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The James A. Baker III Institute for Public Policy of Rice University

in conjunction with

Rice University's Department of Chemical and Biomolecular Engineering,
Department of Civil and Environmental Engineering,
& The Energy and Environmental Systems Institute

Biomass to Chemicals and Fuels:
Science, Technology and Public Policy

Conference Report

January 2008

BIOMASS TO CHEMICALS AND FUELS: SCIENCE, TECHNOLOGY AND PUBLIC POLICY

CONFERENCE REPORT

JANUARY 2008

CONFERENCE SPONSORED BY
JAMES A. BAKER III INSTITUTE FOR PUBLIC POLICY
IN CONJUNCTION WITH
THE RICE UNIVERSITY DEPARTMENT OF CHEMICAL AND BIOMOLECULAR ENGINEERING
THE RICE UNIVERSITY DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
AND THE ENERGY & ENVIRONMENTAL SYSTEMS INSTITUTE OF RICE UNIVERSITY

THIS PAPER WAS WRITTEN BY A RESEARCHER (OR RESEARCHERS) WHO PARTICIPATED IN A BAKER INSTITUTE RESEARCH PROJECT. WHEREVER FEASIBLE, THIS PAPER HAS BEEN REVIEWED BY OUTSIDE EXPERTS BEFORE RELEASE. HOWEVER, THE RESEARCH AND THE VIEWS EXPRESSED WITHIN ARE THOSE OF THE INDIVIDUAL RESEARCHER(S) AND DO NOT NECESSARILY REPRESENT THE VIEWS OF THE JAMES A. BAKER III INSTITUTE FOR PUBLIC POLICY.

THE RICE ENERGY PROGRAM

The Rice Energy Program (REP) is a multi-disciplinary program that includes activities addressing energy science and technology policy and research on emerging energy technologies, environmental implications of energy production and use, and sustainable strategies for fulfilling the world's energy needs. Building on the highly successful Energy Forum created by the James A. Baker III Institute for Public Policy, the Rice Energy Program is supported by both the Baker Institute and the Energy & Environmental Systems Institute (EESI).

Since its founding in 1993, the James A. Baker III Institute for Public Policy has become a leading institution advancing effective foreign and domestic policy. One of the hallmarks of the Institute's early years has been its independent research program on energy issues. The mission of the Energy Forum is to promote the development of informed and realistic public policy choices in the energy area by educating policy makers and the public about important trends—both regional and global—that shape the nature of global energy markets and influence the quantity and security of vital supplies needed to fuel world economic growth and prosperity.

Drawing on Rice University's interdisciplinary expertise in environmental engineering, energy sustainability, economics, political science, history, geology, nanoscience, and anthropology, the Baker Institute Energy Forum has published 16 major studies on energy policy since its inception in 1996. Topics have included the political, social, and cultural trends in the Persian Gulf, Caspian Basin, and Russia; the future energy needs of China, Japan, and Latin America; oil geopolitics, energy security, energy industry deregulation, emerging energy technologies, and U.S. energy policy.

The interdisciplinary nature of the Energy Forum has lent itself to close collaboration with the Environmental & Energy Systems Institute (EESI) which promotes education, research, and community service activities at Rice in the areas of environment and energy. The Institute includes faculty and students in the Schools of Social Sciences, Engineering, Natural Sciences, Humanities, Architecture, and Management. EESI fosters partnerships between academia, business, governments, nongovernmental organizations and community groups to help meet society's needs for sustainable energy, environmental protection, economic development, and public health and safety.

Several centers at Rice University operate under the auspices of EESI, including the Center for Biological & Environmental Nanotechnology (CBEN),and the Center for the Study of Environment & Society (CSES).

The Rice Energy Program promotes collaborative, multi-disciplinary research to address global energy issues. The program currently supports projects in 13 departments and 5 centers in the areas of nanotechnology and energy, carbon capture and sequestration, biofuels and gas hydrates.

THE FUNDAMENTALS OF A SUSTAINABLE U.S. BIOFUELS POLICY

This study is sponsored by Chevron Technology Ventures

The Baker Institute Energy Forum and Rice University's Department of Civil and Environmental Engineering (CEVE) have embarked on a two-year project examining the efficacy and impact of current U.S. biofuels policy. This study is entitled *Fundamentals of a Sustainable U.S. Biofuels Policy*.

In his 2007 State of the Union Address, President George W. Bush championed energy alternatives and emphasized the potential of biomass-derived fuels to fulfill a greater share of our nation's transportation fuel needs. Biofuels, as an alternative to traditional gasoline fuel, can contribute to reducing dependence on foreign oil.

However, successful implementation of a sustainable biofuels program in the United States will require careful analysis of the potential strengths and weaknesses of the currently proposed U.S. policy. Corporate leaders are also in need of more complete data in assessing expanded industry participation in the biofuels arena. More policy research is necessary to identify necessary steps to avoid unintended, negative impacts on sustainable development and the environment, including deleterious impacts on domestic agricultural and food systems, surface and ground water, and overall air quality in the United States. A permanent transition to an effective national biofuels program will also require greater planning to ensure efficient production and transportation logistics, to safeguard fuel standardization and reliability, and to manage input crop competition.

This *Fundamentals of a Sustainable U.S. Biofuels Policy* program aims to investigate the current menu of policies under discussion for broad expansion of biofuels into the U.S. fuel system to 20% and beyond and evaluate the holistic analysis that is needed to develop effective and sustainable implementation to changes in our transportation fuel sector.

ACKNOWLEDGEMENTS

The Energy Forum of the James A. Baker III Institute for Public Policy would like to thank Chevron Technology Ventures and the sponsors of the Baker Institute Energy Forum for their generous support towards this program. The Energy Forum further acknowledges contributions by presenters at the conference on "Biomass to Chemicals and Fuels: Science, Technology and Public Policy."

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ORGANIZING PARTNERS

JAMES A. BAKER III INSTITUTE FOR PUBLIC POLICY

The mission of the Baker Institute is to bridge the gap between the theory and practice of public policy by drawing together experts from academia, government, media, business, and non-governmental organizations in a joint effort to understand and address the underlying forces shaping our world. In the process, it is hoped that the perspectives of all those involved in the formulation and criticism of public policy will be broadened and enhanced, bringing a fresh, informed, and incisive voice to our national debate.

The Baker Institute is an integral part of Rice University, one of the nation's most distinguished institutions of higher education. Rice University's long tradition of public service and academic excellence makes it an ideal location for the kind of intellectual innovation that is required in a world of breathtaking change. Rice faculty and student body play an important role in its research programs and public events. The Honorable James A. Baker, III, the 61st Secretary of State and 67th Secretary of Treasury, serves as the institute's Honorary Chair.

RICE UNIVERSITY DEPARTMENT OF CHEMICAL AND BIOMOLECULAR ENGINEERING

The mission of the Department of CBE is to successfully translate scientific advances into new cost-effective products and processes. The chemical and biomolecular engineer of the future will need a broad education that combines solid grounding on science and engineering fundamentals, with knowledge of advanced computational and experimental techniques, and with interdisciplinary skills that extend from chemistry, biology and materials science to computer science, systems modeling and environmental engineering. This challenge shapes the research and educational missions of our department as it strives to maintain outstanding undergraduate and graduate educational programs so that students will be prepared to assume leadership roles in industry, academia, law, business, medicine and government, to conduct basic and applied research of the highest quality emphasizing interdisciplinary collaboration and the development of partnerships involving academia, industry and government, and to serve as an educational and technological resource for the professional and scientific communities at the local, national, and international levels.

RICE UNIVERSITY DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

The mission of the Department of CEE is to prepare leaders educated in civil and environmental engineering to deal with present and future societal problems - with emphasis on environmental engineering, hydrology and water resources, structural engineering and mechanics, and urban infrastructure and management. CEE is responsible for preparing students to deal with the major engineering challenges of the future in a sustainable manner and to assess the impacts of engineering decisions in global, ethical, and societal contexts. More specifically, we seek to educate undergraduates across the entire campus in a science and technology- based curriculum in civil and environmental engineering, to sustain a highly selective graduate program of collaborative and distinguished scholarly research and practice, and to contribute locally, nationally, and internationally to the advancement and dissemination of knowledge and the quality of life through scholarly research, to apply this research in collaboration with industry and government, and to educate, advise, and help develop science policy at the local, national and international levels.

THE ENERGY & ENVIRONMENTAL SYSTEMS INSTITUTE

EESI brings together faculty and students spanning all of Rice's academic divisions in programs of research, education, and community service that promote the guardianship of environmental quality and natural resources. The institute fosters partnerships between academia, business, governments, non-government agencies, and community groups to help meet society's needs for sustainable energy, environmental protection, economic development, and public health and safety. EESI activities span Rice University's schools of Social Sciences, Engineering, Natural Sciences, Humanities, Architecture, and Management.

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INTRODUCTION

With the decline in domestic oil production and continued strong increases in oil demand, the United States is more dependent on foreign oil than ever before. The United States imported 12.9 million barrels per day (b/d) in 2004—about 63 percent of total consumption of roughly 20.5 million b/d—which is up from 35 percent of total consumption in 1973. The share of imported oil is projected to grow to close to 70 percent by 2020, with the United States becoming increasingly dependent on Persian Gulf supplies. U.S. imports from the Persian Gulf are expected to rise from 2.5 million b/d (22 percent of total U.S. oil imports) in 2003 to 4.2 million b/d (62 percent) by 2020, according to forecasts by the U.S. Department of Energy (DOE). Future U.S. oil consumption is centered squarely in the transportation sector which represents more than two-thirds of total petroleum use and will constitute over 70 percent of the increase in demand.

In light of this expected rise in transportation fuel demand and in the wake of Hurricanes Rita and Katrina, U.S. policymakers have become acutely aware of the need to offer long-term strategies that would prevent gasoline shortages in the future and to lessen America's vulnerability to oil supply shocks from abroad. As debate on the issue emerged in the media and among specialists, the problem of decades of underinvestment and an ongoing shortage of refining capacity in the United States has become more widely understood. Public discussion of the state of the U.S. refining industry is focused on two elements: the difficulties of expanding domestic capacity to meet rising U.S. gasoline demand, and the possible dangers of having so much U.S. refining capacity concentrated in one geographical region that is vulnerable to weather-related disruptions.

Biofuel has been proposed as an environmentally friendly means to supplement the U.S. transportation fuel supply system. In his 2007 State of the Union address, President George W. Bush championed energy alternatives and emphasized the potential of biomass-derived fuels to fulfill a greater share of our nation's transportation fuel needs. In 2006, the United States produced 319,000 b/d of ethanol—mainly from corn—which was more than Brazil, which produced 308,000 b/d of sugarcane-based ethanol. However, current U.S. ethanol production is but a small fraction of the 9.7 million b/d of gasoline fuel used in the United States currently during peak summer driving season.

The Baker Institute's Energy Forum, in conjunction with the Rice University Departments of Chemical and Biomolecular Engineering, Civil and Environmental Engineering, and the Energy and Environmental Systems Institute (EESI), convened to explore the potential role biofuels can play in enhancing U.S. energy security and to discuss the long-term environmental impact of large-scale use, as well as the logistic and economic issues involved in extending biofuels beyond their current role as a 10 percent additive in the existing U.S. gasoline supply.

The conference, "Biomass to Chemicals and Fuels: Science, Technology and Public Policy," held at the Baker Institute Sept. 25–26, 2006, brought together leading scientists, policy experts, students and industry executives from around the world to discuss and debate the potential role of biofuels as an auxiliary energy source for the 21st century and beyond, and to highlight the research and development of new technologies and scientific breakthroughs needed to make biofuels a viable alternative to oil-based fuels. The conference is part of a broader campaign to reinvigorate public interest in the physical sciences. A bipartisan effort to address our energy security dilemma through revolutionary technologies could generate an excitement and idealism similar to the one that swept the nation—and particularly our young people—during the height of the space program in the 1960s and 1970s. By showcasing potentially revolutionary breakthroughs in the biomass area, it is hoped that the conference will increase academic interest in this and other exciting areas of energy science research.

In his opening remarks, Ambassador Edward P. Djerejian set the stage for the conference by outlining the central questions that must be investigated if biofuels are to contribute to U.S. energy security and be integrated feasibly into the American transportation infrastructure. "The major obstacle to expanding the role of biofuels is lack of infrastructure," noted Djerejian. "Current U.S. ethanol production is concentrated in the

Midwest region and difficulties remain with the ethanol distribution system in other parts of the country." Indeed, of the 799 eighty-five-percent ethanol fuel (E85) filling stations in the United States in July 2006, over 45 percent of them were located in two states, Minnesota and Illinois; however, due to recent infrastructure development across the United States, by December 2007 the number of ethanol stations has grown to over 1300. Still, stations in Minnesota and Illinois constitute 35 percent of the current tally.[i] Archer Daniels Midland controls about 25 percent of the ethanol production market share, with the remaining production distributed among 97 biorefineries owned by various, mainly smaller, entities.

Djerejian noted that to have biofuels play a more important role in the U.S. energy equation, new policies and new technologies will be needed. He noted that while there are many biofuel alternatives currently under study in the United States, most are "far from cost-effective using present technology." He added that questions remain about "the viability of relying on corn-based ethanol as the salvo to our fuel diversity solution" and added that other more efficient and effective options need to be investigated. "This search for a more thoughtful understanding of the potential of biofuels has led us to convene today's conference," Djerejian explained.

Opening keynote speaker Andrew Karsner, assistant secretary for renewable energy at the U.S. Department of Energy (DOE), reiterated Djerejian's concerns that the United States faces formidable challenges in the energy sector.

According to Karsner, the reasons for transitioning our energy economy have never been clearer than they are now, whether the driving forces are escalating price signals, geopolitical factors or environmental concerns. "We must surpass the status quo and the incumbent energy technologies which have defined our economic destiny," said Karsner. He added that on the environmental front, the challenges are clear because the pace of global warming is noticeable and an issue that must be confronted. "Nothing can do more to achieve our goals than accelerating the deployment of new energy technologies and ensuring they penetrate markets rapidly."

Karsner also discussed the new geopolitical challenges to energy security, including America's "new competitors in the global arena." He noted that rapid economic development in China and India means that "there are more people drawing on fewer energy resources."

Describing President George W. Bush's vision for the new energy economy, particularly the role of biofuels, Karsner emphasized that the president acknowledged the importance of these issues in his 2006 State of the Union address. "The president declared his ambition to change the way we power our homes, offices and vehicles by embracing new, cleaner and more energy efficient technologies," noted Karsner.

In discussing solutions to the U.S. energy problem, Karsner emphasized the difference between the current technology programs toward alternative energies and past R&D milestones such as the Manhattan Project or the Apollo space program: "What I worry about is that we tend to use them as our analogue—if we just put in enough dollars in any one laboratory at any one given time … they'll emerge at a given moment, and 'Voila! It works!'" He emphasized that the current challenge is much greater because "we are fundamentally discussing the market transformations of the largest industries in the world: the energy and automobile industries."

Karsner said that the scale of the effort that is needed is "unprecedented," and added that what is needed are "thousands of R&D pipelines in the United States, many privately funded, in consortia with national laboratories." He explained that transitioning successfully to an alternative energy market will require coordinated efforts on the part of consumers, industries and government at both the state and U.S. federal levels.

He likened the solution to "a three legged stool, where each leg is indispensable."

- The first leg is research and development in locations such as national laboratories. The U.S. government has invested in climate science and renewable energy technologies with long-term goals. Institutes and universities in the United States are developing energy solutions.
- The second leg is policy. Karsner noted that this leg will require time to properly develop because this is such new territory. "The question is how to plan policies with sufficient predictability, longevity and durability to accommodate the change we seek as our scientific discoveries and innovations find their way into markets," Karsner explained.
- The third leg is markets: equity, investments, finance, etc. Noted Karsner, "We cannot get to sustainability until we address profitability. The government cannot regulate a technology into the market realm without the device being capable of profitably sustaining itself in the market." But he added that markets have imperfections and, therefore, any good policy would need to address the intrinsic nature of these new technologies to survive in an imperfect market.

