grassland to replace crops for feed and food. Studies have confirmed that higher soybean prices accelerate clearing of Brazilian rainforest (*8*). Projected corn ethanol in 2016 would use 43% of the U.S. corn land harvested for grain in 2004 (*1*), overwhelmingly for livestock (*9*), requiring big land-use changes to replace that grain.

Because existing land uses already provide carbon benefits in storage and sequestration (or, in the case of cropland, carbohydrates, proteins, and fats), dedicating land to biofuels can potentially reduce GHGs only if doing so increases the carbon benefit of land. Proper accountings must reflect the net impact on the carbon benefit of land, not merely count the gross benefit of using land for biofuels. Technically, to generate greenhouse benefits, the carbon generated on land to displace fossil fuels (the carbon uptake credit) must exceed the carbon storage and sequestration given up directly or indirectly by changing land uses (the emissions from land-use change) (Table 1).

Many prior studies have acknowledged but failed to count emissions from land-use change because they are difficult to quantify (*1*). One prior quantification lacked formal agricultural modeling and other features of our analysis (*1*, *10*). To estimate land-use changes, we used a worldwide model to project increases in cropland in all major temperate and sugar crops by country or region (as well as changes in dairy and livestock production) in response to a possible increase in U.S. corn ethanol of 56 billion liters above projected levels for 2016 (*11*, *12*). The model's historical supply and demand elasticities were updated to reflect the higher price regime of the past 3 years and to capture expected long-run equilibrium behavior (*1*). The analysis identifies key factors that determine the change in cropland.

1) New crops do not have to replace all corn diverted to ethanol because the ethanol by-product, dry distillers' grains, replaces roughly one-third of the animal feed otherwise diverted.

2) As fuel demand for corn increases and soybean and wheat lands switch to corn, prices increase by 40%, 20%, and 17% for corn, soybeans, and wheat, respectively. These increases modestly depress demand for meat and other grain products beside ethanol, so a small percentage of diverted grain is never replaced.

3) As more American croplands support ethanol, U.S. agricultural exports decline sharply (compared to what they would otherwise be at the time) (corn by 62%, wheat by 31%, soybeans by 28%, pork by 18%, and chicken by 12%).

4) When other countries replace U.S. exports, farmers must generally cultivate more land per ton of crop because of lower yields.

Farmers would also try to boost yields through improved irrigation, drainage, and fertilizer (which have their own environmental effects), but reduced crop rotations and greater reliance on marginal lands would depress yields. Our analysis assumes that present growth trends in yields continue but

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[1] Woodrow Wilson School, Princeton University, Princeton, NJ 08544, USA. German Marshall Fund of the United States, Washington, DC 20009, USA. Georgetown Environmental Law and Policy Institute, Washington, DC 20001, USA. [2] Agricultural Conservation Economics, Laurel, MD 20723, USA. [3] Woods Hole Research Center, Falmouth, MA 02540–1644, USA. [4] Center for Agricultural and Rural Development, Iowa State University, Ames, IA 50011, USA.

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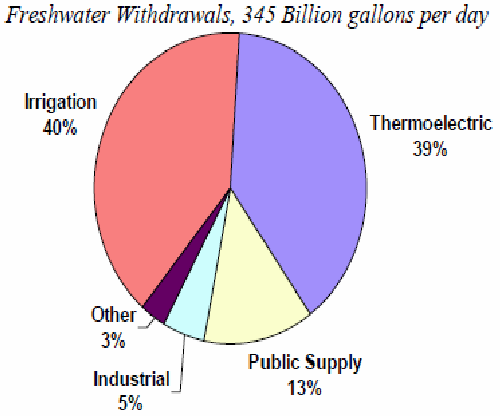
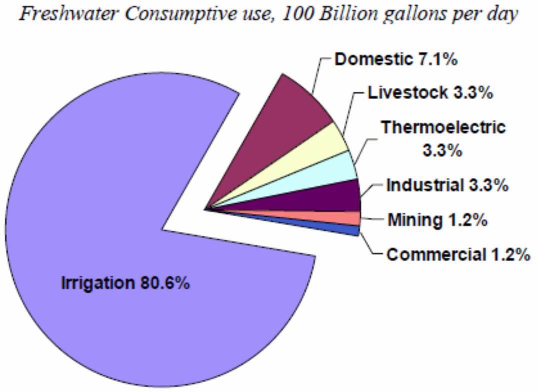
Water Demand & Quality



Freshwater Withdrawals, 345 Billion gallons per day

Figure 5-1. Estimated U.S. Freshwater Withdrawals by Sector, 2000 (USGS 2004)



Freshwater Consumptive use, 100 Billion gallons per day

Figure 5-2. Estimated Freshwater Consumption, 1995 (USGS 1998)

Hypoxia in the Northern Gulf of Mexico

An Update by the EPA Science Advisory Board

May 2000
National Science and Technology Council
Committee on Environment and Natural Resources

An Integrated Assessment

HYPOXIA

in the Northern Gulf of Mexico

Next-Generation Biofuels

- Issues of sustainability and environmental impacts have led to greater attention on second- or third-generation (“next-generation) biofuels
- These biofuels can be produced using a range of cellulosic and other non-conventional feedstocks (e.g., waste residues, dedicated crops, algae)
- Cellulosic biorefineries are also designed for optimal efficiencies

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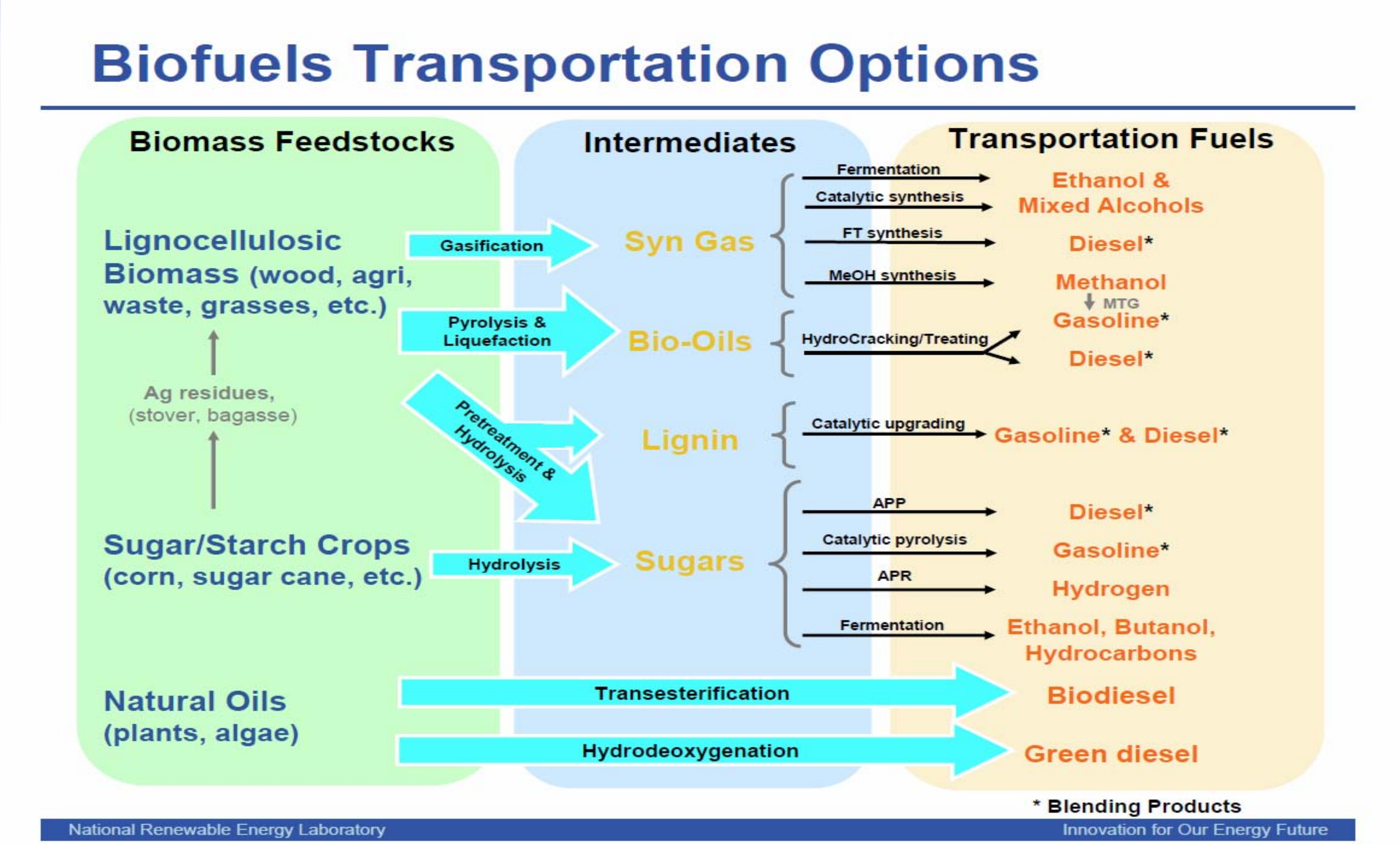
Next-Generation Biofuels *(cont.)*



Biofuels Transportation Options

Biomass Feedstocks

Intermediates

Transportation Fuels

Lignocellulosic Biomass (wood, agri, waste, grasses, etc.)

Ag residues, (stover, bagasse)

Sugar/Starch Crops (corn, sugar cane, etc.)