In the late 1980s, the DOE represented about 90 percent of the invested capital in renewable energy technologies; however, due to vast increases in public interest and private investment, the DOE now represents only 0.3 percent. There were $40 billion of clean energy transactions in the United States last year, excluding market capitalizations.[ii]

The Biomass R&D Technical Advisory Committee tasked the Oak Ridge National Laboratory (ORNL) to research the potential of U.S. land resources to produce a sustainable amount of biomass to displace 5 percent of power, 20 percent of transportation fuels, and 25 percent of chemicals by 2030; this is equivalent to 30 percent of current petroleum consumption in the United States. The resulting report, "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply," in April 2005, commonly referred to as the "Billion-Ton" report, concluded that U.S. forestry and agriculture land resources could sustainably provide for more than 30 percent of current petroleum consumption, requiring more than 1.3 billion dry tons of biomass annually. In July 2006, the DOE issued their roadmap, “Breaking the Biological Barriers to Cellulosic Ethanol: a Joint Research Agenda,” reasserting their goal to “make biofuels practical and cost-competitive by 2012 ($1.07/gal ethanol) and offering the potential to displace up to 30 percent of the nation’s current gasoline use by 2030.” Displacing 30 percent of current gasoline consumption represents the production of about 60 billion gallons of fuel ethanol.

Karsner noted that specific prescriptions in the Energy Policy Act of 2005 reinforce ambitious goals for biofuels in the United States. For example, Section 932 solicits $53 million towards the first joint venture on a commercial scale facility. And, included are both the Loan Guarantee Program, which in its initial phase allows for $2 billion of leverage investment of the federal balance sheet, and the Renewable Fuels Standards, which proscribe how much renewable fuel should be introduced into the market place and at what rates of inclusion.

To reach the targets laid out in the Energy Policy Act of 2005, possible strategies include electricity and plug-in hybrids, biofuels and biodiesel solutions. In 2005, biofuels constituted about 3 percent of total U.S. gasoline consumption with ethanol comprising about 2.85 percent of the gasoline pool and biodiesel comprising 0.21 percent of the diesel pool.[iii] Given current infrastructure, Karsner emphasized that the United States should maximize domestic biorefining capacity for corn-based ethanol so that it paves the way for an ethanol and biofuels infrastructure in general. Still, concerns exists regarding when U.S. corn-based ethanol will hit a production plateau, and therefore the DOE further aims to develop alternatives to corn-based ethanol, specifically to make cellulosic ethanol commercially viable in a conversion plant by 2012, according to Karsner.

In his concluding comments, Karsner emphasized that consumers in the U.S. should have fuel and vehicle choices and E85 should become a nationwide fueling option; he called upon the auto industry to provide more vehicle types of all vehicle classes capable of flex-fuel adaptability, and said that the auto and fuel supply industries must cooperate and anticipate future fuel trends and provide these options at the pump.

In Karsner's opinion, the role of the Department of Energy is to function as a convener and in an "iterative and catalytic role with the private sector and academia," rather than solely promoting in-house advancement. Karsner concluded by noting that the United States "must act on Kennedy's idea of: 'fix the roof while the sun is shining.'"

Biomass and Energy: Advantages and Impact

Following Karsner's keynote speech, Kyriacos Zygourakis, A.J. Hartsook Professor and department chair in chemical and biomolecular engineering at Rice University, presented on "The Potential and Importance of Biomass to the Energy Problem: Bio Sources, Volumes and Environmental Advantages and Impacts."

He discussed the challenges that the United States must meet in order to achieve an energy future that is "sustainable, affordable and secure." To reach that goal, he said that "the U.S. will need a broad portfolio of technologies, lower CO_2 emissions, more fuel choices, improved national security with an expanded domestic energy supply, and the emergence of a new industry that will use biomass as the feedstock for the production of fine chemicals and polymeric materials."

Zygourakis stated that sustainability should be America's first objective, both "to mitigate the adverse environmental and economic effects of global warming and to diversify our energy sources, preventing over-reliance on any single source and limiting the resulting vulnerability of our nation to political events that occur beyond our borders."

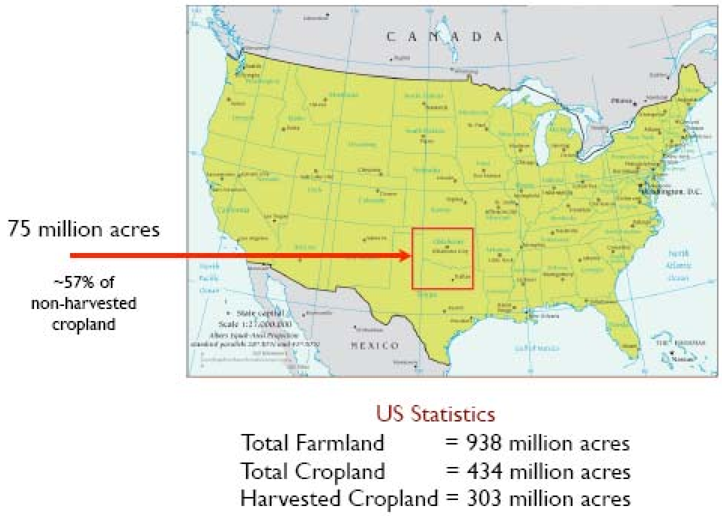
Zygourakis said that developing alternative energy sources is "a major optimization problem for optimal allocation of resources." He added that the United States must consider what energy resources are available, what these sources are used for (electricity, transportation fuels and chemicals), then adopt a path that will meet our future needs for energy and chemicals in the most sustainable, affordable and secure way.

In terms of developing biomass as an alternative fuel and chemical feedstock, many have questioned whether the U.S. has enough biomass to meet demand. According to a 2007 report from the Energy Information Administration (EIA), “about 3.9 billion gallons of ethanol and 91 million gallons of biodiesel were produced in the United States in 2005. According to estimates based on the number of plants under construction, ethanol production capacity could rise to about 7.5 billion gallons and biodiesel capacity to about 1.1 billion gallons by 2008, possibly resulting in excess capacity in the near term.”[iv]

Based upon the conclusions of the “Billion-Ton” report, the DOE adopted targets for U.S. lands to yield 1.3 billion tons of dry biomass from forest (368 million tons) and agricultural (998 million tons) resources in a sustainable manner without affecting food prices. In 2003, the U.S. used about 190 million dry tons of biomass, contributing about 3 percent of U.S. energy needs. Zygourakis explained the land use implications of the DOE target. To produce 60 billion gallons of cellulosic ethanol at an approximate 80 gallons of ethanol per ton of dry biomass, the United States would need 750 million tons of dry biomass. At about 10 tons of biomass yielded per acre of land, the U.S. would require 75 million acres of land to produce 60 billion gallons of ethanol.

Using “Figure 1: U.S. Farmland for Biomass,” Zygourakis illustrated land usage in the United States; the red square represents the 75 million acres necessary for ethanol production. [Other land distinctions are U.S. total crop land (434 million acres) and U.S. harvested cropland (303 million acres).] Using these rule-of-thumb figures, the U.S. could grow the necessary biomass for fuel and still use only about 60 percent of its nonharvested cropland, Zygourakis stated. “However,” he cautioned, “this figure may be too low since the DOE estimates of biomass and ethanol yields are upper-bound predictions for the future and are not currently achievable.”

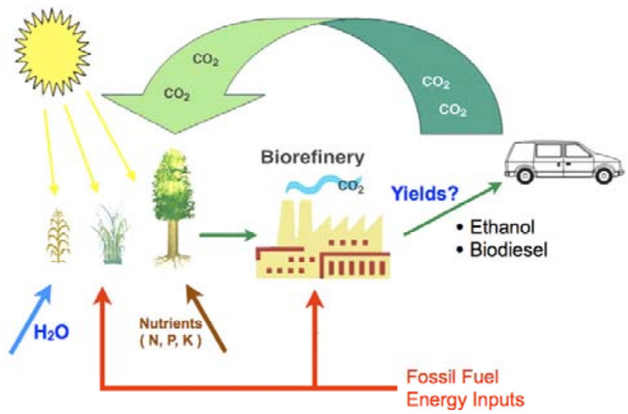
Figure 1: U.S. Farmland for Biomass



To reach the greater potential touted by the DOE and others, Zygourakis said that the United States will need to increase yields, develop no-till cultivation methods, and develop perennial crops (like switchgrass or poplar trees) on at least 55 million acres.[v] Most of the new biofuel production will come from cellulosic ethanol produced via a biochemical route that involves fermentation of the sugars obtained from the cellulose and hemicellulose components of biomass. Smaller amounts of biofuels may be obtained from the thermochemical conversion of agriculture residues.

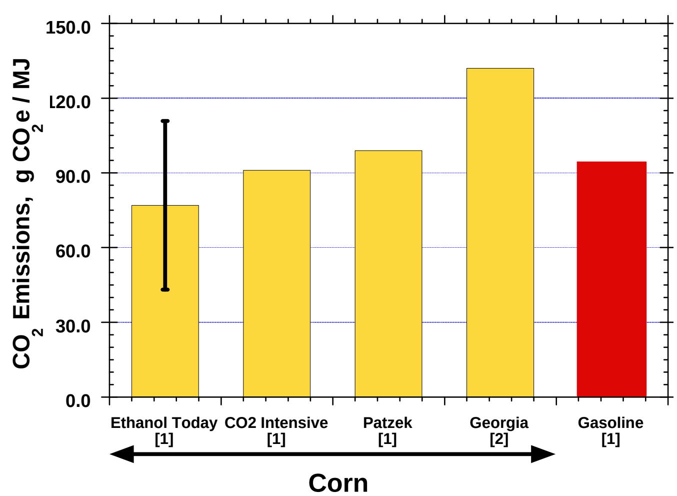
In terms of CO_2 emissions, Zygourakis said that the carbon neutrality of biofuels is a highly contested topic. Some may argue that biofuels are carbon neutral because the amount of CO_2 emitted from automobiles running on biofuels comes from the CO_2 that the plants captured from the atmosphere to photosynthesize the sugars needed for their growth. While it is true that plants capture CO_2 from the atmosphere, Zygourakis noted that large amounts of fossil fuels are required to grow, harvest and transport these plants to the biorefinery, to produce and apply the necessary fertilizers and pesticides and to convert the biomass into biofuels. He added that the production cycle from field to pump contributes a large amount of CO_2, perhaps more CO_2 than what is captured from the atmosphere by the living plant.

Figure 2: Production of Biofuels



The graph below depicts the results from recent studies that analyzed the net greenhouse gas (GHG) emissions for corn ethanol produced by various methods. These studies showed either a small net decrease or a small net increase in total CO_2 emissions when we use corn ethanol for fuel instead of gasoline. Zygourakis concluded: "Even if there is a net reduction in CO_2 from corn-ethanol, this gain is going to be relatively small, so if we want a significant reduction, we are going to have to look at other alternatives like cellulosic ethanol."

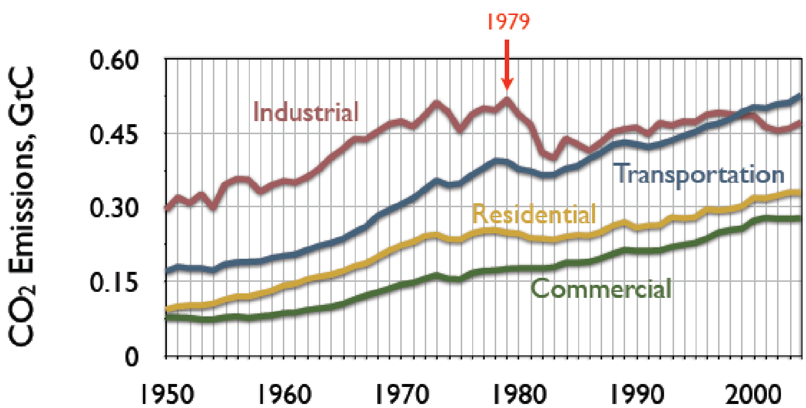
Figure 3: Net GHG Emissions from Corn Ethanol and Gasoline



*Source: Data from [1] Farrell et al., Science, **181**, 506-508 (2006) and [2] Groode and Heywood, LFEE-2007-02 RP (2007).*

Zygourakis said that optimistic assessments of cellulosic ethanol claim that it can reduce carbon emissions up to 0.2 gigatons of carbon (GtC) per year. While this may be significant, it is still a small fraction of the total reductions of carbon emissions that will be required. The following plot shows the steady increase of carbon emissions in the U.S. over the past 50 years. [vi] The U.S. currently emits 1.67 GtC per year, and if we take no measure to reduce our emissions, this rate is expected to rise to 2.71 GtC per year by 2056.[vii]

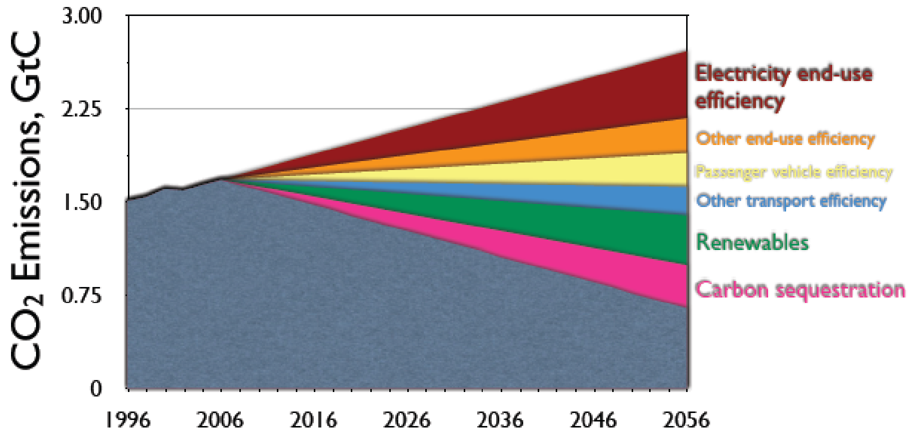
Figure 4: CO_2 Emissions by Sector



Climate scientists predict that the average global temperature rise will remain below 2°C only if we stabilize the atmospheric CO_2 concentration to 450 parts per million (ppm). To meet this goal, the cumulative world emissions in the 21st century must not exceed 480 GtC. The U.S. allocation of carbon emissions for this century will then be 84 GtC. And this means that the U.S. must lower its annual CO_2 emissions from 1.67 GtC now to 0.64 GtC by 2056 and 0.2 GtC by 2100.

To achieve such reductions in CO_2 emissions, Zygourakis said that the United States must pursue a combination of practices that may include cellulosic ethanol, advanced vehicle design to improve fuel efficiency standards, conservation efforts in electricity consumption and end-user efficiencies, and carbon sequestrations methods.[viii]

Figure 5: CO_2 Stabilization Wedges



Zygourakis then observed that petroleum gives us much more than gasoline and diesel fuel. We also get most of our materials from oil: fibers for our clothes, bedding and carpets, food packaging, plastic bottles, plastics for computers and entertainment devices, almost the entire interior of our cars. "We literally float on oil as we drive our cars on the freeways," Zygourakis said and asked: "Where will the hydrocarbon feedstock for these materials come from if fossil fuels were to become too scarce and expensive? The only sustainable source of hydrocarbons is biomass."

Zygourakis noted that a 1999 National Research Council (NRC) report found that the land and agricultural resources of the United States are sufficient to satisfy domestic and export demands for food, feed and fiber and still produce the raw materials for most bio-based industrial products. He concluded by saying that the biorefineries of the future will most likely convert biomass primarily to chemicals, through efficient molecular transformations and optimized processes that parallel those of our familiar petrochemical industry.

NATIONAL INITIATIVES AND ENERGY SECURITY

Proponents of biofuels often argue that ethanol and other biofuels can enhance energy security by providing a substitute to oil as a transportation fuel and thereby reducing dependence on foreign sources of oil. Biofuels have become an important component of

U.S., Brazilian and European energy policy as a source of diversification of fuel supply. Other countries are also pursuing biofuels as a supplement in fuel, including India, China, Colombia, Indonesia, Malaysia and the Philippines. The International Energy Agency projects that biofuels may rise from around 1 percent of total world road fuel consumption in 2004 to 4 percent by 2030 under its reference case projections.

In his presentation “Biofuels: The Mindset Shift,” Sergio Trindade, director of science and technology at International Fuel Technology, Inc., discussed the trends in energy consumption and Brazil’s experience in diversifying its national fuel production and distribution system to include biofuels.

Referencing a May 1, 2006, editorial in *The New York Times*, Trindade stated that one positive result of high oil prices is the public reverberation. He said that Americans are now discussing the use of substitute fuels both to reduce U.S. vulnerability to producers in unstable areas of the world and to reduce anthropogenic contributions to global warming.

Brazil, the United States and the European Union (EU) are the dominant world ethanol producers. National biofuel policies tend to vary according to available biofeedstock for fuel production and national agriculture policies. In the case of Brazil, the United States and the EU, ethanol production has received government support via mandates and price subsidies. In the EU, the Biofuels Directive requires that biofuels comprise 5.75 percent of transportation fuels by 2010 (measured by energy content). Brazil’s biofuel production is based entirely on sugarcane and currently displaces 40 percent of the country’s gasoline consumption, according to Trindade.

<u>Brazil</u>

Trindade noted that Brazil announced a pro-alcohol program in 1975 in response to the 1973 increase in oil prices. Brazil’s military leader, General Ernesto Geisel, mandated in 1975 that gasoline be mixed with 10 percent ethanol at first and increased the amount to

25 percent ethanol by 1980.[ix] The government offered sugar companies corporate loans to finance the construction of ethanol plants and guaranteed prices for the new product.

Brazil increased its efforts to integrate ethanol into its energy market following the 1979 Iranian revolution that led to another global oil-price shock. Under the leadership of General João Baptista Figueiredo, the ProAlcohol program increased ethanol production, required state-run Petrobras to supply filling stations with the new fuel, and gave car companies tax breaks to produce ethanol-powered vehicles. By 1980, every foreign and domestic auto manufacturer in Brazil was offering a car powered on ethanol only. The government encouraged its citizens to purchase the vehicles by offering a price support that made ethanol 35 percent cheaper than gasoline. The Datagro consulting firm estimates these incentives to have cost the Brazilian government over $16 billion in 2005 dollars from 1979 to the mid-1990s.[x]

The Brazilian ethanol project was endangered in the late 1980s when oil prices plummeted, leaving the country subject to hyperinflation. The government was forced to cut spending across the board, including its ethanol price supports. Ethanol-powered car sales fell drastically, and critics began to say that the entire program had succeeded only at wasting government funds. However, the government's continued demand that all gasoline be mixed with ethanol kept the program alive and forced sugar companies to develop ways to cut production costs and increase efficiency. The improvement in car technology, to include flex fuel cars that could run on either ethanol or gasoline without sacrificing performance, gave the industry a boost; Fernando Damascenco, chief engineer at the Brazilian unit of Italian car parts company Magneti Marelli, developed a cheaper flex fuel engine that overcame cost barriers; converting a car into a flex fuel vehicle would now cost about $100.[xi] The company sold its design in 2002 to Volkswagen, and it is now used by five major car manufacturers in the country, including Ford's Brazil unit. The flex fuel engines are now used in over 70 percent of all automobiles sold in Brazil.[xii]

As gasoline prices rose again at the turn of the century, ethanol regained its popularity. Between 1975 and today, Brazil has tripled its ethanol output from 2,000 liters to 6,000 liters per hectare.[xiii] To help the industry and encourage the use of alcohol fuel, the government kept the tax rate on ethanol fuel at about one-fifth the rate on gasoline. Today, Brazil has a large biofuel infrastructure, with more than 50,000 sugarcane growers, about 346 mills and distilleries (with around 50 more under construction), and some 160 distributors throughout the country. Trindade said that "every gasoline station in Brazil has the facilities to sell ethanol," and that the "facilities were gained by eliminating premium gasoline and using the existing infrastructure of gas stations." He also said that one advantage that Brazilian drivers have in a new, mixed-fuel economy is that the Brazilian flex fuel/ethanol (FFE) cars can burn any combination of oil and ethanol, allowing drivers to purchase a blend based on what is most cost-effective at the time of their fuel purchase.

Brazil is now a major ethanol exporter and supported the New York Board of Trade futures and options market for ethanol in 2004. Brazil's transition to a mixed-fuel economy took several decades to establish successfully, and significant research and policy initiatives were undertaken during the process. From the Brazil example, Trindade drew the following lessons that he says are vital to replicating a successful biofuels industry:

- Cooperation between stakeholders is fundamental in crafting effective ethanol policy. In Brazil, there is an integrated gain for each participant in the sugarcane to ethanol chain:
    - There must be cooperation and consensus among the oil industry, auto industry, and ethanol and sugar producers;
    - There must be cooperation between the growers and processors of feedstock;
- Agricultural research is important, as is government backing.

Trindade noted that comprehensive utilization of surplus bagasse and the development of biorefining as a business is a major element to a successful ethanol program. Brazilian sugar mills use the residue discarded from the compressed stalks to generate electricity that is then used to power the ethanol production process as well as sold to the national grid, Trindade explained. Liquid waste and other by-products are used to fertilize the cane fields themselves.

Brazil is actively trying to promote ethanol production programs in other countries by offering to share its production techniques. Brazil understands that assisting others in the development process will shorten start up time in these countries and lower their initial costs. Having other countries incorporate ethanol as a significant energy source will make the fuel an international commodity and provide Brazil with a profitable export.

In 2005, Brazil produced approximately 313,000 barrels a day of ethanol and exported 39,000 bbl/d.[xiv] The country's ethanol production is expected to increase 37.5 percent, and ethanol exports are expected to nearly double by 2015–16. Brazil is also the world's largest ethanol consumer, consuming approximately 275,700 bbl/d of its 290,000 bbl/d in 2006.[xv] But there are environmental concerns that expansion of sugarcane cultivation to meet domestic ethanol needs (and future increases in international export demand) could threaten Brazil's already endangered rainforests.

Brazilian producers estimate that their sugar cane ethanol is cost effective so long as oil prices remain above $30 a barrel, and that this number will continue to drop as technologies advance.[xvi] At the same time, a February 2006 Organization for Economic Co-operation and Development (OECD) report suggests Brazilian ethanol is currently cost effective at $39 a barrel.[xvii] Despite the discrepancy, Brazil still achieves greater cost efficiency than is estimated for the United States, Canada and the EU; their methods are estimated to become profitable without subsidies when crude oil prices range from $44 to $145 a barrel, depending on the fuel source. [xviii]

Brazilian ethanol has had limited entry into European and American markets because of heavy import duties. The United States levies a $0.54 per gallon import duty in addition to an ad valorem tariff of 2.5 percent on all ethanol imports.[xix] Brazilian officials are frustrated by these high taxes because it inhibits foreign investment in their program. This is exacerbated by the $0.51 domestic tax credit/subsidy issued on each gallon of ethanol used as motor fuel.[xx] In response to these tariffs issued in other countries, Brazil has issued a 20 percent ad valorem duty on imported ethanol.[xxi]

The United States

Though Brazil has historically been the largest ethanol producer, in 2005 the United States surpassed Brazil in ethanol production for the first time. The U.S. Energy Bill of 2005 required 7.5 billion gallons of renewable fuel to be produced annually by 2012. Trindade noted that by 2006, the United States had actually surpassed the requirement of 4 billion gallons of renewable fuel, producing 4.9 billion gallons of ethanol.[xxii] More recently, the U.S. Congress passed the Energy Independence and Security Act of 2007 on December 18, 2007, which raised corporate average automobile fuel efficiency standards (CAFE) to 35 miles to the gallon by 2020, with first improvements required in passenger fleets by 2011. The legislation increased the Renewable Fuels Standard (RFS) to require 9 billion gallons of renewable fuels consumed annually by 2008 and progressively increase to a 36 billion gallon renewable fuels annual target by 2022 (of which 16 billion is slated to come from cellulosic ethanol). The bill specifies that 21 billion gallons of the 36 billion 2022 target must be “advanced biofuel,” which on a life cycle analysis basis must encompass 50 percent less greenhouse gas emissions than the gasoline or diesel fuel it will replace. “Advance biofuels” include ethanol fuel made from cellulosic materials, hemicellulose, lignin, sugar, starch (excluding corn) and waste, and biomass-based biodiesel, biogas and other fuels made from cellulosic biomass.

The transition to biofuels consumption in the United States first gained momentum in the 1980s when the production of gasohol, a 10 percent blend, was attempted in the context of the phase out the use of leaded gasoline. Trindade noted that “though many of the distilleries built for this endeavor failed, the import of ethanol during this period instilled an industry confidence in the concept of biofuels.” Eventually, the shift towards foreign ethanol imports was blocked by national power politics of domestic sugar and farming interests, ending in the passing of trade barriers to ethanol imports such as the $0.54 per gallon tariff and the 2.5 percent ad valorem tax.

In 1990, after nearly eight years of hearings and legislative wrangling, the U.S. Congress passed sweeping amendments to the Clean Air Act that established a rigid national standard for reformulated gasoline (RFG), setting minimum oxygen standard for gasoline formulations and thereby promoting the market for ethanol and methyl tertiary-butyl ether (MTBE) to be used as an additive to gasoline. Initially, many refiners favored MTBE as an additive over ethanol for logistical and cost reasons. MTBE could be blended into gasoline right at the refinery and then the RFG mixture could be easily transported to market. Given ethanol's high affinity for absorbing water, in order to reduce the risk of contamination, ethanol has to be transported separately by barge, truck or rail car to end-use distribution centers and then added at the end of the distribution chain. Separate transportation, storage and blending facilities were needed to utilize ethanol as a component for RFG and ethanol manufacturing—concentrated in the U.S. Midwest—was generally distant from main demand markets on the U.S. coasts. This meant that most gasoline producers used MTBE rather than ethanol to meet the reformulated gasoline standards.

However, in recent years, MTBE has been banned as an additive to gasoline following greater awareness of the possibility that the chemical caused contamination of the water table. In practice, then, the industry had to switch from using MTBE to adding ethanol as the key additive to achieve cleaner fuel, creating new demand for ethanol. Thus, ethanol became an attractive additive to gasoline as a replacement for MTBE, increasing the octane level to 110 from about 90, and for its usage in cold winters. At present, about 6 billion gallons of ethanol are needed in the United States to replace MTBE as a fuel additive. Thus, so far, current ethanol production is not yet significantly replacing gasoline per se, but replacing additives that are being removed from the fuel system.

Trindade emphasized that there are several obstacles to overcome in the U.S. biofuel market. One of the largest obstacles is transporting biofuels and another is selecting an efficient fuel alternative. He said that infrastructure development is particularly lacking, as most ethanol supply is located in the Midwest, but demand is based in California and the East Coast; as a result, the exchanging of futures contracts in corn ethanol in Chicago has not been very successful.

Trindade warned that E85 is inefficient and a national fuel system based on E85 would present complications as "the vehicles under such a system are designed to be flexible while the distribution infrastructure is not." One option Trindade suggested involved eliminating one of the grades of gasoline currently in gas stations and replacing it with E95.

Trindade concluded his presentation by noting that there are many barriers to national biofuel policy, including investor perception of risk, shortage of capital, and concerns that a push to biofuels will adversely affect food supply. Moreover, Trindade noted that there is no substitute for conservation. "Increasing the supply of biofuels might lead us from a situation of wasting fossil fuels to a system of wasting biofuels."

He noted that "biofuels can play a role in a diverse fuel mix, but in relying on new energy sources, policymakers must consider how information technology interacts with transportation needs." And he said that the United States and other nations should follow the European example by looking at the effective utilization of rail and public transportation, in addition to tapping policies that promote conservation such as CAFE standards.

<u>The European Union</u>

In his presentation "The European Union and Bioenergy," Melvyn Askew, head of the Agriculture and Rural Strategy group at the Central Science Laboratory of the United Kingdom, addressed major constraints to bioenergy development in Europe and the pathway forward. In the EU, the Biofuels Directive requires that biofuels comprise 5.75 percent of transportation fuels by 2010 (measured by energy content).

Askew began his talk by identifying two major constraints to promoting bioenergy. "The first is that no one knows what options are available. The second is that few people entering the industry understand the needs of all players: the farmers, the producers and the end users," he said. He also noted the importance of determining the best use for biomass and suggested that looking at biofuel's potential as a gasoline substitute was not a broad enough view, as the next generation of biofuels may have multiple end-uses and biofuel by-products have yet to be fully explored.

According to Askew, the EU is promoting bioenergy programs, evidenced by several government issued white papers and directives. "Each EU member state sets its own directives and pursuant methods, and incentives vary by state," he said. For example, in a 1999 European white paper, the authors claimed that about 50 million acres of farm land would be needed to provide 135 million tons of biomass per year; in addition, the paper called for photovoltaic and other alternative energy sources.

He noted that many European countries were pursuing these shared objectives in different ways. Germany, which is currently one of the world's largest producers of biodiesel, has offered government support that is time-limited. Several other EU countries' directives call for biofuels to replace gasoline and diesel consumption. For example, a British directive calls for 5 percent displacement of gasoline and of diesel by 2010.

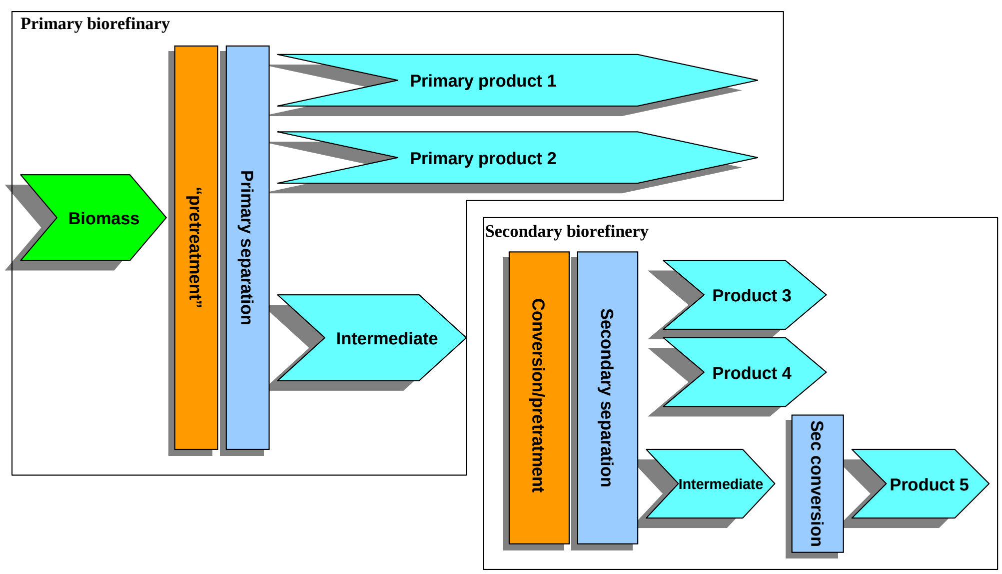
Askew stated that Britain consumes nearly 20 million tons of gasoline and an additional 20 million tons of biodiesel annually; he then calculated that 5 percent displacement of gasoline and diesel would therefore require approximately 1 million tons of biofuel and 2.5 million hectares of land for feedstock, respectively. However, Askew noted that current estimates cite only 1 million hectares of land in Britain available for further biofuel production.

Rather than aim at a short-term range of 2010, Askew suggested that a long-term vision for biofuels in the EU is needed. He highlighted three stages to the transition toward a bioenergy economy.

- **Stage 1**: *Present to 2010* (focus on biodiesels);
- **Stage 2**: *2010 to 2020* (focus on bioethanol and sunfuel; Askew noted that such fuels may be based on gels, innovations in Iogen technologies, and sophisticated diesel-powered trains capable of running on a synthetic biofuel);
- **Stage 3**: *2030 and beyond* (focus on integrated biorefineries).