Natural Oils (plants, algae)

Gasification → **Syn Gas**
- Fermentation → Ethanol & Mixed Alcohols
- Catalytic synthesis → Ethanol & Mixed Alcohols
- FT synthesis → Diesel*
- MeOH synthesis → Methanol ↓ MTG Gasoline*

Pyrolysis & Liquefaction → **Bio-Oils**
- HydroCracking/Treating → Gasoline*, Diesel*

Pretreatment & Hydrolysis → **Lignin**
- Catalytic upgrading → Gasoline* & Diesel*

Pretreatment & Hydrolysis, Hydrolysis → **Sugars**
- APP → Diesel*
- Catalytic pyrolysis → Gasoline*
- APR → Hydrogen
- Fermentation → Ethanol, Butanol, Hydrocarbons

Transesterification → Biodiesel

Hydrodeoxygenation → Green diesel

* Blending Products

National Renewable Energy Laboratory

Innovation for Our Energy Future

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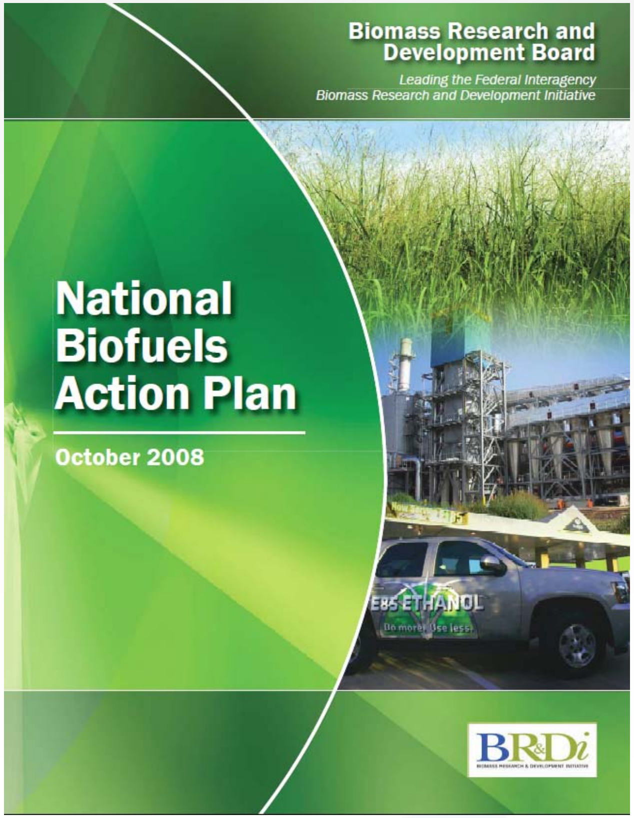
National Biofuels Action Plan

- Inter-Agency plan detailing the collaborative efforts of federal agencies to accelerate the development of a sustainable biofuels industry
- Developed in response to President Bush's stated "Twenty In Ten" goal in 2007 to cut U.S. gasoline consumption by 20% over the next 10 years
- Provides high-level overview of current and future federal activities and research needs



Biomass Research and Development Board

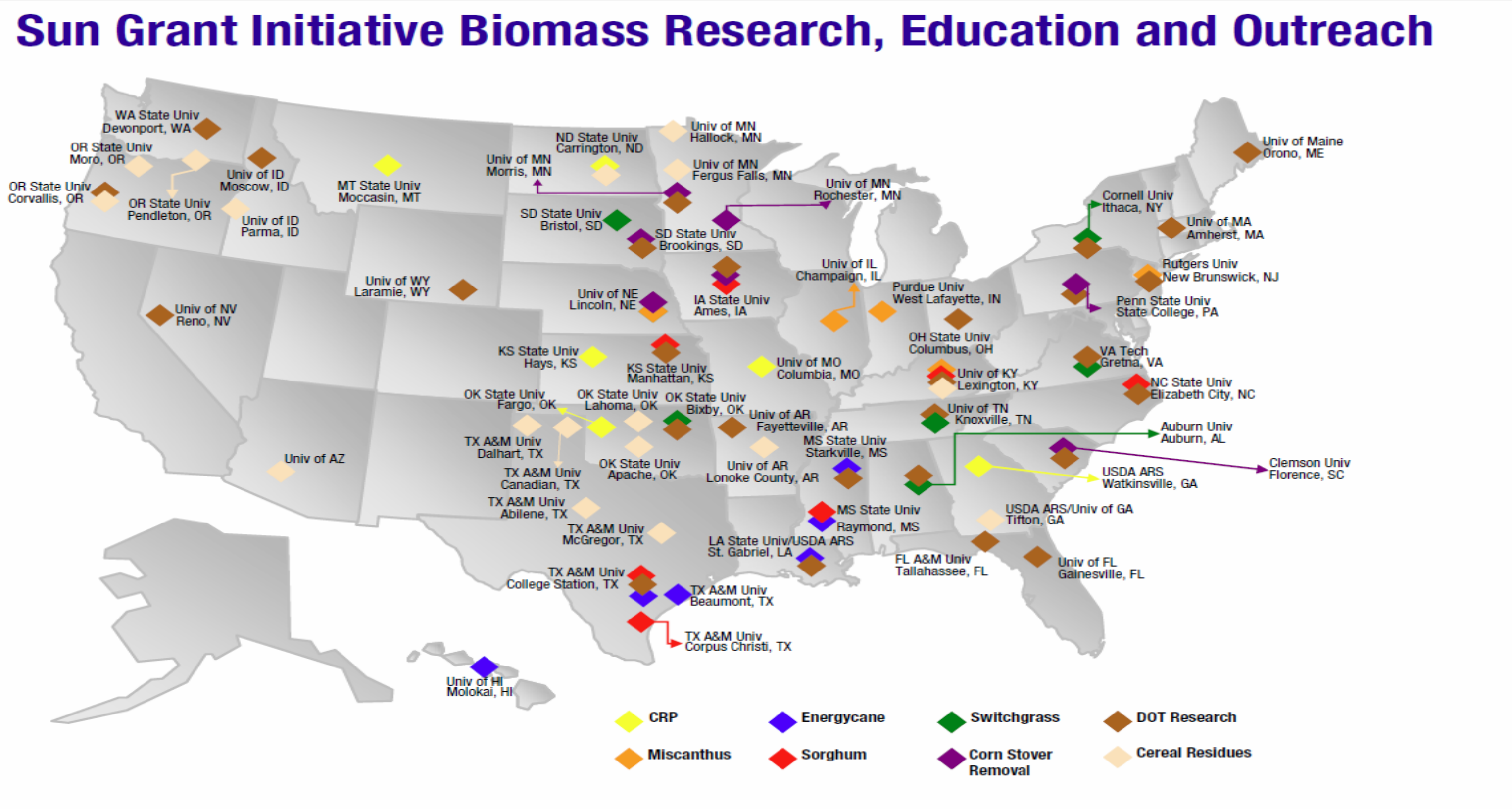
Leading the Federal Interagency Biomass Research and Development Initiative

National Biofuels Action Plan

October 2008

BR&Di

Feedstock Field Trials



Sun Grant Initiative Biomass Research, Education and Outreach

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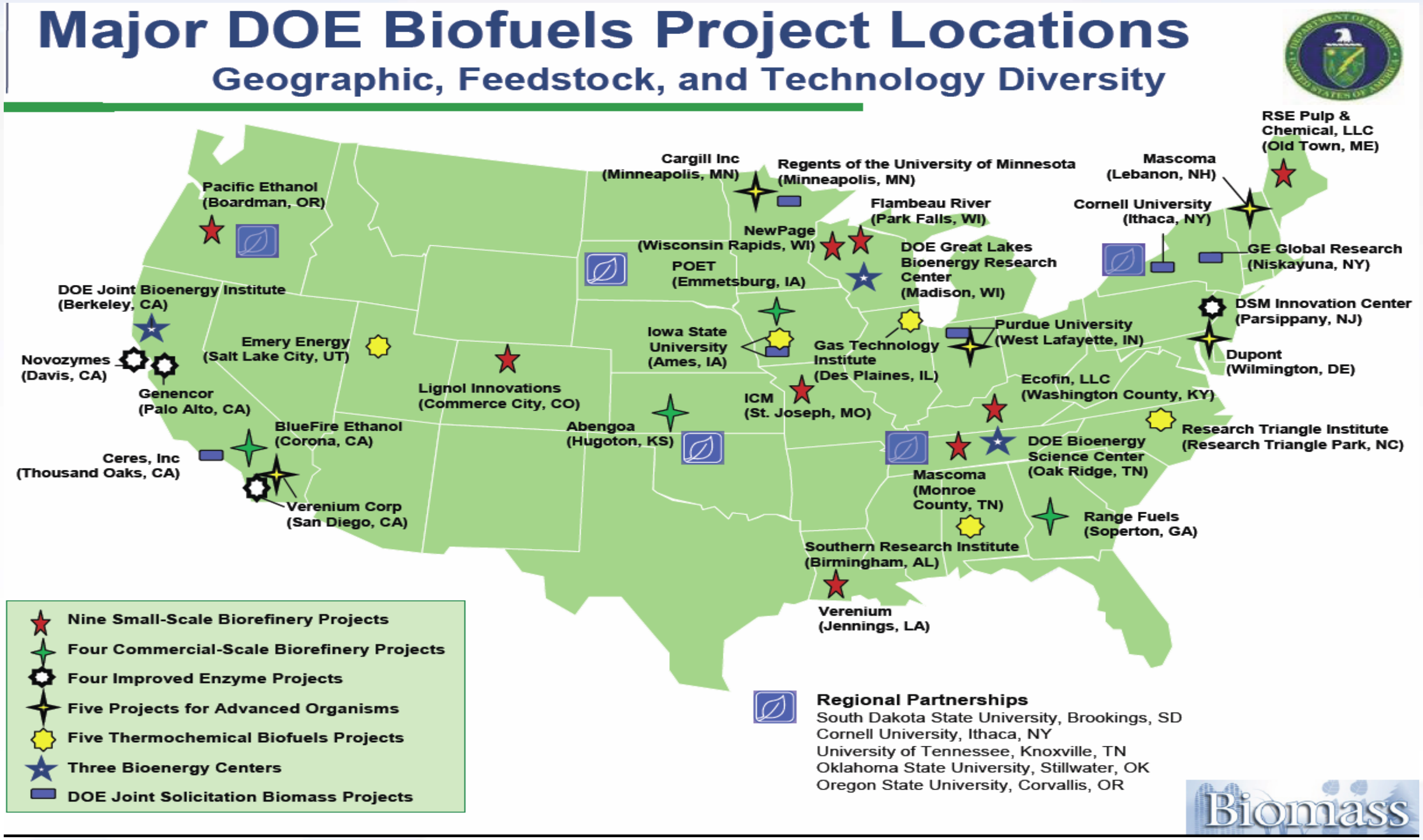
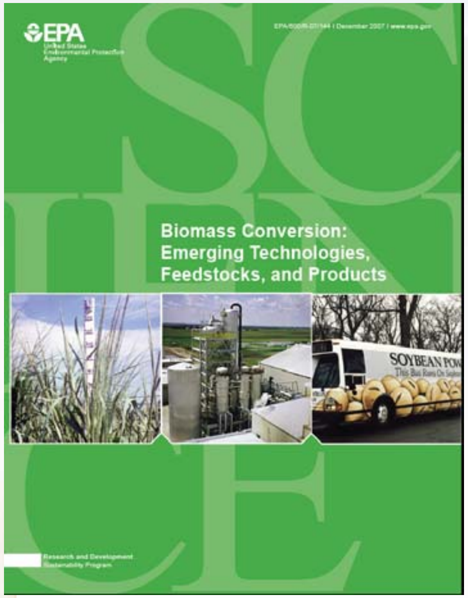
Biorefinery Projects