Askew observed that achieving these three stages depends on successful development and innovation of biofuels and biorefinery processes. To date, Askew noted that the biorefinery process is underdeveloped. He said that the fossil fuel industry should serve as an example of a refinery process where little to nothing is discarded; the biorefinery industry must focus on adding value to the agricultural inputs and exploit the many types of biomass resources. (See “Figure 6: Value-Added Biorefinery.”)

Figure 6: Value-Added Biorefinery



Source: J. Sanders (2006)

Over the next 15 years, Europe is expected to further reduce its consumption of oil crops and rely more heavily on short rotation forestry and perennial grasses.[xxiii] Askew noted that bioresources have the potential to decrease emissions, improve energy efficiency in building design, and reduce fuel constraints, but he suggested that these benefits can only be achieved if the entire life of products and their energy impacts are considered in the decision-making process for how to exploit biomass' potential.

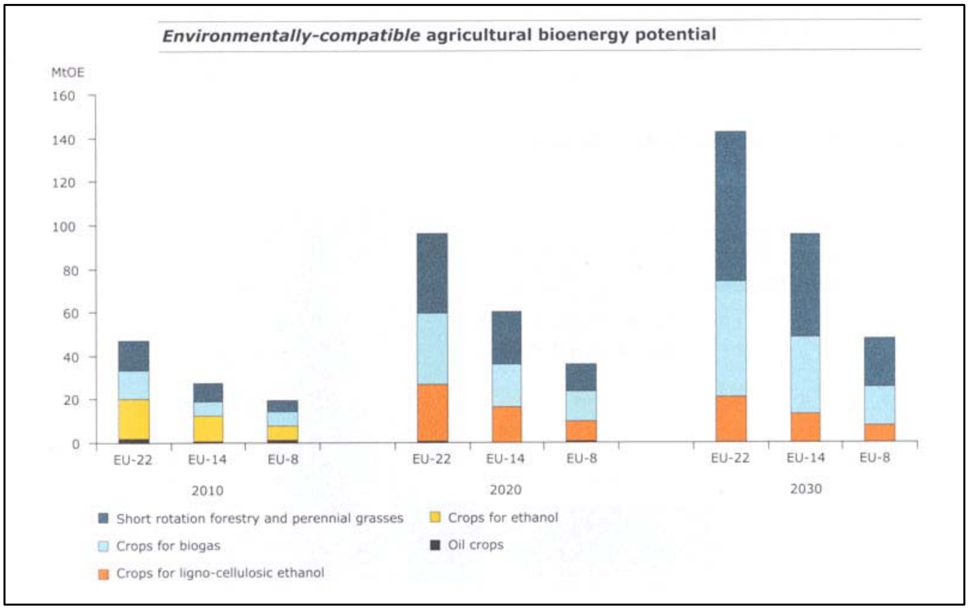
Figure 7: Biofuel Generations

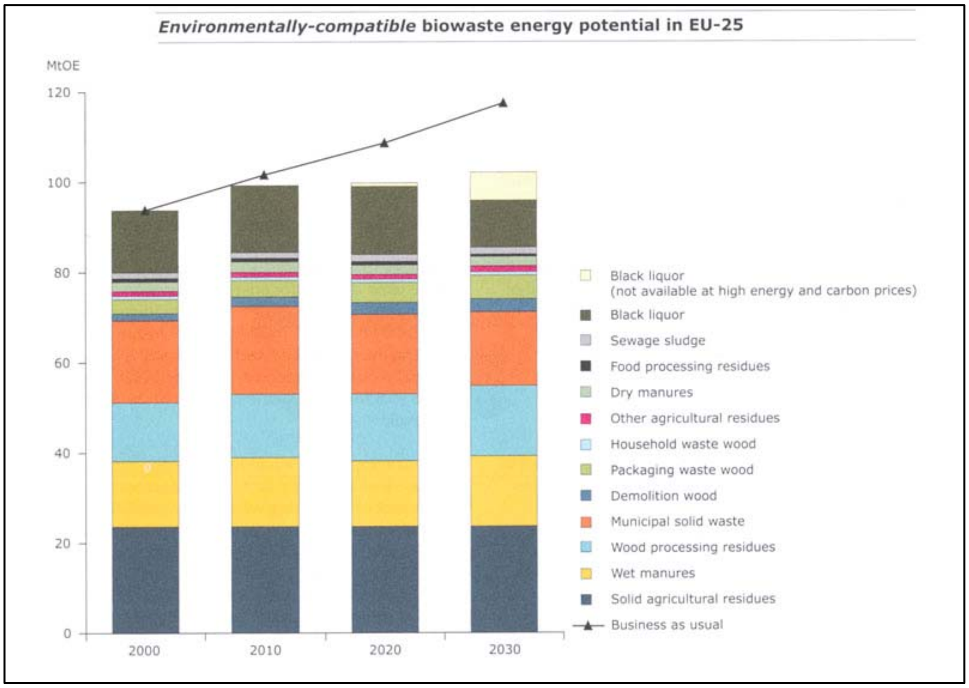
First generation (conventional) biofuels			
Biofuel type	**Specific names**	**Biomass feedstock**	**Production process**
Bioethanol	Conventional bioethanol	Sugar beet, grains	Hydrolysis & fermentation
Vegetable oil	Pure plant oil (PPO)	Oil crops (e.g. rape seed)	Cold pressing/extraction
Biodiesel	Biodiesel from energy crops Rape seed methyl ester (RME), fatty acid methyl/ethyl ester (FAME/FAEE)	Oil crops (e.g. rape seed)	Cold pressing/extraction & transesterification
Biodiesel	Biodiesel from waste FAME/FAEE	Waste/cooking/frying oil/animal fat	Transesterification
Biogas	Upgraded biogas	(Wet) biomass	Digestion
Bio-ETBE		Bioethanol	Chemical synthesis

Second generation biofuels			
Biofuel type	**Specific names**	**Biomass feedstock**	**Production process**
Bioethanol	Cellulosic bioethanol	Lignocellulosic material	Advanced hydrolysis & fermentation
Synthetic biofuels	Biomass-to-liquids (BTL): Fischer-Tropsch (FT) diesel Synthetic (bio)diesel Biomethanol Heavier (mixed) alcohols Biodimethylether (Bio-DME)	Lignocellulosic material	Gasification & synthesis
Biodiesel	Hydro-treated biodiesel	Vegetable oils and animal fat	Hydro-treatment
Biogas	SNG (Synthetic Natural Gas)	Lignocellulosic material	Gasification & synthesis
Biohydrogen		Lignocellulosic material	Gasification & synthesis or Biological process

Source: Central Science Laboratory

Figure 8: Biomass Potentials





Source: European Environment Agency

The Impact of Politics in the United States on Biofuels Policy

In her presentation, Margie Kriz, correspondent for the *National Journal*, discussed possible legislation and future political initiatives as regard biofuels in the United States. Kriz began her talk by noting that "when it comes to Washington, ethanol—or should I say biofuels—have the potential to please almost everyone. Farmers love it, so 20 senators from agricultural states will vote for it; environmentalists love it because [biofuels] reduce greenhouse gases (in theory), and they replace [the consumption of] oil and other fossil fuels; biofuels are supported by all presidential candidates; and the American public is big on renewable energy."

Kriz noted that there has been growing attention paid to alternative fuels by both presidential candidates and congressional representatives. President Bush mentioned ethanol in his 2005, 2006 and 2007 State of the Union addresses.

In his 2007 State of the Union address, Bush announced an ambitious target to reduce the growth in U.S. gasoline use by 20 percent over the next 10 years. The president noted that the nation was "addicted to oil" and added that U.S. dependence on imported oil makes it "more vulnerable to hostile regimes, and to terrorists—who could cause huge disruptions of oil shipments, raise the price of oil, and do great harm to our economy." The president outlined his program by proposing to increase the supply of renewable and alternative fuels by setting "mandatory fuels standards" to require 35 billion gallons of renewable and alternative fuels in 2017, roughly displacing 15 percent of projected annual gasoline use in that year. The president's plan also called for modernization of the corporate average fuel economy standards and rules for light trucks to reduce projected annual gasoline use by 8.5 billion gallons, representing a future 5 percent reduction in gasoline demand. When combined with the supply of alternative fuels, the result would be a total reduction in projected annual gasoline use of 20 percent.

Under the 2007 White House plan, the president's new target was proposed to supplement the DOE target goal under the Energy Policy Act of 2005, requiring that 30 percent of 2004 U.S. transportation fuel consumption be displaced with biofuels by 2030. Renewable and alternative fuels are defined by the White House as corn ethanol, cellulosic ethanol, biodiesel, methanol, butanol, hydrogen and alternative fuels.

Recent presidential candidates have also included ethanol in their campaign tours. “One of the most popular things for the candidates to do this summer [2006], other than go to the Iowa State Fair, was tour an ethanol plant,” said Kriz.[xxiv]

Beyond the presidential campaign trail, ethanol was a local campaign issue in the November 2005 congressional elections, with ethanol featured in political campaign ads and slogans. Senator Jim Talent, R-Mo., referred to himself as “Mr. Ethanol” until Democratic opponent Claire McCaskill unearthed the fact that 15 years ago Talent voted against a state ethanol fund, Kriz explained as an example. By virtue of its importance in congressional races, it has impacted debates within Congress as well. Kriz said that “Democrats are promising to invest heavily in energy resources in rural areas, as a strategy designed to appeal to so-called red-state voters.”

Despite the growing popularity of ethanol legislating, Kriz noted that “not everyone wants to give money to promote the biofuels industry. Some Republicans want to eliminate the entire price support structure for agriculture—including anything that would go to ethanol. And legislators from oil states will oppose ethanol legislation, regardless of which party proposes it.” But she noted that in her opinion, ethanol legislation would continue to dominate the energy debate. “Ethanol and biofuels are going to be front and center in the Congress, no matter who controls the Congress.”

The passage of the Energy Independence and Security Act of 2007 by the Democrat-controlled Congress on December 18, 2007, increased the Renewable Fuels Standard (RFS) to require 9 billion gallons of renewable fuels to be consumed annually by 2008 and progressively increase to a 36 billion gallon renewable fuels annual target by 2022 (of which 16 billion is slated to come from cellulosic ethanol). By 2017, the legislation requires 24 billion gallons of renewable fuel to be consumed in the United States. The bill specifies that 21 billion gallons of the 36 billion must be "advanced biofuel," which has 50 percent less greenhouse gas emissions than the gasoline or diesel fuel it will replace. By the 36 billion gallon renewable fuels mandated for 2020, 16 billion gallons of cellulosic biofuel is required. The legislation also authorized grants of $500 million between 2008 and 2013 to encourage production of advanced biofuels that reduce lifecycle GHG emissions by at least 80 percent. The new legislation also allows for grants for research, development, demonstration and commercial application of biofuel production by institutions of higher learning or consortiums including institutions of higher learning.

The Geopolitics of Alternative Energy

In his presentation "Biofuels: Crude Realities," Gal Luft, executive director of the Institute for the Analysis of Global Security, began by laying out the geopolitics of alternative energy. "We [the United States] cannot win the war on terrorism while funding the opposing side through our purchase of oil. Plans that call for increasing biofuel from 2 percent of our energy supply to even 5 percent will have virtually no impact on our security," he explained. Given this, Luft emphasized four key questions integral to the biofuel debate: Are biofuels a legitimate fuel alternative to oil? Can there be a true U.S. national market for biofuels, or are biofuels only feasible for Midwesterners? Can the United States develop transportation and distribution infrastructure? And is the U.S. government up to the task of creating a sensible biofuels policy?

There are several motivations for encouraging biofuels, according to Luft—among them national security, climate change and third world development—and these motivations come from conflicting perspectives which involve competing groups that lobby for legislation before the U.S. Congress.

Luft said that "dialogue on biofuels and alternative fuels in general is full of myths, exaggerations and lies, making it unlikely that our government will pursue the correct path." Luft stated that the greatest thing that can be done to improve the United States' energy policy would be to move the presidential primaries out of Iowa. As an example of how agricultural interests get involved to create policies that run against energy security goals, Luft noted that oil imported from hostile or risk-prone suppliers like Venezuela and Russia is not taxed, yet ethanol imported from friendly, stable Brazil is taxed; he argued that one reason for this discrepancy is that presidential candidates feel the need to gain the support of ethanol lobbies during the Iowa primaries.

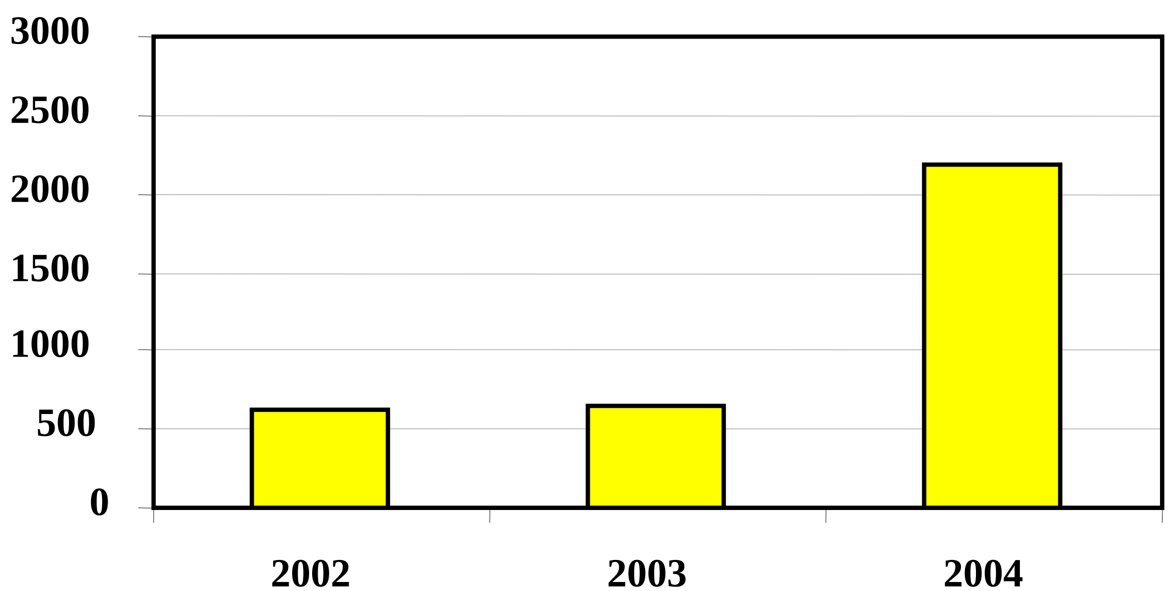
Luft remarked that politicians on both sides of the political spectrum have realized that infrastructure must be provided in order for alternative energies to penetrate the market, and that providing infrastructure is both politically and economically feasible. Manufacture of flexible-fuel vehicles (FFVs) is highly feasible and requires only a low cost adjustment from cost car makers (about $100 per car, according to Luft). Luft argued that alcohol pumps could be added to one quarter of the nation's pumping stations at a cost of only $3 billion, which is low in comparison to the $12 billion spent by the oil industry to introduce reformulated gasoline. However, industry participants attending the conference contested this claim, saying that costly separate tanks would be needed to offer a full alcohol blend, not just conversion of an existing pump within current infrastructure.

Luft complained that "current U.S. government policy gives the impression that there is only one option for alcohol-based fuel due to the influence of the ethanol lobby." He added that "the Energy Policy Act of 2005 focused almost entirely on ethanol, mentioning it 76 times, [while almost] ignoring methanol, mentioning it only three times. But gasoline, ethanol and methanol can all be combined in a flexible fuel vehicle's engine."

According to Luft, emphasizing the use of ethanol over other renewable fuels is a mistake; the U.S. should diversify its alternative fuel options. "Cellulosic ethanol is not ready for production: there is not one full-scale demonstration that shows its costs, inputs and outputs; corn production is limited and cannot be easily scaled up, limiting the ethanol that can be produced from it. Sugarcane is the only serious candidate for providing an expanded ethanol supply," Luft explained.

Regarding market penetration of ethanol, Luft said that significant market penetration will occur only if sugarcane-based biofuel is imported. The Brazilian Association of Sugar Cane and Ethanol Producers has noted the potential for expansion: "Today no more than 7.5 million acres are used to produce 4.5 billion gallons. But we have in Brazil more than 250 millions acres that can be taken as a potential area to expand agriculture—respecting all preservation areas, especially our rain forests."

Figure 9: Brazil's Ethanol Exports are Rising *(in 1000 kl)*



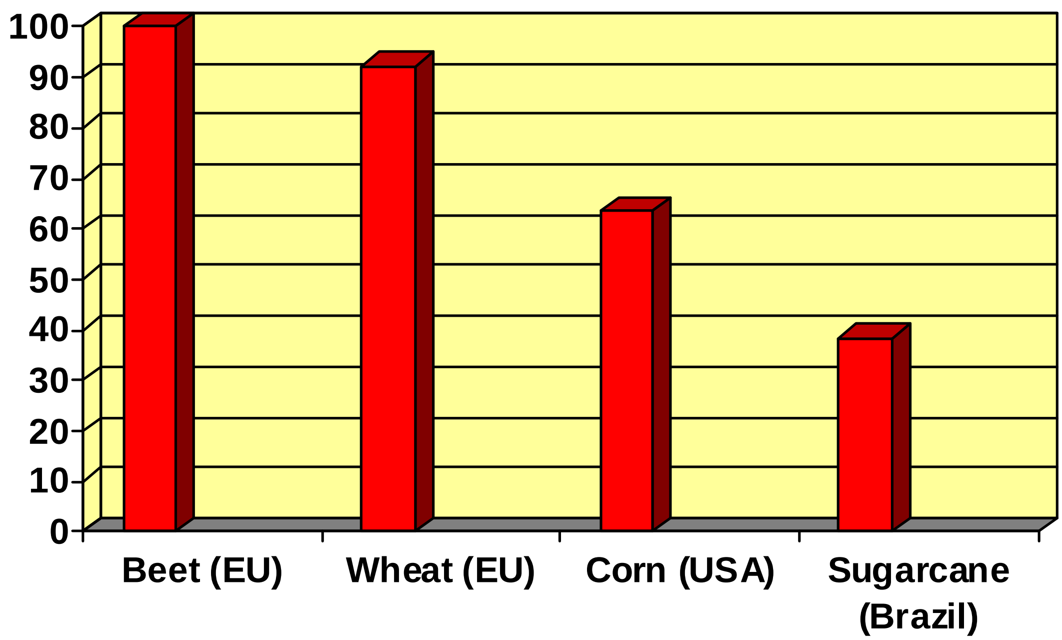
Source: Ministry of Development, Industry and Foreign Trade

Luft argued further that sugarcane-based ethanol is the least expensive feedstock and has the highest energy output/energy input compared to feedstocks such as wheat, corn and sugar beet. (See "Figure 10: Ethanol Energy Balance.")

Figure 10: Ethanol Energy Balance

Raw Material	Energy Output / Energy Input
Wheat	1.2
Corn	1.3 – 1.8
Sugar Beet	1.9
Sugar Cane	8.3

Figure 11: Sugar Cane is the Cheapest Feedstock to Ethanol



Source: UNICA, F.O.Lichts

According to Luft, the most pragmatic approach is to increase the amount of ethanol in the fuel system slowly over time. Although E85 has been introduced in the United States and is the highest percentage of ethanol that will allow an engine to start in cold climates, E85 vehicles have to be refueled more frequently than conventional technology and this may discourage the wider adoption of E85 technology. Operating with E85 fuel lowers the range a vehicle can go without refueling by about 25 percent because ethanol has lower energy content than gasoline. Instead, the U.S. needs to offer a wider number of motorists to be able to utilize blends of ethanol in between E10 and E85. “Rather than encouraging a small portion of the population to use a large percentage of ethanol, U.S. policy should emulate the Brazilian experience by encouraging a large portion of the population to use a smaller amount of ethanol; then, as the population becomes acclimated to alcohol, blends can be increased to contain more alcohol,” he said.

Figure 12: The Brazilian Experience – Percent Ethanol in Gasoline

Year	%Ethanol
1977	4.5
1979	15
1981	20
1985	22
1998	24
1999	20–24
2002–	25%
Source	Luft

“Since 70 percent of Americans currently have no access to ethanol, ethanol is primarily a boutique fuel in the Midwest; only when imports are encouraged will ethanol penetrate the rest of the country, and if the U.S. refuses to promote imports, exportable ethanol supplies will go to other countries, such as China or India,” concluded Luft.

Luft noted that moving to flexible-fuel vehicles needed to be coupled with diversification beyond ethanol. He said that policy should favor the development of FFVs that could work with multiple alcohols, including global electric motors (GEM), ethanol, gasoline and methanol. “Methanol is a viable alternative to ethanol,” Luft said. “Though it has a lower energy content than ethanol, methanol emits less carbon and can be produced from any carbon-carrying substance—unlike ethanol—making methanol far more scalable.

Additionally, one ton of biomass can be converted into 186 gallons of methanol, compared with only 125 gallons of ethanol (basing my numbers on the Btu equivalent with Iogen technology). Production of methanol is also a considerably easier chemical process," stated Luft.

He also warned that existing legislation on FFVs has created problems for the development of an effective car mileage standard system in the United States. Under the current fuel economy regulations, car manufacturers receive a 1.2 mile per gallon (mpg) credit for every FFV that they produce that can run on either E85 or conventional gasoline. This is considered problematic, because few of the FFVs being used to earn this credit in Detroit actually operate on alternative fuel. Less than 1,000 out of 170,000 gasoline stations in the United States offer E85 fuel. Still, despite proposals to the contrary, this loophole in the U.S. CAFE standards system was not reformed under the newly passed Energy Independence and Security Act of 2007.

COMMERCIAL PERSPECTIVES: OUTLINING THE POSSIBILITIES

Auto Industry Perspective

In her presentation "Sustainable Mobility: Energy Efficiency and Advanced Technology Pathways," Susan M. Cischke, vice president of environmental and safety engineering at Ford Motor Company, gave a car company perspective on alternative fuels, noting that the auto industry faces the challenge to maintain a critical balance among the desires of the consumers, the products consumers purchase, and environmental practice and cost structures.

Cischke asserted that auto industry has made progress on the fuel economy issue and aims to do more. She added that the automotive industry is dedicated to pursuing alternative fuel vehicles with a focus on improving fuel economy to promote U.S. energy security. She noted that the industry has been focused in the near term on creating energy efficiency in advanced gasoline internal combustion engines but that increasingly companies will be offering hybrid power trains and modern clean diesel engines as a mid-term solution, especially in niche markets such as urban stop-and-go driving conditions. In 2006, about 10 percent to 15 percent of the auto market consisted of hybrids. Hybrid electric systems include efficient electric motors that drive the wheels and extract energy as the car slows down. Regenerating braking can return as much as half of an electric vehicles' kinetic energy to storage cells as the car is slowing down, giving this kind of car a major advantage in stop-and-go traffic conditions as opposed to a traditional combustion engine system with its mechanical drive train system powered by the combustion engine, which uses more fuel in stop-and-go conditions.

Cischke said companies are also looking at plug-in hybrid cars but that issues remain, including the cost and weight of batteries and the coordination with the development of the U.S. electricity grid. Electricity provider PG&E of California has unveiled a new vehicle to grid (V2G) technology to move power between electric vehicles and hybrid plug-ins and the grid. If 1 million next-generation V2G vehicles were to come to the road, they could generate up to 10,000 megawatts of electricity or the equivalent of 20 average-size power stations, according to a study by AC Propulsion Inc., a California electric vehicle company.

Ford also thinks that modern, clean diesels will be a core technological component in how the company approaches efficiency and fuel economy during the next 40 years. Though challenges include fuel quality and tailpipe emissions standards, diesels have the potential to attain a significant increase in fuel economy of up to 20 percent to 30 percent; these vehicles also outperform vehicles with traditional designs with improved emissions performance and less noise and odor than the diesels of the past. Many auto manufacturers and consumers are beginning to recognize the possibilities of biodiesel and the benefits of diesel vehicles, as seen in Europe, where diesel vehicles constitute upwards of 50 percent of the market. Even in a small scale setting like Rice University, a small-scale biodiesel production project can meet the demands of the campus shuttle fleet. (See Appendix.)

For now, Cischke said that ethanol is a lower-risk proposition to meet calls for alternative fuels. Ford is promoting the development of E85 industries and infrastructure with nearly 2 million flexible fuel vehicles on the road by the end of 2006. By that time, U.S. automakers will have produced 6 million FFVs. If all of these vehicles operated on E85, over 3.6 billion barrels of gasoline a year could be replaced with alternative fuel. On June 28, 2006, Ford, General Motors (GM) and Daimler Chrysler voluntarily committed to doubling their production of FFVs by 2010. "There are and will be many FFVs on the road in the near future," noted Cischke, "but there are many difficulties in getting to that point."

Cischke said that because ethanol (E85) is a unique fuel with unique properties, the components to produce an FFV—fuel tanks, pumps, lines, injectors and calibrations—have to be adjusted. "For carmakers, the greatest challenge is the research and development work to adjust the calibrations so that vehicle could run across the spectrum of percentages from 0 percent to 85 percent ethanol content fuel. "Such a system does not exist at present," according to Cischke. She said it would take Detroit more time to develop a calibration system that could respond to varying ethanol content in between the ranges of the current 10 percent and E85. Cischke noted that biodiesels from various biomass sources further complicate the implementation of a universal calibration system as each input material will create a fuel of a differing formulation.

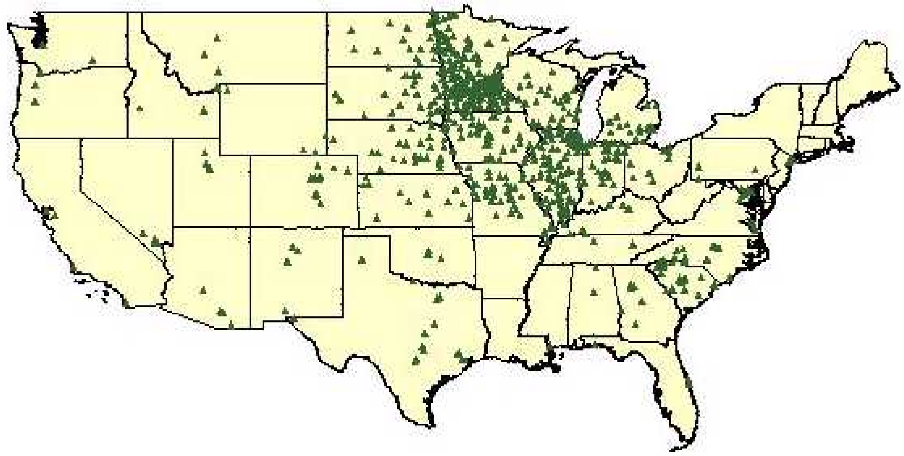
"Due to these technical variations in fuel types, it is a double R&D workload to obtain certification for the FFV vehicles to run both on ethanol (E85) and on gasoline (typically with an ethanol content of 10 percent to 15 percent); calibration must account for differences in climate, temperature, altitude, etc.," she explained. As an example of these difficulties, Cischke added that since the ethanol content of E10 and E20 has high evaporative qualities, meeting emissions standards is challenging in this range of fuel composition. She noted that "ethanol has a lower investment cost than hydrogen in infrastructure development and technology investment in terms of what is being done now, though as cellulosic ethanol comes online significant technology investments will be necessary."

Confirming what Karsner stated in his opening remarks, Cischke agreed that the ethanol path is caught between the classic "chicken or egg" debate regarding the lack of infrastructure for ethanol vehicles: Does the vehicle come first and then access to fuel supplies, or does the fuel infrastructure need to be developed first to drive consumer demand for the ethanol vehicle? Cischke said, "Ford's ethanol vehicle has been on the market for nearly 10 years now, but the fuel infrastructure is still lacking. The auto industry is faced by challenges to include the technological development of FFVs, ethanol production and feedstock diversity, and supply and transport infrastructure, and consumer awareness."

E85 stations are located primarily in the Midwestern states. (See "Figure 13: Distribution of E85 Fueling Stations in the United States.") In June 2006 the U.S. Energy Information Administration (EIA) reported that there were 799 E85 fueling stations in the United States (out of about 170,000 fueling stations); by September 2007, the DOE reported that this number surpassed 1,200.[xxv] Cischke believes that more E85 stations can help solve the "chicken or egg" dilemma.

For its part, Cischke said, "Ford, in collaboration with VeraSun [Energy Corporation], is currently developing the Midwest Ethanol Corridor, incorporating 50 new E85 stations between Chicago and Kansas City. Other collaboration will be forthcoming between Ford and BP to further develop this corridor, and Congress has passed bills to encourage converting midgrade pumps. According to Ford Motor Company public statements, Ford estimates that pump conversion costs are approximately $20,000 per pump, though estimates vary."[xxvi]

Figure 13: Distribution of E85 Fueling Stations in the United States



Source: Ford

One hindrance to the use of E85 is that consumers are ill-informed regarding the ability to mix fuels in FFV tanks; FFV calibration sensors are designed to recognize any composition of fuel and will run even if you add a high ethanol content fuel to a partial tank of gasoline. Because consumers sometimes fear that owning an FFV reduces the resale value of their vehicle due to concerns over complicated technology, Ford terminated its practice of labeling FFVs; however, the company is starting to advertise the vehicles again.

In terms of greenhouse gas emissions, according to Ford, on a grams-per-mile basis—looking at the GHG output produced from production to use, alternative fuels provide a benefit over traditional gasoline:

- E85 with dry mill corn ethanol:
  About 400 ghg/mi (~100 GHG less than traditional gasoline vehicle);
- E85 with wet mill corn ethanol:
  About 425 ghg/mi (~75 GHG less than traditional gasoline vehicle);
- E85 with cellulosic ethanol:
  About 180 ghg/mi (has negative GHG/mi output from well-to-pump).

Longer term, Ford is currently testing a demo fleet of hydrogen internal combustion (H_2ICE) shuttle buses in cooperation with the state of Florida, the Dallas-Ft. Worth airport, the Canadian government, and others; test results will help the auto and fuel industries as well as policymakers address issues and concerns with infrastructure development for a hydrogen economy. H_2ICE vehicles could function as a bridge, fostering infrastructure development as the industry progresses toward reducing the cost of fuel cell vehicles, according to Cischke.

Cischke said that “fuel cell powertrains are the highest efficiency technology” to date; the auto industry considers technological advances in hydrogen and fuel cells as the future in transportation. Ultimately, the auto industry views fuel cells and the hydrogen economy as the “endgame,” though the horizon for impact is about 20 to 30 years in the future. Some auto manufacturers, including Ford, are already on the road today with test fleets of fuel cell vehicles. In 2006, Ford had about 25 Focus fuel cell vehicles on the road working to improve the technology. However, to make these vehicles competitive, the cost must be reduced by “one to two orders of magnitude,” according to Cischke. To have test fleets in a significant volume is a very costly endeavor as the test cars approach nearly $1 million each. In the meantime, they must determine from which source to obtain the hydrogen and develop affordable fuel cell technology.