EPA Regulations & Activities

- Proposed revisions to the National Renewable Fuel Standard Program (RFS2)
- Participation in Biomass R&D Board (leading working groups on Sustainability and Environmental, Health, & Safety)
- Publications related to biomass conversion technologies and permitting of biofuels facilities
- Development of *Biofuels Strategy* and *Report to Congress* on environmental and resource conservation issues

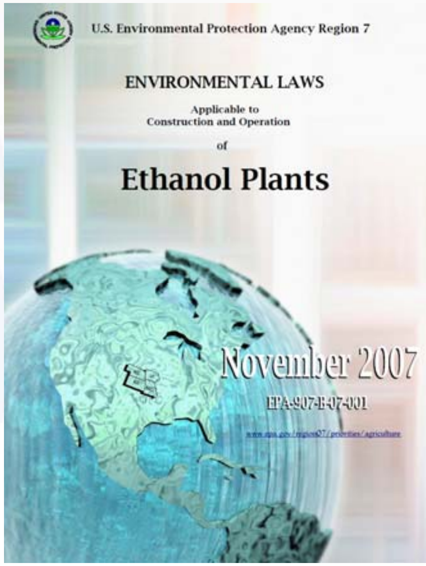


EPA
United States
Environmental Protection
Agency

EPA/600/R-07/144 | December 2007 | www.epa.gov

Biomass Conversion:
Emerging Technologies,
Feedstocks, and Products

Research and Development
Sustainability Program



U.S. Environmental Protection Agency Region 7

ENVIRONMENTAL LAWS

Applicable to
Construction and Operation
of

Ethanol Plants

November 2007

EPA-907-B-07-001

www.epa.gov/region07/priorities/agriculture

What’s Missing?

- Next-generation biofuels are believed to have the potential to avoid many of the environmental challenges associated with conventional biofuels
- However, few attempts to synthesize and document the current state-of-knowledge on how next-generation biofuels compare to conventional biofuels
- This information is needed to understand potential tradeoffs and better inform public policy

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Study Purpose

- Provide qualitative review of how next-generation biofuels will fare relative to conventional biofuels across range of factors
- Derive quantitative estimates using life-cycle assessment and systems engineering modeling tools
- Identify data gaps and research needs

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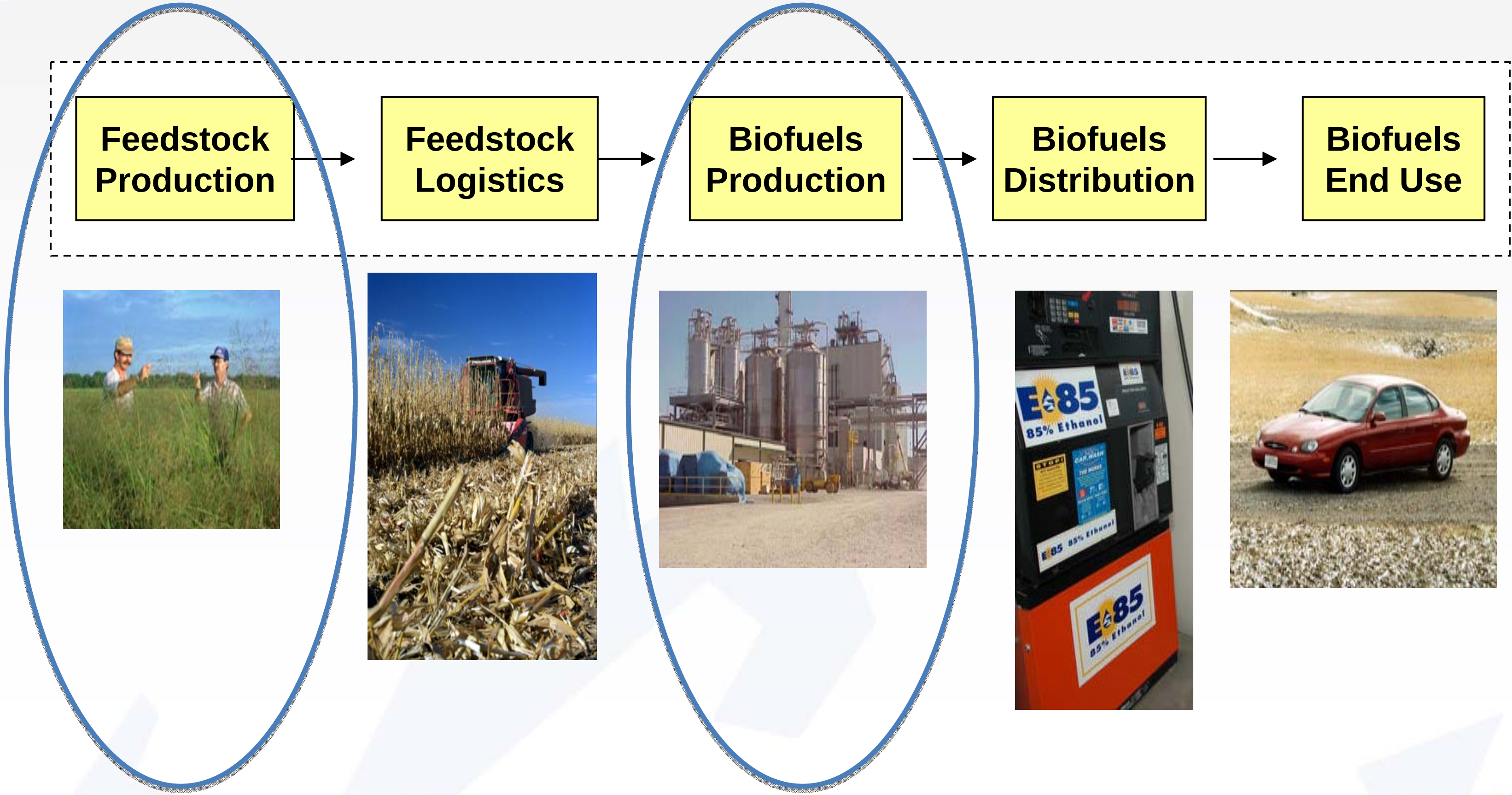
Biofuels Supply Chain



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

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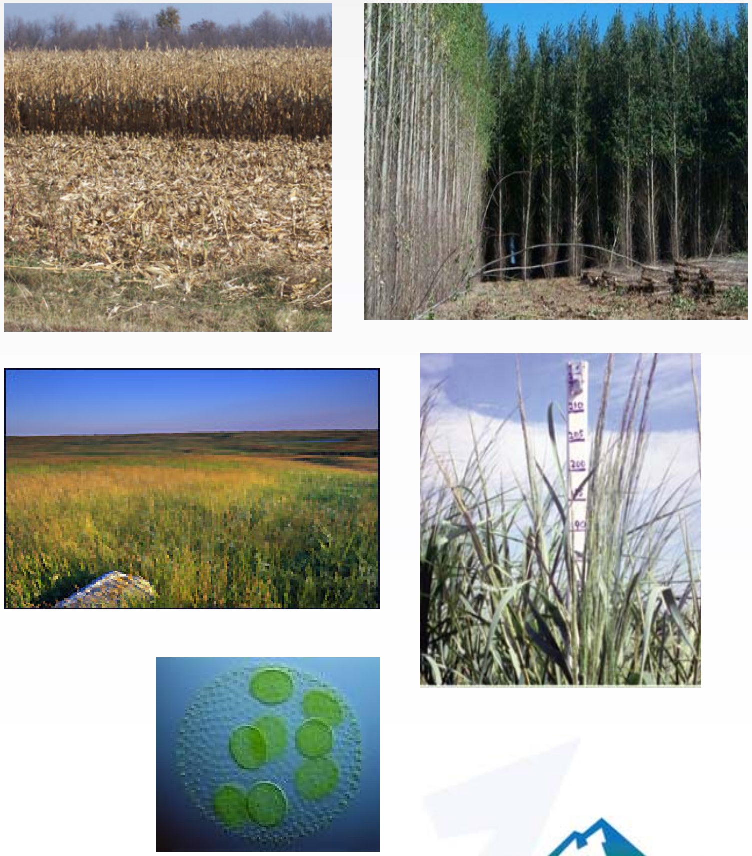
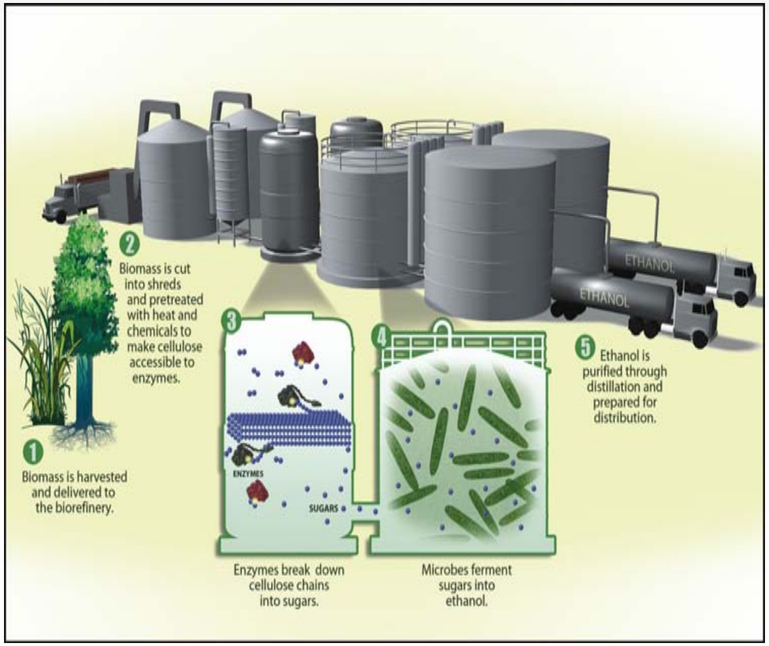
Next-Generation Feedstocks

- Municipal solid waste
- Forest residues and thinnings
- Annual crop residues
- Dedicated herbaceous perennial energy crops
- Short-rotation woody crops
- Microalgae



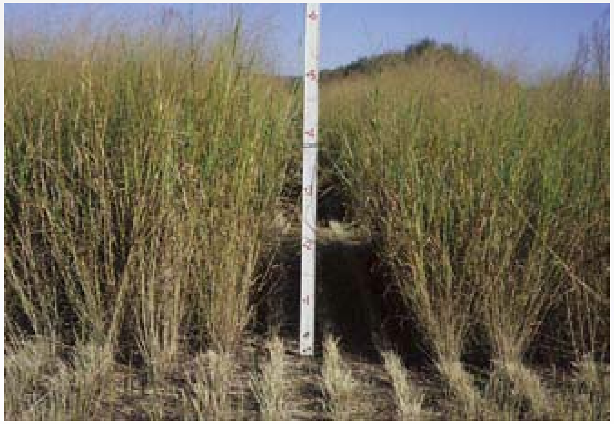
Cellulosic Ethanol Biorefineries

- Biochemical (enzymatic or acid hydrolysis) platform
  - Uses yeast or bacteria, isolated enzymes, or strong acids to break down cellulose into sugars
  - Fermentation and distillation processes similar to corn-grain ethanol
- Thermochemical (gasification) platform
  - Reacts feedstocks under conditions of limited oxygen and high temperature to create synthesis gas
  - Syngas is converted to ethanol via a catalyst after cleaning and conditioning



High-Level Review

- Reviewed published literature (e.g., peer-reviewed papers, federal government reports, technical presentations, workshop materials)
- Conducted interviews (e.g., federal government, national laboratories, Universities)
- Participated in meetings held by inter-agency Biomass R&D Board
- Visited feedstock field trials and cellulosic pilot and/or proposed commercial-scale biorefineries



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Comparative Modeling

- SimaPro life-cycle assessment (LCA) model used to assess environmental and sustainability metrics during feedstock production
- AspenPlus process engineering (mass-balance) model used to assess environmental and sustainability metrics during fuel conversion

SimaPro 7

Introduction into LCA

aspentech

Aspen Plus®

Process modeling tool for conceptual design, optimization, and performance monitoring of chemical processes

Aspen Plus has a proven track record of providing substantial economic benefits throughout the process engineering lifecycle, from conceptual design and engineering to production. It brings the power of process simulation to the engineering desktop, and delivers a unique combination of modeling technology and ease of use. *Aspen Plus* enables companies to rapidly design new processes and deliver new products to market faster.

Aspen Plus is a proven, industry-standard solution with over twenty years of use in the field. Customers have recognized and reported:

- $15 million per year in incremental profitability from process optimization
- $10 million per year in capital savings resulting from improved designs
- $1 million per year of reduced labor costs from improved conceptual engineering workflow

The Challenge: Improve Engineering Efficiency, Lower Overall Costs

Across the chemical process industries, companies are faced with global economic growth, dynamic market conditions, and competitive pressures to improve quality and reduce time to market. Companies must find innovative ways to reduce capital and operating costs and increase engineering efficiency so as to maximize plant performance and profitability.

The AspenTech Solution: Model the Chemical Process—Start to Finish

Fundamental to improving performance of the plant is an accurate representation of the basic processes. Companies need a solution that will enable them to develop that information and then build the models required to optimize enterprise performance. *Aspen Plus* provides the solution to meet this need, solving the critical engineering and operating problems that arise throughout the lifecycle of a chemical process.

Aspen Plus predicts process behavior using engineering relationships such as mass and energy balances, phase and chemical equilibrium, and reaction kinetics. With reliable thermodynamic data, realistic operating conditions, and the rigorous equipment models, engineers are able to simulate actual plant behavior. Applications include:

- Improving engineering productivity and reducing costs
- Ensuring accuracy and timeliness of engineering designs
- Providing engineering support to plant operations
- Optimizing designs for large-scale integrated chemical plants

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General Findings

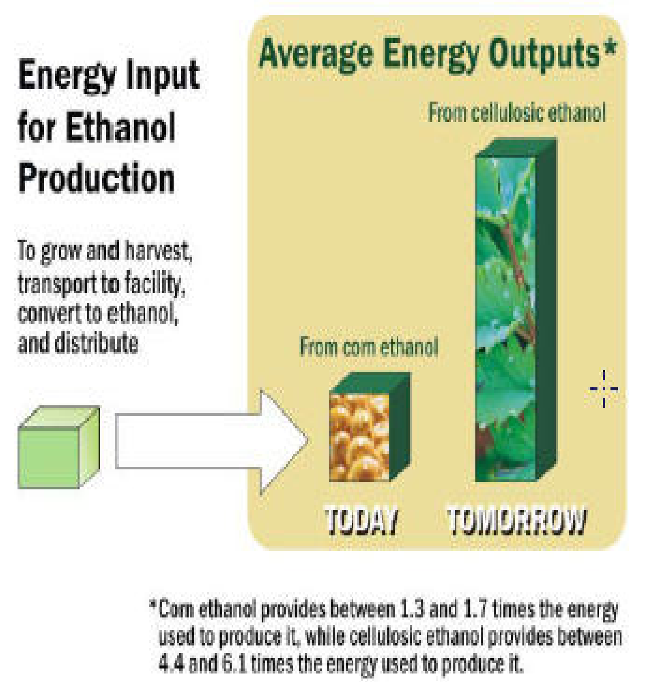
- Next-generation biofuels are expected to fare better on most (not all) factors evaluated compared to conventional biofuels
- However, there is significant uncertainty regarding how well next-generation biofuels will actually fare when produced on a commercial scale
- The magnitude of these differences may also vary significantly among feedstocks and technologies and will depend on many factors

Next-Generation Feedstocks: Why Fare Better?

- Fewer production inputs required
- Fewer GHG and air pollutant emissions
- Improved soil health and quality
- Fewer water demands and water quality impacts
- Less significant biodiversity and land-use changes

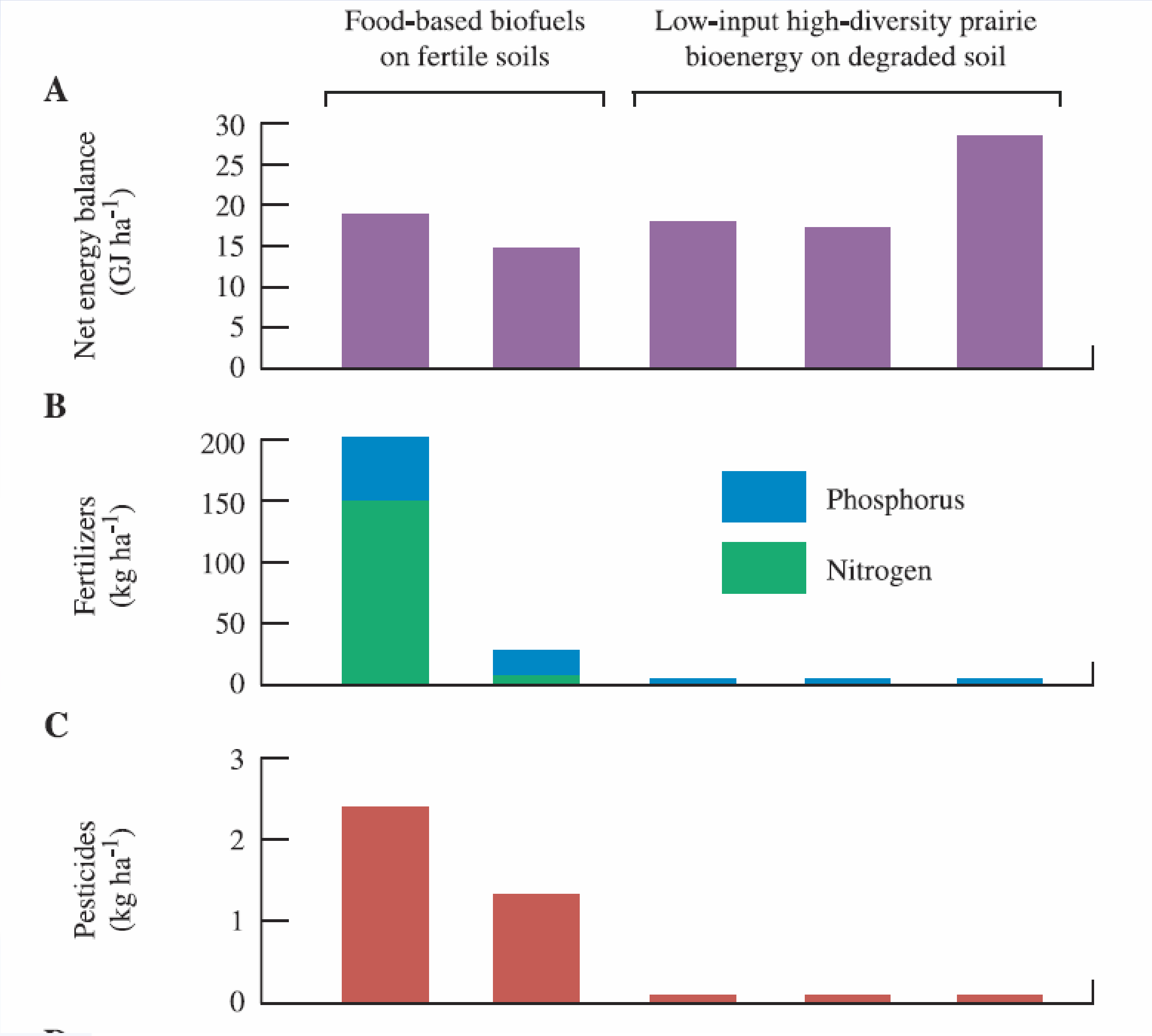
Production Inputs

- Expected to require fewer energy and chemical (pesticide, fertilizer) inputs during feedstock production
  - Production of farm or field inputs
  - Field preparation activities
  - Planting and establishment activities
  - Feedstock harvesting and collection
- Fewer inputs during early life-cycle stages results in fewer downstream impacts



*Corn ethanol provides between 1.3 and 1.7 times the energy used to produce it, while cellulosic ethanol provides between 4.4 and 6.1 times the energy used to produce it.