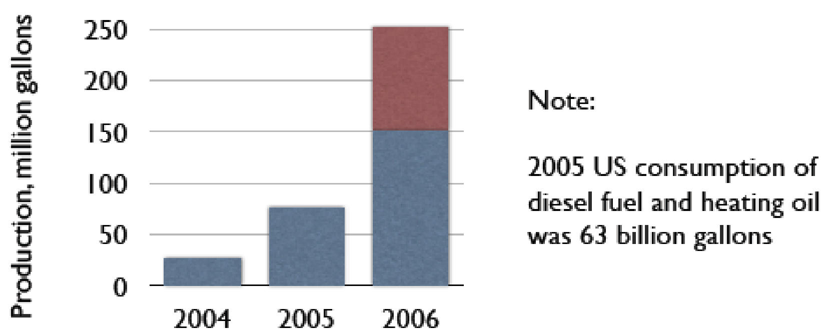
In her concluding comments, Cischke emphasized that “while the problem is great, it is not insurmountable.” She said that the auto industry believes that the solution to our fuel and transport industries lies in an integrated approach between manufacturers, consumers and policymakers. “There is more than one solution, but all solutions will require vast capital investments. The automotive industry must continue to accelerate the deployment of advanced technology vehicles. Furthermore, we must continue to improve the efficiency of the products and to educate the consumers in ecodriving and caring for the vehicles,” Cischke said. She added that research and development must be pursued in advanced alternative fuels such as cellulosic, biobutanol and biodiesel in addition to ethanol, looking towards backwards-compatible fuels for the existing vehicle fleet as a bridge to the vehicle future. “Ethanol is not the only solution,” she noted.

Oil Industry Perspective

In his presentation "Biofuels: The Winning Formula," William C. Spence, chief executive officer and president of Galveston Bay Biodiesel, discussed industry investment in biofuels—particularly biodiesel and ethanol—and the logistical hurdles to their market integration and production.

The U.S. DOE estimates that biodiesel could account for 10 percent of the U.S. petroleum diesel market by 2015. Spence said he believed that this kind of target, which would require 6 billion gallons to be produced, would be a challenge on a feedstock basis. (See "Figure 14: U.S. Biodiesel Production.") A national 2 percent blend mandate would require over 2 billion gallons of biodiesel annually. According to Spence, "In 2005, the U.S. market produced 75 million gallons, which was expected to grow to a run rate of 300 million gallons by the fourth quarter of 2006; whereas, the European market in 2005, where there is a mandate to have a 5.7 percent blend, produced 906 million gallons of biodiesel."

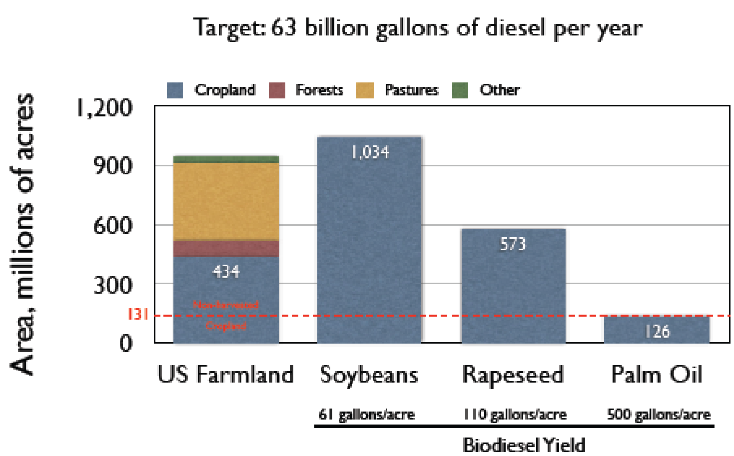
Figure 14: U.S. Biodiesel Production



Spence explained that biodiesel is very versatile, meeting niche market demands. Biodiesel can benefit the environment as it is a lubricity agent, in combination with diesel, and helps to remove sulfur from fuel; also, pure biodiesel (B100) is used in primarily pristine environments such as national parks, U.S. ports and major waterways. Furthermore, there are many biodiesel blends that are well-suited for different environments and uses. Aside from B100, there is blended biodiesel (B20), which is currently used in proactive fleets such as those of the U.S. military, various state departments of transportations, commercial users, bus fleets and boats. B100 reduces net CO_2 emissions by 78 percent compared to petroleum diesel, according to Spence, and also significantly lowers total particulate matter pollution and SO_x. However, biodiesel use can potentially increase NO_x pollution at certain blends and this is something the industry needs to study further.

Spence also said that biodiesel markets are mainly located in states with existing mandates, so the legal infrastructure exists to promote these markets as they grow. In the marketplace, Spence said that "biodiesel prices are currently discounted to drive consumer acceptance of the fuel type, though prices do vary slightly based on end use, availability, mandates and image." He said that biodiesel moves on a competitive basis with heating and diesel fuels and that eventually, biodiesel will sell at parity to low or ultra-low sulfur diesel in the fuels market.

Figure 15: Replacing Petrodiesel with Biofuels

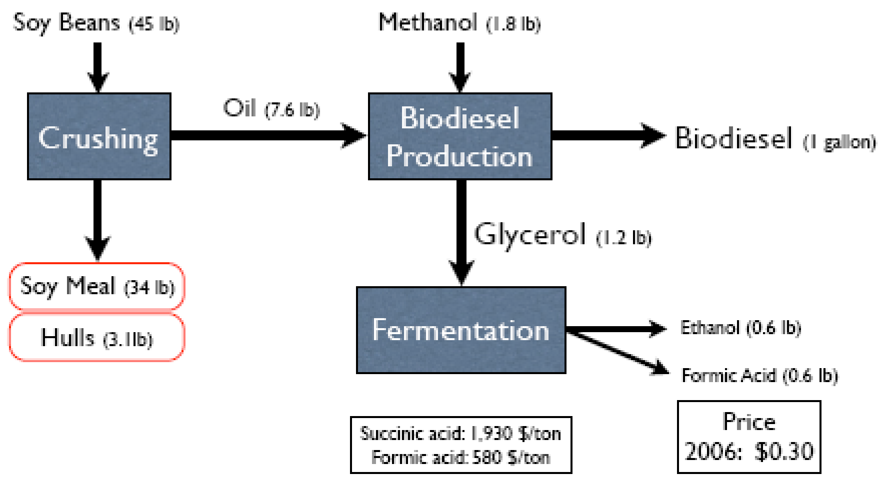


Spence explained that biodiesel lacks some of the logistical complications of ethanol and can be transported within the existing distribution chain while ethanol transport remains more problematic. For example, Spence noted that transporting high volumes of ethanol is taxing upon U.S. railroad infrastructure. In the present market, the delivery tank cars for moving ethanol have to be contracted out a year in advance. By contrast, biodiesel can be transported in current pipelines at a cost of several cents a gallon below the costs of shipping by truck. Biodiesel also blends easily into petroleum-based diesel fuels (unlike ethanol, which absorbs water) and provides 94 percent of the Btu content of petroleum-based diesel, obviating the consumer acceptance problems associated with the efficiency of E85 ethanol fuel.

However, there are some difficulties to overcome in the biodiesel industry; the industry is focused on how to overcome problems of quality assurance and industry standards across production facilities. According to Spence, demands for industry standards are driven by problems with biodiesel quality from smaller facilities. There are about 45 biodiesel plants currently in operation, most of which are small and are concentrated primarily in the Midwest (though larger facilities have been opening on the coasts in recent years). Spence said that it was difficult to set standards because “biodiesel can be produced from most types of vegetable oil and some animal oils; therefore, the quality of the biodiesel varies according to which vegetable or animal oil you used in production, as each type of oil has varying flow characteristics and co-flow properties.” The industry is currently looking for technological methods to establish a uniform quality standard for biodiesel regardless of the feedstock used.

More specific to the U.S. market are problems related to soybean oil and the biodiesel industry. From 2005–2006, U.S. soybean production was 2.9 billion bushels, which is enough to produce 4 billion gallons of biodiesel. (See “Figure 16: Biodiesel from Soy Beans.”) Spence stated that soybean oil is the preferred oil source in the United States, but there is little excess soybean oil in the market. Therefore, he concluded that new feedstocks and waste feedstocks would be key in the future to ensure there is enough supply to meet biofuel, and particularly biodiesel, demand.

Figure 16: Biodiesel from Soy Beans



<u>Technology Potentials</u>

In his presentation on "Getting Serious about Biofuels: Technology Potentials," Adam Schubert, U.S. product strategy manager at the BP Fuels Management Group, posed the question of how to make biofuels a profitable business that can make a significant, sustainable contribution to the United States and global supply picture. He noted that the business would have to stand on its own and that government-backed incentives should not be the only driver considered. The industry, Schubert noted, needs to be able to make technological progress to make biofuels cost-competitive with traditional fuel options. He said the industry needs to work to ensure that biofuels will have the same reliability and quality standards as existing fuels to avoid erratic prices and public recriminations. "As biofuels are expected to constitute 20 percent of U.S. transportation fuel, at that level of integration in the market, deficiencies of a few percentage points in biofuel supply can cause large price spikes," he said. (See "Figure 17: Combined Technology Case.")

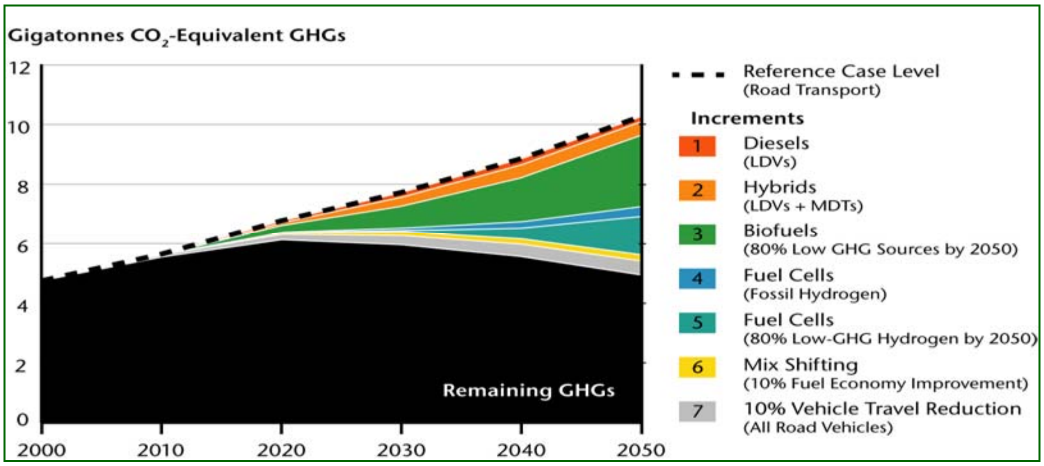
According to Schubert, technological advances must address the following issues:

1) Biofuels must be economically viable, providing sufficient incentives to everyone involved in the supply chain;
2) Biofuels must be functional and reliable;
3) Biofuels must be deliverable day-to-day;

4) Biofuels must be consistent in quality and formulations;
5) Biofuels must meet consumer demand for vehicle range and fuel cost.

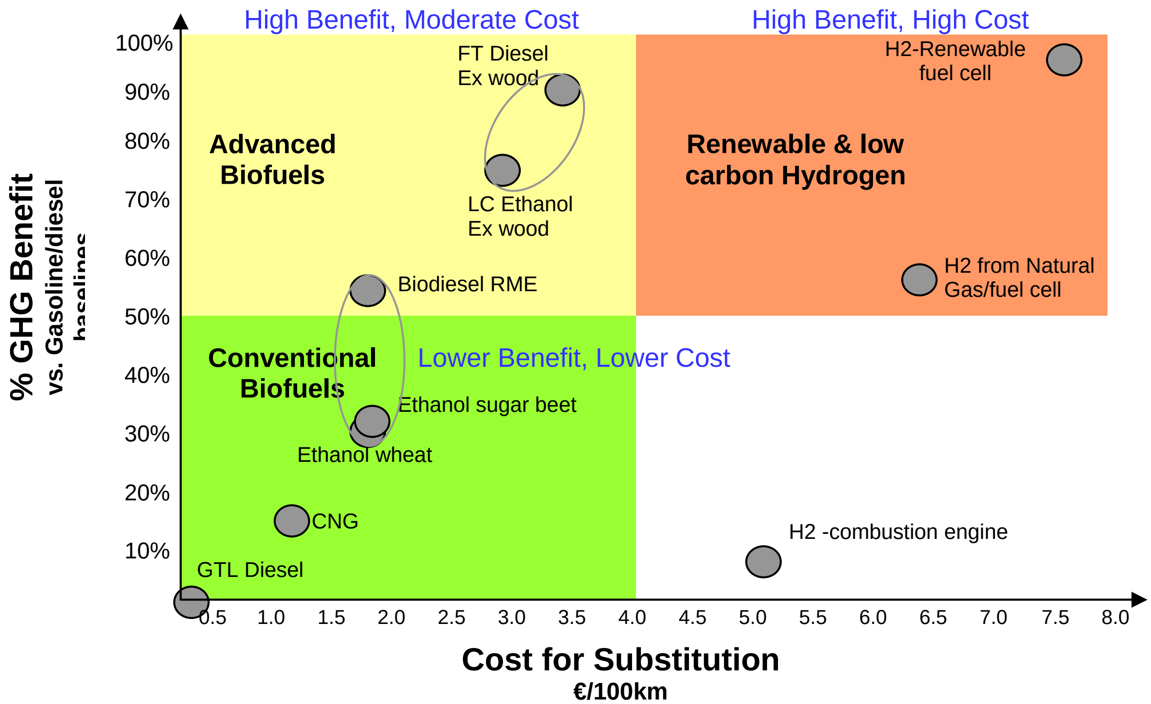
To drive development to meet these demands, Schubert says better feedstocks, better processes and better fuel molecules are needed. Ethanol is not the only possible solution and there might be other kinds of biofuels and road transport methods that can offer better economics, greater efficiency and improved environmental performance.

Figure 17: Combined Technology Case



In order to provide the biofuel penetration necessary to meet future U.S. consumption, Schubert stated that technological advances must be aimed at altering the plant technology used to produce biofuels—including those in ethanol fermentation and biodiesel transesterification. Different feedstocks result in different molecules, which have different properties, cold flow, storage stability and product consistency. Regarding infrastructure changes, turning towards alternative molecules more efficient than ethanol would be appropriate; however, science has not yet identified which molecules are the most efficient, and undoubtedly requirements will change over time. Schubert observed that "it is important that we not get locked into one molecule and lose sight of our goals—sustainable fuels and air quality—rather than producing a particular type of fuel."

Figure 18: GHG Benefit vs. Cost*



**Reference-WTW Analysis of Future Automotive Fuels & Powertrains in the European Context-Version 2a, December 2005. Concawe/European Council for Automotive R&D / European Commission Joint Research Centre*

Schubert noted that large economies of scale will be needed to make biofuels a commercial business that can contribute large scale supply in the United States. “This will likely mean changing the crop basis for producing biofuels,” Schubert noted, “but it will be difficult to convince farmers to change to alternative crops, which have different cash flows and rotate on different time scales than those to which they have become accustomed to growing.”

BP is researching advanced biofuel alternatives that respond to consumer and policy concern over greenhouse gas reduction, secure fuel supply, and agricultural support. In June 2006, BP announced the formation of their new biofuels business, and the company has committed $500 million during the next 10 years for an energy biosciences institute to be located at University of California, Berkeley. BP has been using ethanol for 25 years and is currently the largest ethanol user in the United States, at 575 million gallons a year. BP also expects its involvement in biodiesel to grow in future years. According to Schubert, “BP wants to apply to biofuels those bioscience advances that have been successfully applied to the pharmaceutical and food industry.” To achieve this, BP is working with DuPont on developing biobutanol and is conducting research on the potential of detropha—a nonedible crop that can be grown on marginal land—as a biodiesel feedstock.