Net Energy Balance



Hill 2007 (adapted from Tillman et al. 2006)

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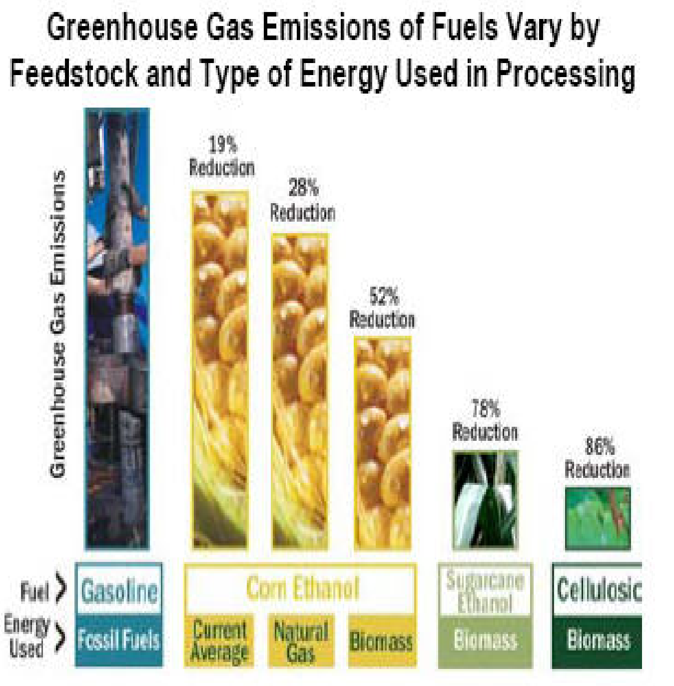
GHG & Air Pollutant Emissions

- Anticipated reductions in GHG and air pollutant emissions
  - Less significant land-use or conversion impacts
  - Greater carbon sequestration in soil, plant, and root systems
  - Fewer chemical inputs
  - Less energy-intensive management practices
- Potential avoided emissions from intentional burnings and wildfires



Greenhouse Gas Emissions of Fuels Vary by Feedstock and Type of Energy Used in Processing

Source: Wang et al, *Environmental Research Letters*, Vol. 2, 024001, May 22, 2007

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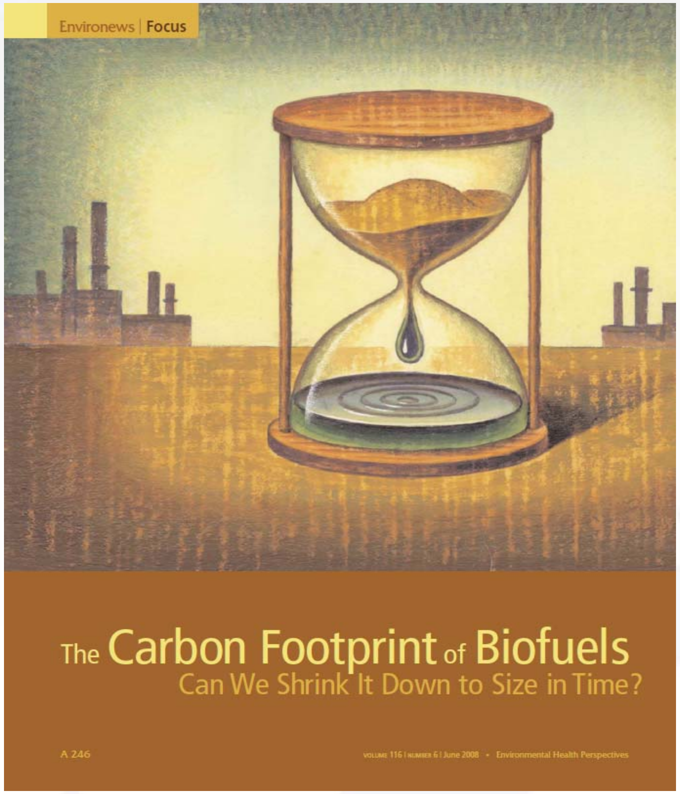
Carbon Impact of Biofuels


Environews | Focus

The Carbon Footprint of Biofuels

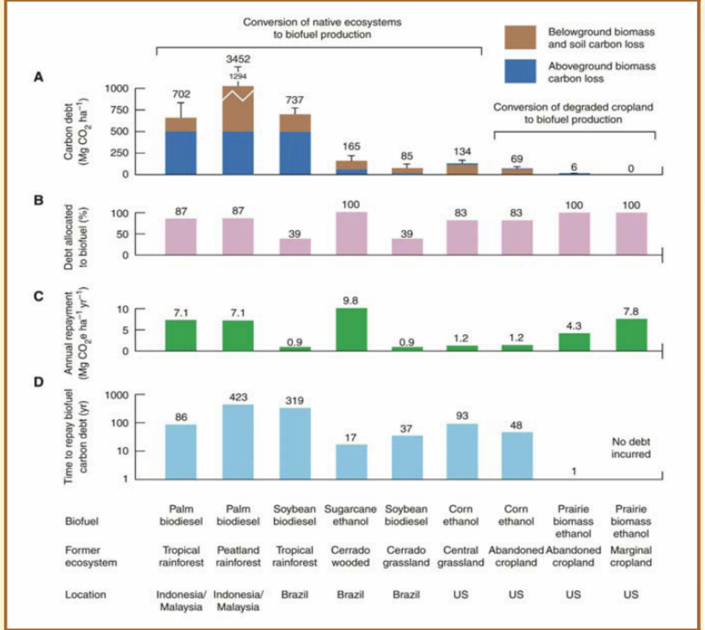
Can We Shrink It Down to Size in Time?

A 246

VOLUME 116 | NUMBER 6 | June 2008 • Environmental Health Perspectives

Cellulosic feedstocks offer the promise of biofuels that are nearly carbon neutral if grown on marginal lands; the feedstocks might even sequester carbon, instead of causing its release from the soil. But it's still up in the air as to whether cellulosic ethanol will become a commercial reality.

Carbon Impact of Nine Biofuel Scenarios



(A) Carbon debt, including CO_2 emissions from soils and aboveground and belowground biomass resulting from habitat conversion. (B) Proportion of total carbon debt allocated to biofuel production. (C) Annual life-cycle greenhouse gas reduction from biofuels, including displaced fossil fuels and soil carbon storage. (D) Number of years after conversion to biofuel production required for cumulative biofuel greenhouse gas reductions, relative to the fossil fuels they displace, to repay the biofuel carbon debt.

Source: From Fargione et al. Science 319:1235–1237 (2008). Reprinted with permission from AAAS.

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Soil Health & Quality

- Fewer adverse impacts on soil health and quality expected
  - No direct impacts to soil or less intensive management practices used (e.g., tillage, fertilization)
  - Enhanced soil organic carbon and reduced soil erosion rates
- Could improve soil quality if placed as buffer strips to reduce erosion and runoff from conventional crops

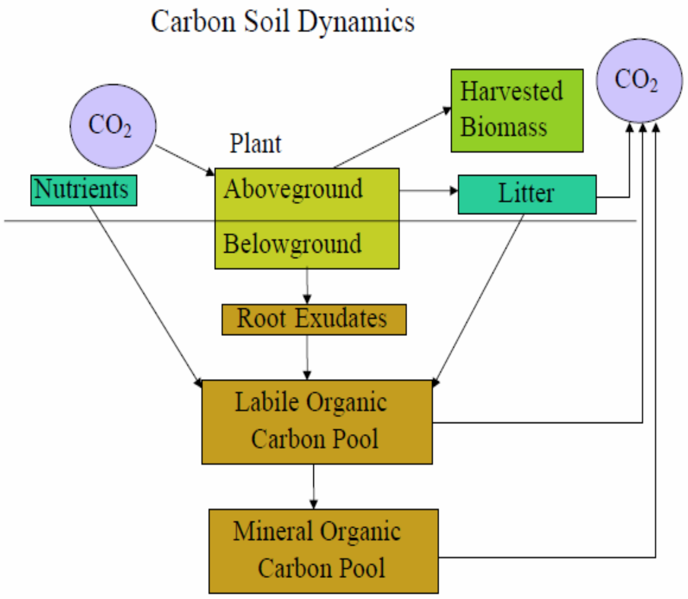

Figure 2 Soil Carbon Dynamics

Adress. 2002

Water Use & Quality

- Fewer fresh water demands expected
  - No direct water consumption or minimal irrigation required
  - Greater water efficiency and heat/drought tolerance
  - Wastewater used for irrigation
- Fewer adverse effects on water quality expected due tp less runoff and nitrogen loading to waterways

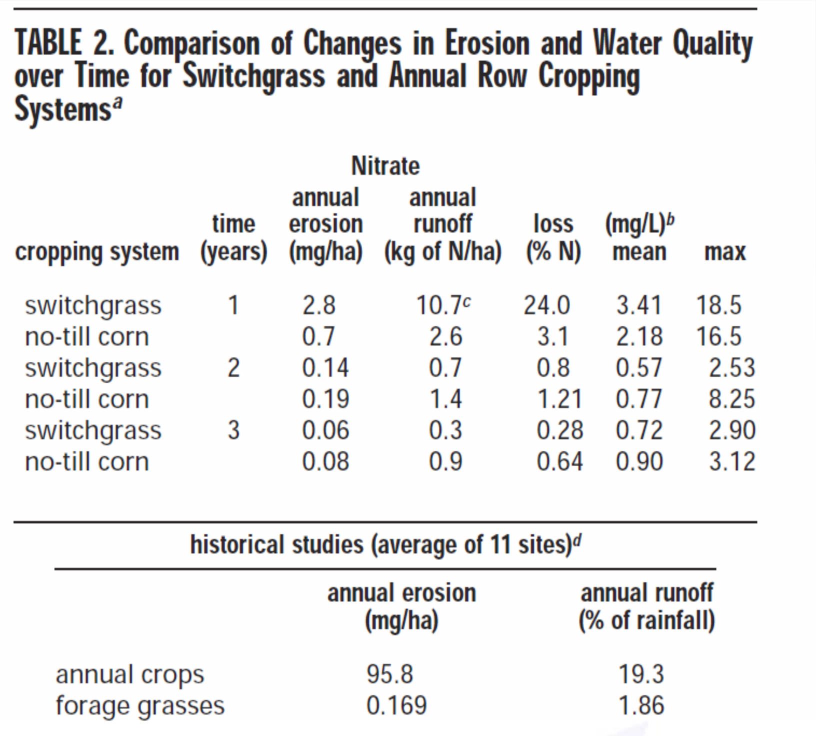

TABLE 2. Comparison of Changes in Erosion and Water Quality over Time for Switchgrass and Annual Row Cropping Systems[a]