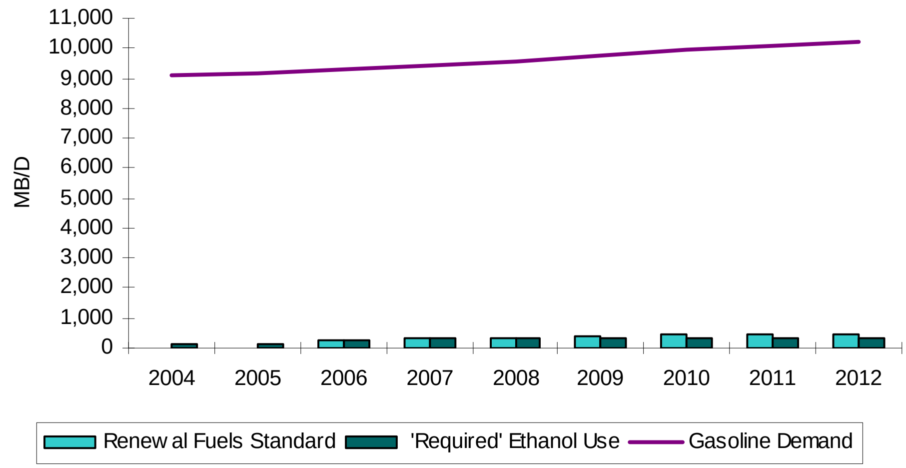
Schubert concluded that BP feels “biobutanol is one alternative that shows promise for the immediate future, given the infrastructure and technology currently in place.” It is produced from the same feedstocks as ethanol, with minimal process changes; can be blended into gasoline at the refinery and transported via pipeline (because it does not have ethanol’s water solubility issue) and it can be used at higher blend concentrations than ethanol in unmodified vehicles; its energy content is closer to gasoline (reducing the fuel economy impact for the consumer of ethanol), and butanol can be blended with ethanol, enhancing the performance of ethanol blends in gasoline.

<u>Agriculture and Commodity Industry Perspective</u>

In his presentation on “Opportunity, Risk, Volatility, and Public Policy,” Paul D. Addis, chief executive officer of Louis Dreyfus Energy,[xxvii] raised critical questions surrounding the problems that could emerge from the integration of energy and agriculture markets.

Addis emphasized that while the growth of domestic ethanol and biodiesel are a logical and useful contribution to resolving the current hydrocarbon shortage and enhancing energy security, they are only a partial solution which at the same time raise a number of national security, foreign policy, food and competitive market issues. Noting that ethanol and biodiesel has become “fashionable,” Addis projected that biofuels could achieve a 5 percent share of gasoline stocks by 2012.

Figure 19: RFS Volumes, 'Required' Ethanol Volumes and Gasoline Demand



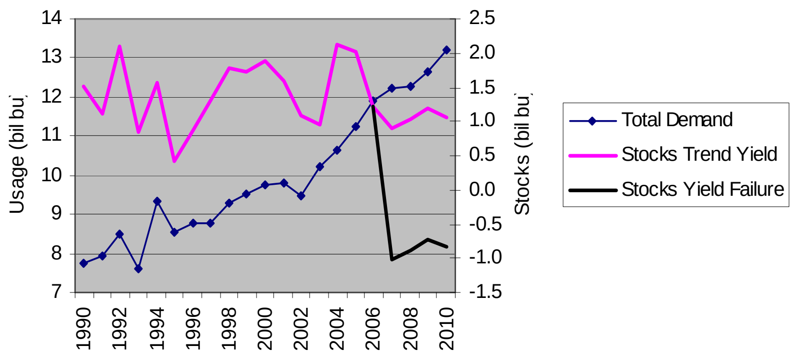
Source: Louis Dreyfus Energy

But even with this potential as alternative fuels, Addis questioned whether it is sound public policy to subsidize ethanol and biodiesel production and buttressed domestic supplies with duties on imported ethanol. Addis pointed out that the current "distortion of free trade retards development off the highly efficient Brazilian ethanol industry" and creates "associated risks such as price volatility."

By contrast, if the United States, as a foreign policy and energy policy initiative, encouraged the developing world, especially in the Western Hemisphere, to develop an ethanol industry with targeted and short-term production subsidies, it would both create a vibrant agricultural economy for these countries, leading to further economic development, and help U.S. relations with the participating countries.

Addis noted that there are currently three uses for grains and oil seeds: feeding livestock, providing food for humans, and converting to energy as fuel. He said that the portion of energy supply that comes from ethanol and biodiesel is relatively small, so demand for these products will not be a major driver to energy prices in the foreseeable future. But the opposite is not true. Energy demand for ethanol could potentially drive agricultural prices and create distortions especially in a time of a grain supply shock, such as a major drought. Due to rising demand for corn as a feedstock for ethanol production, inventories of corn in 2007 are at their lowest level since 1995 (a drought year), even though 2006 yielded the third largest corn crop on record. Commentators are starting to note that the "enormous volume of corn required by the ethanol industry is sending shock waves through the food system."[xxviii]

Figure 20: U.S. Corn Usage & Carry Out Stocks



Source: Louis Dreyfus Energy

According to Addis, if a drought occurred, the biofuel industry, supported by subsidies, would win over the agricultural feedstock and agrofood industries in a competition over supply and prices, which would then drive food inflation. "The effects of a grain supply shock caused by a drought in the United States would be far more pronounced on livestock industry and grocery prices than on energy prices," Addis said. The higher oil prices would be, the more ethanol producers could afford to pay for corn. At $80 per barrel oil, ethanol producers can afford to pay over $5 per bushel for corn. Even in a free market—with no government subsidies of ethanol production—a drought could have similar impacts on food prices, Addis noted. This is particularly salient since scientists have warned that one impact of global warming, if unchecked, could be extreme drought in the U.S. Midwest.

In the United States, the growth in ethanol production has influenced not only prices for corn and other grains, but also other crops, as use of land to grow corn and soybeans for biofuels is reducing acreage being utilized for other crops. Rising feed prices are also hitting livestock and poultry businesses and hitting other countries such as Mexico, which saw a doubling of the costs of tortilla flour in 2006 as more corn was used for fuel.

"The future of biofuels," Addis concluded, "will consist of making cellulosic products economically viable through the support of federal research dollars and via increasing agricultural yields in order to alter the supply and ecological impacts."

ENVIRONMENTAL ISSUES

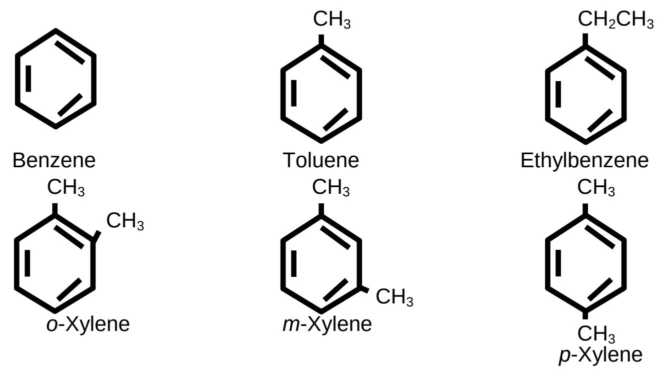
In the session on the environmental impact of biofuels production and use, conference participants advocated increased research in identifying necessary steps to avoid unintended and negative consequences on sustainable development and the environment, including deleterious impact on domestic agricultural and food systems.

Groundwater quality impacts

In his presentation "Ethanol in Fuel: Microscopic and Macroscopic Implication for Groundwater Pollution," Pedro J. Alvarez, chair of the department of civil and environmental engineering at Rice University, discussed groundwater contamination that come about through the leaking of gasoline additives into the ground.

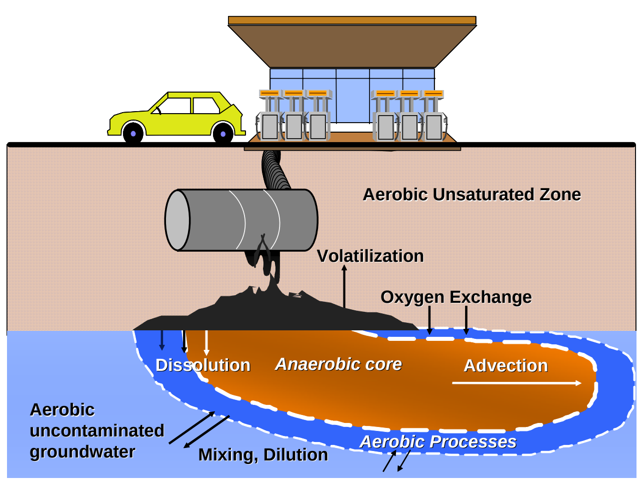
According to Alvarez, 11 million gallons of gasoline reach the subsurface every year from 450,000 leaking underground storage tanks (USTs). Gasoline leachates are toxic because they contain benzene, toluene, ethylbenzene and xylene—a group of hydrocarbons commonly known as BTEX. (See "Figure 21: Contaminants of concern with fuel spills: BTEX.")

Figure 21: Contaminants of concern with fuel spills: BTEX



Of BTEX compounds, benzene is the biggest concern as it causes leukemia. While benzene moves along the contamination flow, it is slowly degraded by native soil bacteria, which creates a steady state where the plume does not grow or shrink. Benzene plumes will typically extend 200–300 feet for 20–50 years. Leaking USTs create plumes of contaminant that migrate in the direction of groundwater. Physical, chemical and biological processes act upon the plume, reducing or enlarging the overall plume length. Water-soluble compounds will move along the groundwater while insoluble compounds will not. Natural attenuation will take care of biodegradable compounds while recalcitrant compounds will remain. Long and persistent pollution plumes may reach drinking water wells, posing a public health hazard.

Figure 22: Leaking Underground Storage Tanks (USTs)



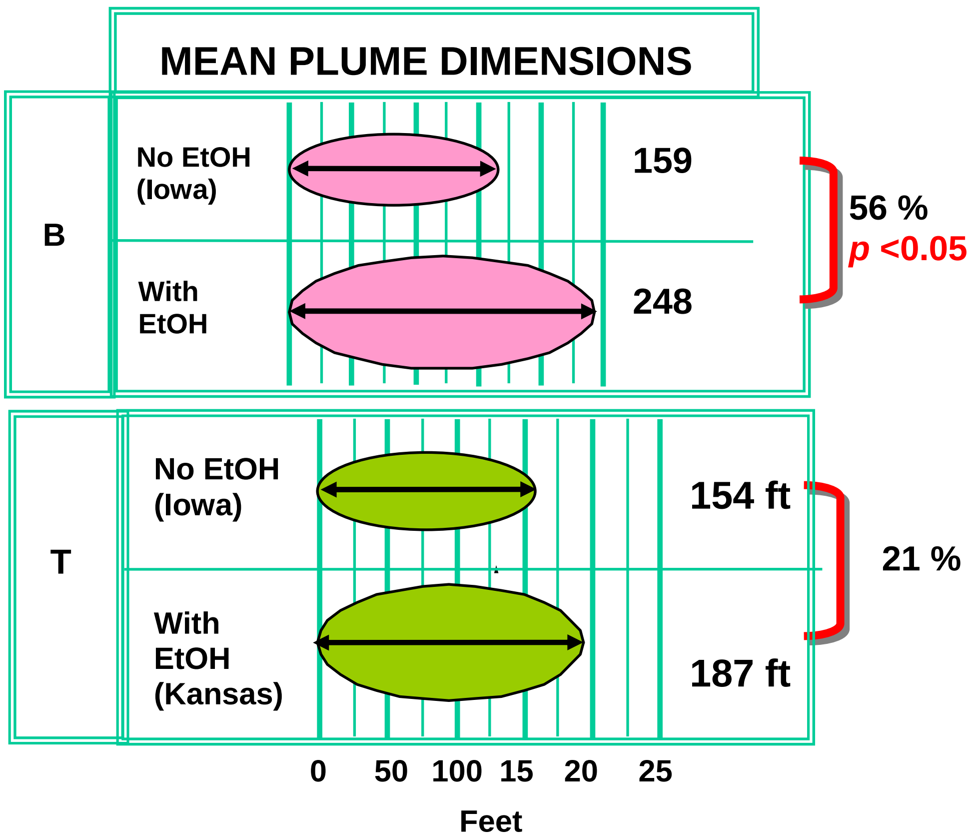
In 1990, the Clean Air Act (CAA) mandated blending gasoline with methyl tertiary-butyl ether (MTBE) and the addition of catalytic converters to reduce carbon monoxide (CO) and unburned hydrocarbon emissions to improve air quality. However, engineering the solution to this problem created another. MTBE is very soluble and recalcitrant. When leaking from underground storage tanks it may create a pollution plume 1,000–10,000 feet long. In addition, MTBE is considered a potential carcinogen. Therefore, though MTBE improved air quality, it was determined detrimental to groundwater quality and was phased out and replaced by ethanol.[xxix]

But as before, the solution to one problem may be the origin of another. In the event of a gasohol (gasoline and ethanol) spill, two liquid phases are created with different transport characteristics. Soluble ethanol moves along the groundwater flow while BTEX remains as a pollution source constantly bleeding to the water phase. Although initially ethanol creates a co-solvency effect that increases the rate at which the BTEX dissolves into the water phase, ethanol eventually washes out of the system while BTEX remains.

Ethanol also has different biodegradation characteristics. It is preferred over BTEX by microbes so that even a small amount of ethanol in the system has a severe inhibitory effect on the degradation rate of BTEX. This inhibitory effect of ethanol on specific BTEX degradation activity can be offset by additional cell growth. Three bacteria working at 50 percent capacity are more efficient than one working at 100 percent capacity. However, this growth cannot continue ad infinitum because the ethanol biodegradation will exert such a high oxygen and nutrient demand that it will very quickly drive the system to an anaerobic state, under which BTEX cannot degrade well. The presence of ethanol also leads to genotypic dilution—the microorganisms that thrive on ethanol are 'incompetent' at efficiently breaking down BTEX.

Thus, an ethanol leak as a pollutant would most likely lead to larger and more recalcitrant plumes but whether this increase in size is significant will depend on the release scenario and the characteristics of the site. Field experiments showed that benzene plumes reached up to 80 feet longer in the presence of ethanol. This is of relative importance for public health since laws require a drinking well to be at least a quarter mile from a gas station. Alvarez concluded that given the choice between ethanol and MTBE, "the impacts of ethanol mixtures are of shorter duration, and are less significant and more manageable than those associated with MTBE."

Figure 23: What is the Overall Effect of Ethanol?



Source: Rice University

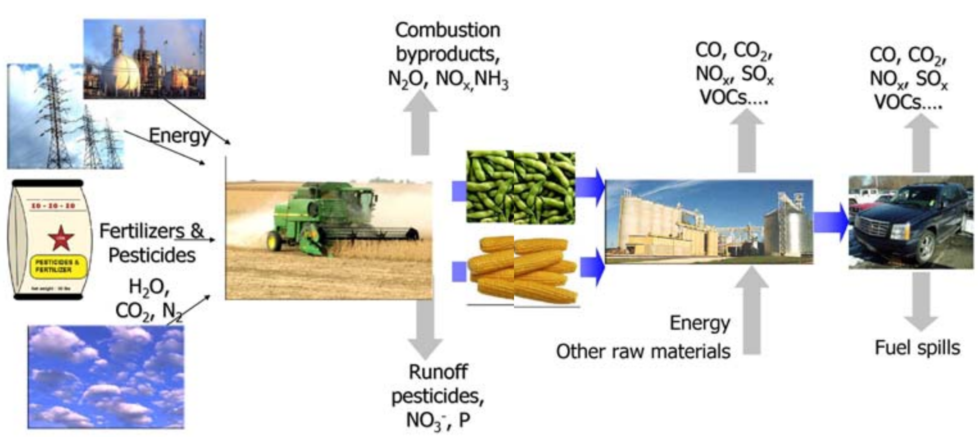
<u>Surface Water Quality and Net Energy Value</u>

Biofuels impact the environment not only directly in the form of leakages from storage facilities, but also in their production earlier in their lifecycle. There are many issues associated with the agricultural production of the crops used as feedstocks. Nutrient and pesticide runoff from fields is affecting surface water quality in nearby rivers and lakes as well as distant oceans. In her presentation on "Life Cycle Analysis and Environmental

Assessments," Susan E. Powers, professor and associate dean for research and graduate studies in the Coulter School of Engineering at Clarkson University, discussed her research of the nitrogen and carbon cycles, which she conducted through a life cycle assessment (LCA) on the corn-soybean rotation agricultural system.