			Nitrate			
cropping system	time (years)	annual erosion (mg/ha)	annual runoff (kg of N/ha)	loss (% N)	(mg/L)[b] mean	max
switchgrass	1	2.8	10.7[c]	24.0	3.41	18.5
no-till corn		0.7	2.6	3.1	2.18	16.5
switchgrass	2	0.14	0.7	0.8	0.57	2.53
no-till corn		0.19	1.4	1.21	0.77	8.25
switchgrass	3	0.06	0.3	0.28	0.72	2.90
no-till corn		0.08	0.9	0.64	0.90	3.12

historical studies (average of 11 sites)[d]

	annual erosion (mg/ha)	annual runoff (% of rainfall)
annual crops	95.8	19.3
forage grasses	0.169	1.86

McLaughlin et al. 2002

Displacing Conventional Crops With Switchgrass

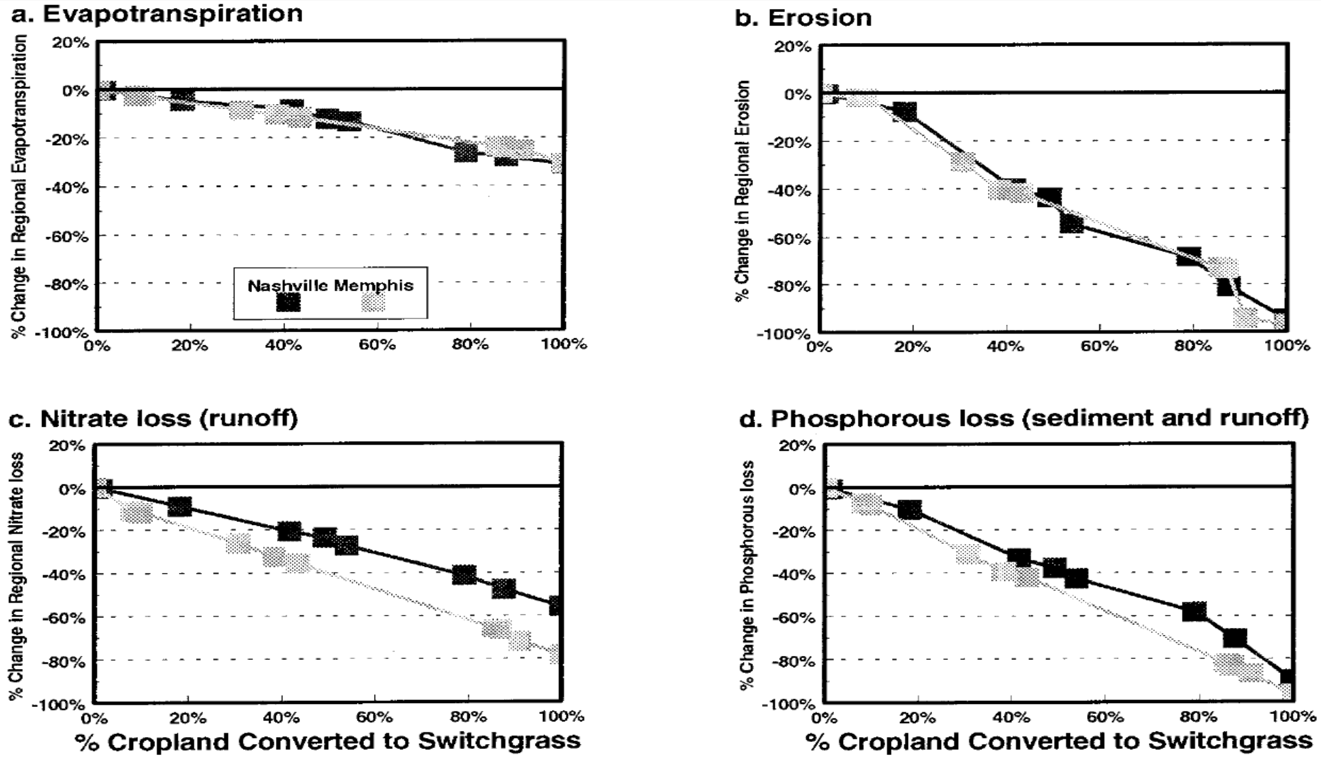

Figure 6. Regional changes in **(a)** evapotranspiration, **(b)** erosion, **(c)** nitrate loss in runoff, and **(d)** phosphorus loss (both sediment and runoff) with increasing adoption of switchgrass in the Memphis and Nashville regions.

Graham et al. 1996

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Biodiversity & Land-Use Changes

- Some feedstocks are anticipated to have few land-use changes or impacts
- However, impact of large-scale land-use changes on biodiversity and ecosystem services depends on many factors (e.g., land type, growing method)
- Some feedstocks may also have positive impacts, such as enhancing landscape diversity and providing new habitats

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Next-Generation Feedstocks: Could Fare Worse

- Produced on cultivated agricultural land
- Intensively managed as monocultures
- Best practices are not used
- New CO_2 inputs required
- Greater local or regional water demands
- Removed at unsustainable rates
- Affect biodiversity and existing habitats

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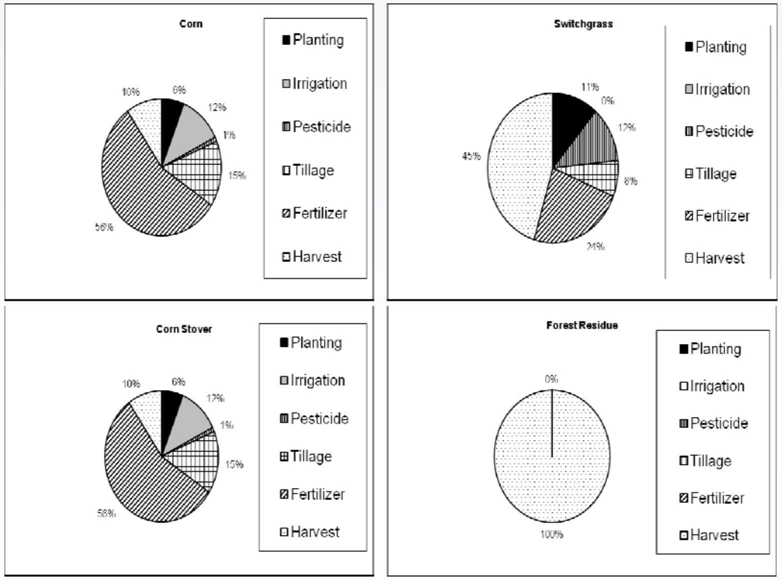
Life-Cycle Analysis Model

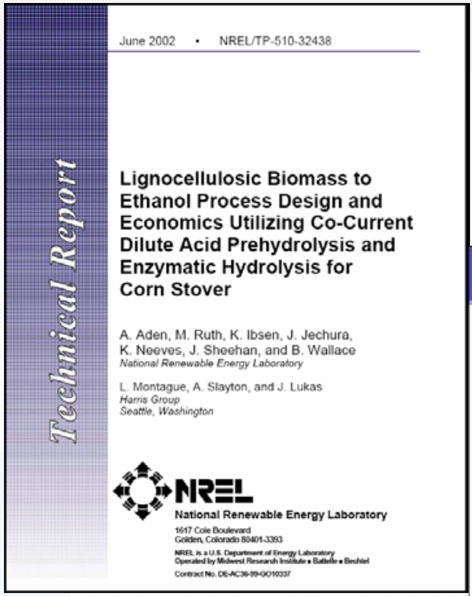
		% Change Relative to Corn Production (per Metric Ton)		
		Forest Residues	Switchgrass	Corn Stover
GHG Emissions	Carbon dioxide (CO_2)	-93	-90	-23
	Dinitrogen monoxide (N_2O)	-99	-56	-23
	Methane (CH_4)	-98	-83	-23
Air Pollutant Emissions	Carbon monoxide (CO)	-85	-89	-23
	Lead (Pb)	-87	-88	-23
	Nitrogen oxides (NOx)	-75	-86	-23
	Ozone (O_3)	-99	-89	-23
	Particulates < 2.5 μm ($PM_{2.5}$)	-94	-87	-23
	Particulates < 10 μm (PM_{10})	-90	-90	-23
	Sulfur dioxide (SO_2)	-90	-92	-23
Water Use	Groundwater	-100	-100	-23
Water Quality	Atrazine loadings[1]	-100	-99	-23
	Biological oxygen demand (BOD)	-85	-86	-23
	Chemical oxygen demand (COD)	-87	-86	-23
	Nitrate loadings	-100	-100	-23
	Phosphorous loadings	-100	-100	-23

Figure 1. Source Contribution for Carbon Dioxide (CO_2) Emissions During Feedstock Production



Cellulosic Ethanol Biorefineries: Why Fare Better?

- Fewer GHG and air pollutant emissions
- Fewer water demands
- Potentially fewer wastewater streams
- Potentially greater solid waste



June 2002 • NREL/TP-510-32438

Technical Report

Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover

A. Aden, M. Ruth, K. Ibsen, J. Jechura,
K. Neeves, J. Sheehan, and B. Wallace
National Renewable Energy Laboratory

L. Montague, A. Slayton, and J. Lukas
Harris Group
Seattle, Washington

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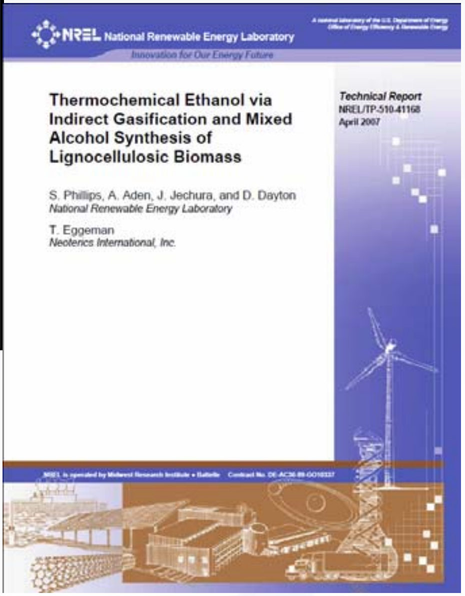

NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass

Technical Report
NREL/TP-510-41168
April 2007

S. Phillips, A. Aden, J. Jechura, and D. Dayton
National Renewable Energy Laboratory

T. Eggeman
Neoterics International, Inc.

GHG & Air Pollutant Emissions

- Biomass expected to be used as energy source rather than fossil fuels
  - Burn lignin residues (biochemical)
  - Divert a portion of syngas (thermochemical)
- Do not expect significant differences in emissions from conversion operations
  - Scrubbing units
  - Flue gas

Photo courtesy of Industrial Innovations

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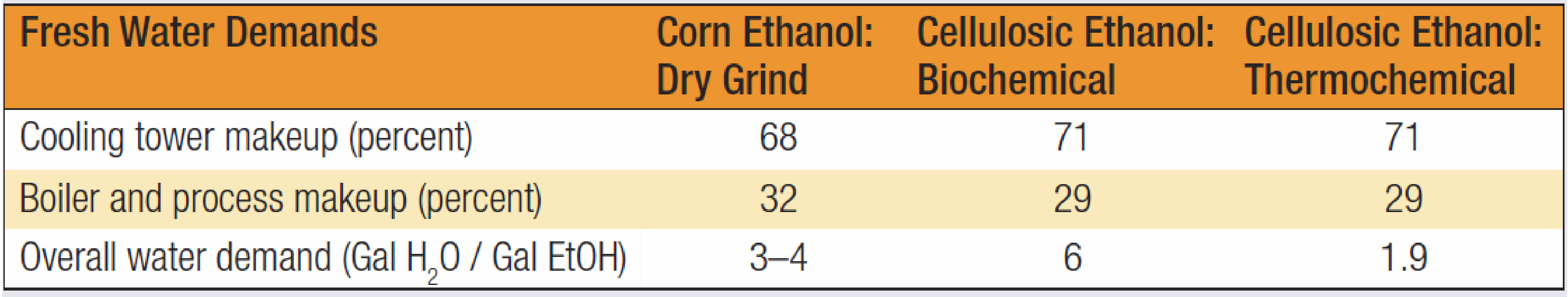
Water Use

- Biorefineries require a significant amount of water to convert biomass to fuel (processing and cooling)
- Thermochemical platform optimized for water use by using forced-air cooling in place of water (biochemical platform has not yet been optimized, but underway)

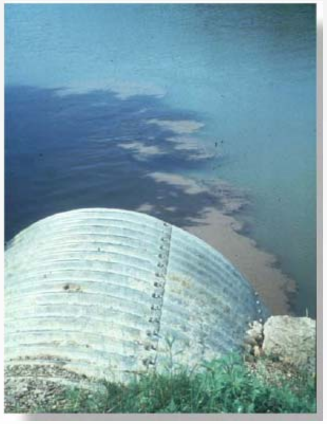


Fresh Water Demands	Corn Ethanol: Dry Grind	Cellulosic Ethanol: Biochemical	Cellulosic Ethanol: Thermochemical
Cooling tower makeup (percent)	68	71	71
Boiler and process makeup (percent)	32	29	29
Overall water demand (Gal H_2O / Gal EtOH)	3–4	6	1.9

Aden 2007

Wastewater & Solid Waste

- Designed for zero wastewater discharge (expected to have virtually all process water recycled onsite)
- However, solid waste is expected to be generated from several sources
  - Boiler
  - Conditioning tanks



EPA Region 7 Photo

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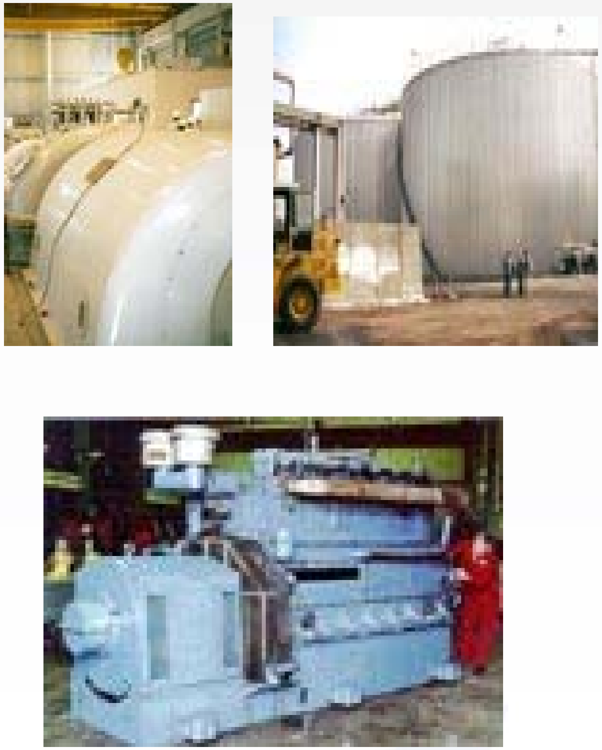
Next-Generation Conversion Platforms: Could Fare Worse

- Biomass is not sufficient source of energy
- Pioneer plants do not operate at optimal levels (e.g., process water needed to scrub tar)
- Off-site wastewater treatment needed (e.g., scrubbing water)
- Lime is used as conditioning agent (gypsum waste)



Process Engineering Model

		Model Estimates (Kg per Liter Ethanol)*					
		Forest Residues		Switchgrass		Corn Stover	
		Biochemical	Thermochemical	Biochemical	Thermochemical	Biochemical	Thermochemical
GHG Emissions	Carbon dioxide (CO_2)[1]	0.75	0.85	0.75	0.85	0.75	0.82
	Carbon dioxide (CO_2)[2]	2.74	3.50	2.89	3.68	2.11	3.63
	Methane (CH_4)[2]	0.00003	0.00	0.0001	0.00	0.0001	0.00
Air Pollutant Emissions	Carbon monoxide (CO)[2]	0.002	0.00	0.003	0.00	0.002	0.00
	Nitrogen oxides (NOx)[2]	0.002	0.005	0.003	0.027	0.002	0.033
	Sulfur dioxide (SO_2)[2]	0.003	0.0003	0.004	0.003	0.003	0.002
Water Use	Fresh (Make-Up)	7.20	2.56	8.61	2.17	6.16	2.67
Waste Water	Treated (Off-Site)	0.00	0.03	0.00	0.03	0.00	0.03
Solid Waste	Ash/Sand	0.03	0.03	0.16	0.37	0.14	0.05
	Gypsum Waste	0.23	0.00	0.28	0.00	0.24	0.00
	Sulfur	0.00	0.0002	0.00	0.002	0.00	0.001

[1] Emissions from scrubbed CO_2 vent

[2] Emissions from flue gas

*Kg per ton (dry) assuming 2000 dry metric tonnes per day and 15% moisture content of feedstock

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Data Gaps & Research Needs

- Impacts of major land-use changes are largely unknown
- Ultimate human health and environmental impacts are not quantified
- Methods and analytical approaches have not been standardized
- There are no universally accepted metrics or sustainability indicators
- Lack of analytical and decision-support tools to ensure optimal decisions

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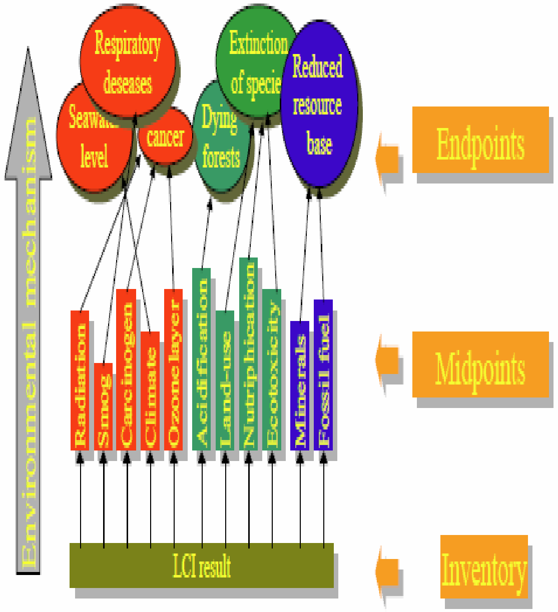
Impacts of Major Land-Use Changes

- Depending on feedstock, increased biofuels production could result in significant changes in current land use
- Little is known about how major land-use changes will affect the environment, human health, or social well-being
- The magnitude of these impacts will depend on many factors, including existing land type (cultivated vs. uncultivated land)

Human Health & Environmental Impacts

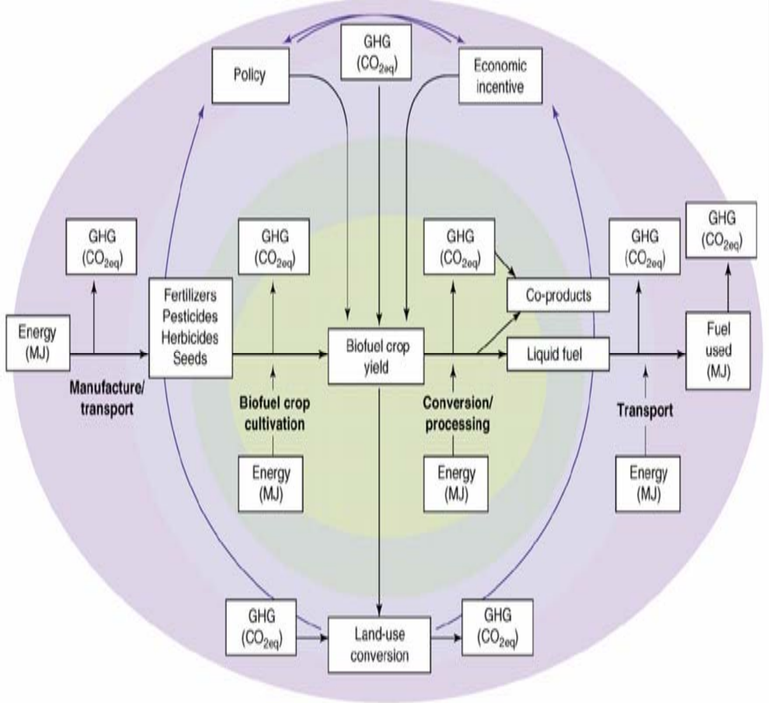
- Like any technology, increased biofuels production could result in significant adverse impacts to human health and/or the environment
- Much of the research and analyses to date have focused on quantifying releases rather than actual impacts
- Existing impact assessment life-cycle tools may not address ultimate outcomes of interest



SimaPro 7. 2008. Introduction to LCA.. Product Ecology Consultants.

Standardized Methods & Assumptions

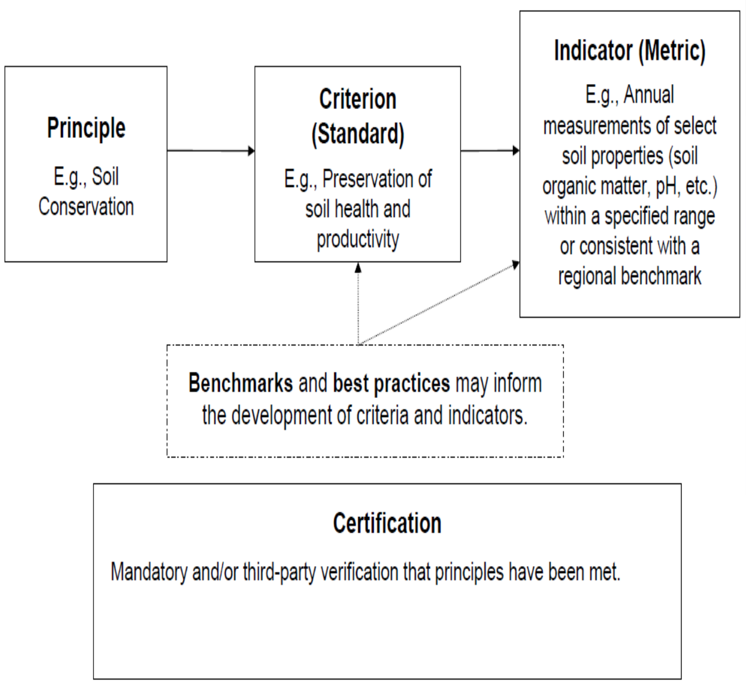
- Assessing the life-cycle impacts of biofuels requires consideration of many factors
- There is currently no standardized approach for conducting such assessments and assumptions vary widely
- Choice of system boundary, allocation method, and other factors can have a significant influence on the results of a life-cycle assessment



Davis et al. 2009. Life-cycle analysis and the ecology of biofuels. Trends in Plant Science. In Press.c

Universal Metrics & Indicators

- Appropriate benchmarks, metrics, and indicators are needed to ensure sustainable biofuels production
- There are currently no universally accepted metrics and data and modeling limitations hinder efforts to identify, measure, and evaluate indicators
- This could have global consequences (e.g., trade guidelines, certification schemes)



Principle

E.g., Soil Conservation

Criterion (Standard)

E.g., Preservation of soil health and productivity

Indicator (Metric)

E.g., Annual measurements of select soil properties (soil organic matter, pH, etc.) within a specified range or consistent with a regional benchmark

Benchmarks and **best practices** may inform the development of criteria and indicators.

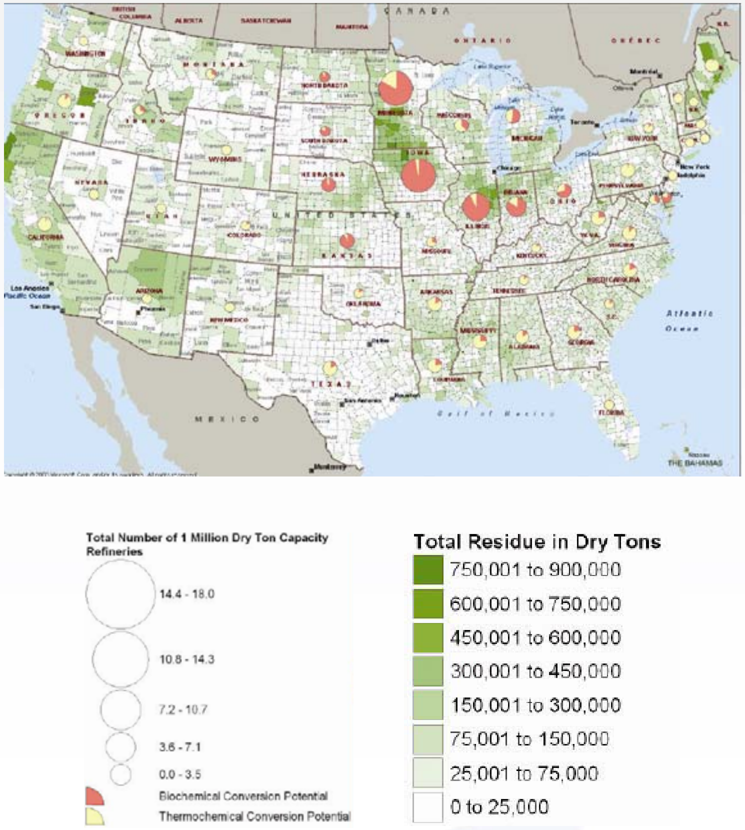
Certification

Mandatory and/or third-party verification that principles have been met.

Hecht., A. 2009. Metrics models and tools for evaluating the impacts Of biofuels. NAS Workshop.

Decision-Support Tools

- Environmental and sustainability trade-offs associated with the production of biofuels are inevitable
- A consistent framework that explicitly considers such trade-offs and other unintended consequences is needed
- Analytical tools capable of identifying, quantifying, and weighting uncertainties and potential trade-offs can help inform decisionmakers about which biofuels to produce where and how



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Conclusions

- There continues to be significant interest in the expansion of biofuels and a wealth of information exists on different aspects of the biofuels supply chain
- However, many uncertainties and data gaps remain, particularly with respect to the environmental and health impacts and sustainability of biofuels
- Continued research will be necessary to ensure optimal technology, management, and policy decisions at relevant spatial and temporal scales

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Published Paper

Williams, P.R.D., Inman, D., Aden, A., and Heath, G.A. 2009. Environmental and sustainability factors associated with next-generation biofuels in the U.S.: what do we really know? *Environmental Science & Technology*. 43:4763-4775.

Critical Review

Environmental and Sustainability Factors Associated With Next-Generation Biofuels in the U.S.: What Do We Really Know?

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ANDY ADEN,[‡] AND GARVIN A. HEATH[§]
E Risk Sciences, LLP, 4647 Carter Trail, Boulder, Colorado 80301, National BioEnergy Center, National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, Colorado, and Strategic Energy Analysis Center, National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, Colorado

Received January 23, 2009. Revised manuscript received April 26, 2009. Accepted May 6, 2009.

In this paper, we assess what is known or anticipated about environmental and sustainability factors associated with next-generation biofuels relative to the primary conventional biofuels (i.e., corn grain-based ethanol and soybean-based diesel) in the United States during feedstock production and conversion processes. Factors considered include greenhouse (GHG) emissions, air pollutant emissions, soil health and quality, water use and water quality, wastewater and solid waste streams, and biodiversity and land-use changes. Based on our review of the available literature, we find that the production of next-generation feedstocks in the U.S. (e.g., municipal solid waste, forest residues, dedicated energy crops, microalgae) are expected to fare better than corn-grain or soybean production on most of these factors, although the magnitude of these differences may vary significantly among feedstocks. Ethanol produced using a biochemical or thermochemical conversion platform is expected to result in fewer GHG and air pollutant emissions, but to have similar or potentially greater water demands and solid waste streams than conventional ethanol biorefineries in the U.S. However, these conversion-related differences are likely to be small, particularly relative to those associated with feedstock production. Modeling performed for illustrative purposes and to allow for standardized quantitative comparisons across feedstocks and conversion technologies generally confirms the findings from the literature. Despite current expectations, significant uncertainty remains regarding how well next-generation biofuels will fare on different environmental and sustainability factors when produced on a commercial scale in the U.S. Additional research is needed in several broad areas including quantifying impacts, designing standardized metrics and approaches, and developing decision-support tools to identify and quantify environmental trade-offs and ensure sustainable biofuels production.

Introduction

Modern liquid biofuels are promoted in the United States (U.S.) as a means of achieving national energy independence and security and reducing greenhouse gas (GHG) emissions (*1–5*). First-generation (i.e., conventional) biofuels in the U.S. are produced primarily from major commercial crops such as corn (*Zea mays, L.*)-grain ethanol and soybean (*Glycine mix, L.*) biodiesel (*6, 7*). Under the U.S. Energy and Independence Security Act of 2007, conventional biofuel production is permitted to increase through 2015 up to the 15 billion gallon per year cap set on corn-grain ethanol (*4*). However, issues of sustainability and environmental impacts have been raised in response to the wide-scale production and use of conventional biofuels. For example, traditional intensive corn-grain and soybean production practices are associated with high rates of chemical (e.g., fertilizer, pesticide) inputs, extensive water consumption in some regions, and many deleterious environmental effects such as soil erosion, surface water pollution, air pollution, and biodiversity losses (*8–13*). Furthermore, recent studies suggest that increased biofuel production, particularly conventional biofuels, could result in a substantial "carbon debt" because the quantity of carbon dioxide (CO_2) released from direct and indirect land-use changes will be far greater than the GHG reductions from the displacement of fossil fuels (*14, 15*). Although some have been critical of these studies (*16, 17*), and advances in agronomy and biofuel conversion efficiencies have been noted (*12, 18, 19*), the expansion of conventional annual crops for biofuels may still have negative long-term environmental consequences unless more sustainable practices are employed (*10, 20*).

The desire for more diverse and sustainable fuel sources has led to greater attention being focused in the U.S. on second- and third-generation (i.e., next-generation) liquid biofuels which are produced through a variety of feedstocks and conversion technologies (*7, 21–25*). Although the literature suggests that next-generation biofuels have the potential to avoid many of the environmental challenges that face conventional biofuels (*9, 10, 15, 26–28*), few attempts have been made to synthesize and document the current state-of-knowledge on how the production of next-generation biofuels compares to conventional biofuels. The purpose of this paper is 2-fold: (1) qualitatively summarize the literature in regard to what is known or anticipated about environ-

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[†] E Risk Sciences, LLP.
[‡] National BioEnergy Center.
[§] Strategic Energy Analysis Center.

10.1021/es900250d CCC: $40.75

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Useful Websites

- http://www1.eere.energy.gov/biomass/
- http://www.epa.gov/OMS/renewablefuels/
- http://riley.nal.usda.gov/nal_display/index.php?info_center=8&tax_level=3&tax_subject=6&topic_id=1052&level3_id=6599&level4_id=0&level5_id=0&placement_default=0
- http://bioweb.sungrant.org/About
- http://www.nrel.gov/learning/re_biofuels.html

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QUESTIONS?