LCA documents materials and energy flows throughout a product's life. Stages of the life cycle of a biofuel include upstream raw materials production (e.g. fertilizers or energy), farming, biofuel processing, and final consumption. Farming requires energy, fertilizers and pesticides, and H_2O, CO_2 and N_2 from the environment, and it generates combustion byproducts (N_2O, NO_x, NH_3), and runoff pesticides (NO_3^-, P). The bioconversion process uses feedstock, energy and other raw materials and generates emissions of CO, CO_2, NO_x, SO_x, and volatile organic compounds (VOCs). The use of biofuel products by the consumer will also generate similar types of emissions. Numerous LCAs have been performed in biofuels to analyze air quality impacts and energy use but important omissions have resulted in less than accurate results. In many LCAs for corn ethanol, all impacts are attributed to a single product (ethanol) while other by-products with economic value are generated but not assessed. Such is the case of all remaining protein after the fuel is taken; this protein can be used as food but few have considered it a valued by-product, according to Powers.

Figure 24: Lifecycle Perspective I and II



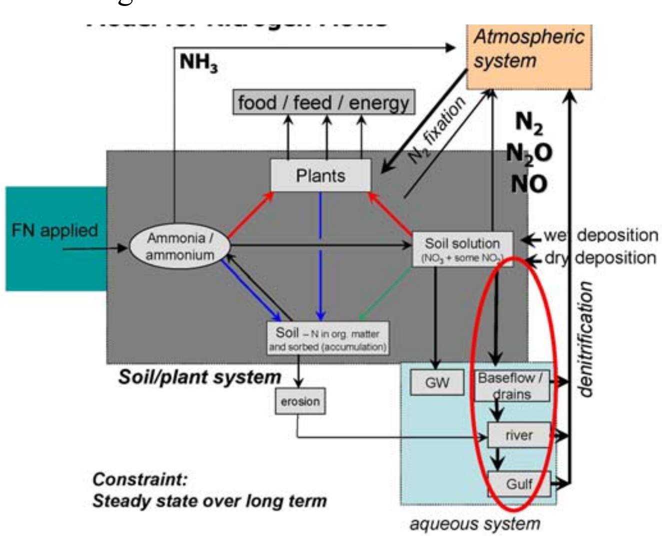
Source: Powers

Environmental Impacts of Agricultural Activities

Corn and soybean farming affect both the nitrogen and carbon cycles. These effects vary in scale and the region in which they are felt. Carbon's impacts are more global, affecting global climate change, while nitrogen's impacts are more regional.

<u>Nitrogen Cycle</u> The nitrogen (N) cycle is complex, involving the conversion of N_2 to ammonia and nitrates through different mechanisms. N greatly increases agricultural yields but excess reactive nitrogen is responsible for many environmental problems, including acidification, smog formation, eutrophication/hypoxia and global warming potential in the form of N_2O. Powers analyzed N flows in the corn-soybean rotation system. Nutrient runoff from fertilized soybean fields provokes eutrophication, an accumulation of nutrients in water that prompts algal blooms. Organisms in the affected aquatic environment will die and decay, creating a high oxygen demand. Extreme cases of eutrophication create hypoxia and drive oxygen levels so low that the ecosystem is no longer capable of supporting life. Hypoxia has given rise to the so-called Dead Zone in the Mississippi River Delta, which is the size of the state of Massachusetts and can be traced to corn-soybean farming in the Midwest.

Figure 25: Model for Nitrogen Flows

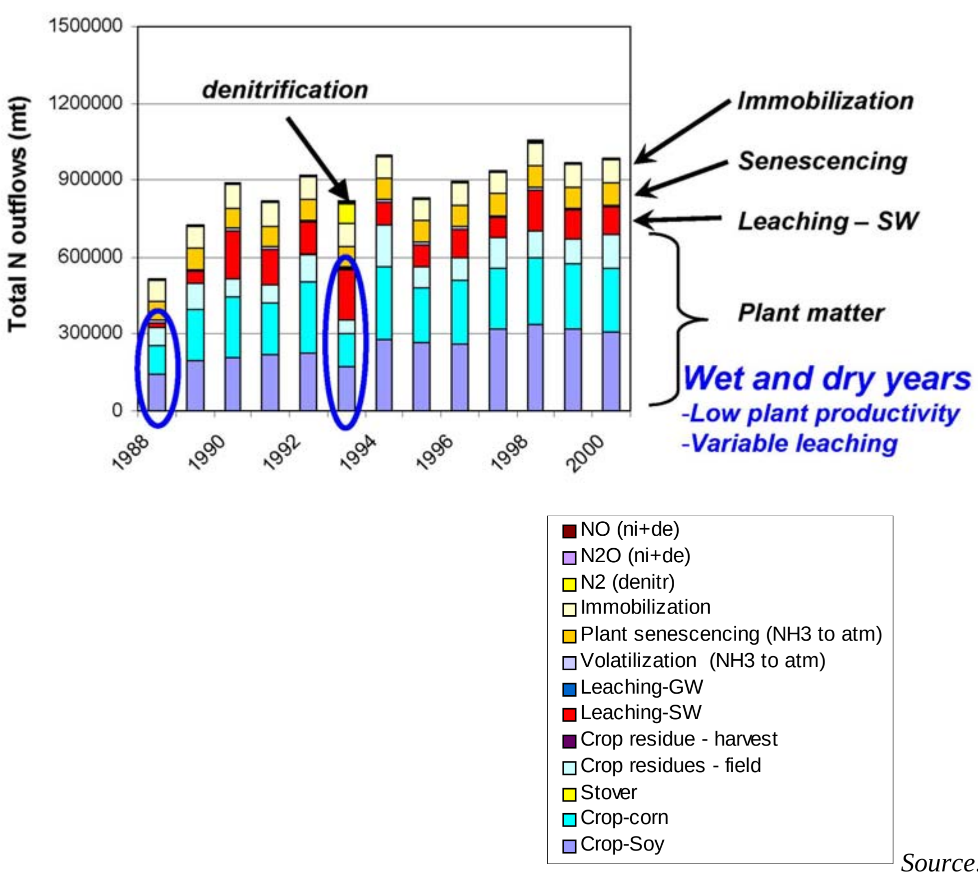


Sources: Canter (1997), deVries (2003), Blackmer (1987)

When assessing environmental impacts, the use of averages is generalized, but often the environmental impacts occur in the extremes. In the case of eutrophication and hypoxia, there is an extreme variability in impact dependent on rainfall. In drought years, there is no rain fall flows to carry nitrogen; in flood years, water carries more nutrients to the affected zones exacerbating the eutrophication/hypoxia phenomenon. Therefore, there is a linear relationship with rainfall.

In addition, it is important to note the scale of the impact. N-related impacts have a regional scale, and impacts in some regions are created by decisions in others. For example, in its attempt to reduce gasoline demand and promote a clean fuel policy, California promotes ethanol as an additive to gasoline, which encourages corn production in the Midwest, the nitrogen runoff from which creates dead zones in the Gulf of Mexico and the Chesapeake Bay.

Figure 26: Nitrogen Outflows

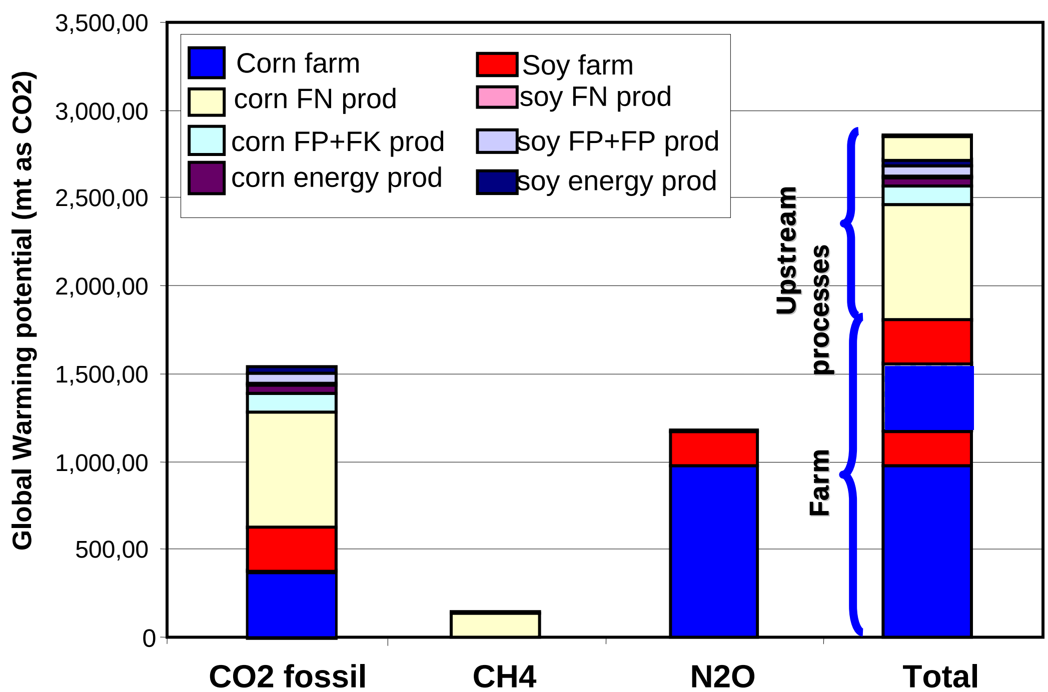


Source: Powers

Carbon Cycle Many argue that biofuels have a carbon neutral cycle—carbon (C) emitted during the combustion is uptaken during plant growth—but this does not account for methane and CO_2 released upstream of chemical processes and energy production and distribution. While the carbon benefit may still be considerable when compared to fossil fuels in terms of green house gas (GHG) emissions and global warming potential (GWP), other considerations must be taken into account, as the carbon is lost from the soil through erosion.

When comparing C vs. N cycles, Powers acknowledged "the impacts derived from each of them are different, and so are the scales of those impacts." There is a fundamental trade-off between the global climate change and the regional impacts of eutrophication and hypoxia, she added. There is a benefit in the C-related impact due to reduction of GHG emissions and fossil fuel consumption, whereas there are detriments in N-related impacts, which can be regional, like eutrophication and hypoxia, or global, as with GWP caused by N_2.

Figure 27: Global Warming Potential



Source: Powers

Thanks to the generous $0.51/gallon federal tax credit for ethanol refiners and blenders, as well as the $0.54/gallon tariff placed on imported ethanol, the domestic ethanol industry is booming and is being touted as a viable U.S. alternative fuel of choice. One reason ethanol fuels are on the rise in the United States is that they are bolstered by regulations that require ethanol to serve as a cleaner substitute to former gasoline additive MTBE, whose use is being phased out because of concerns its widespread distribution was creating a danger to groundwater. Despite its public prominence, however, critics question whether corn-based ethanol is the best choice among the options for biofuels and other nonpetroleum based alternatives. Some scientists and economists have suggested that corn-based ethanol requires a large expenditure of energy to produce and therefore is a less desirable substitute for oil than other possible biofuel alternatives

Other biofuel alternatives currently under consideration in the United States include soybean-based biofuel and cellulosic ethanol produced from switch grass or wheat straw. Although these fuels are thought to be more efficient than corn-based ethanol, the benefits of soybean biodiesel and cellulosic ethanol still face several limitations. Soybean biodiesel is said to generate 93 percent more energy than is required for its production, yet per acre it produces only one-seventh the amount of fuel that corn-based ethanol is currently yielding. Cellulosic ethanol is thought to have the most long-term viability and has the added benefit of using a nonfoodstuff source, yet this alternative is not cost-effective using present technology. Investment is also increasing in facilities to produce biodiesel fuel from waste oil and oil-rich plants as well as ethanol produced from agricultural waste. All these options present opportunities to diversify the U.S. fuel system.

The variety of alternatives raises questions regarding the relative cost-effectiveness and feasibility of the various sources for biofuels and other commodity chemicals that can be produced from biomass materials. In the conference session "Economic and Policy Issues: Comparative Values," Kenneth B. Medlock III, fellow in energy studies at the

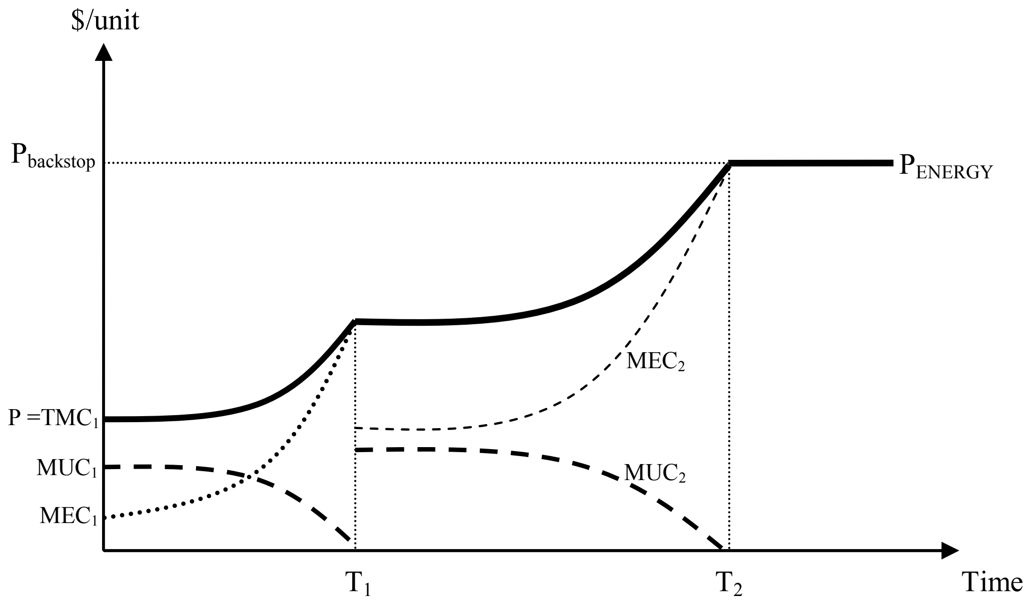
Baker Institute and adjunct assistant professor in the department of economics at Rice University, set the stage by discussing the economic and policy issues of energy use, diversification and substitution in the context of renewable fuels.

Diversification and Substitution

Medlock noted that transitioning to a biofuel economy is about substitution in energy use based on resource economics. In the case of depleting resources, economists consider the following: there are multiple resources with increasing marginal extraction costs over time; the opportunity cost to extract these resources drops over time because there is a substitute waiting on the horizon; eventually a “back-stop” is reached such as a renewable fuel. “Ultimately, any type of resource that is depleting or restrained is a *transition* fuel; at some point in the future, we will use only renewable fuels because cost will dictate that these are the most commercially viable, economic energy sources,” he explained.

“Figure 28: Substitution in Energy Use” summarizes this long-term scenario. Energy prices follow a cyclical pattern, as opposed to the simple depiction in the graph. As it becomes more difficult to extract conventional resources with existing technologies, the price of fuel will continue to rise; this price hike will in turn make investment in innovative technologies more attractive. Thus, as the technology is deployed, the learning curve eventually evens out and the technology costs tend to fall over time. Therefore, developing technology and recovery of higher-cost energy resources (those unconventional and/or hard to reach energy resources) will be delayed until more conventional and easily attained resources are exhausted and it is cost-effective to do so. In other words, transition to a second resource will only occur when the price is high enough to compensate extraction.

Figure 28: Substitution in Energy Use



Energy substitution in the short run is really about short-run ‘switching.’ According to Medlock, biofuels have the greatest potential as a short-run ‘switching’ option.

Developing and deploying the necessary capital to support short-run 'switching' to biofuel options will only occur when the price of the primary fuel (gasoline) is high enough to compensate the extraction and production of an alternative fuel option. Encouraging investment in these capital intensive, alternative fuel options is difficult because the value represented by any of these options does not particularly accrue to any single entity; rather, it accrues to the aggregate—the stereotypical “problem of the commons” (which then typically leads to an argument for policy intervention).

Medlock explained that the private sector will typically not engage in such expenditures unless there is some expected rate of return; this required rate of return hinges on expectations of future prices. A firm will make the decision to invest in those opportunities that give them the greatest expected rate of return. For example, the industry will ask where biofuels stack up in relation to conventional fuels before it will consider investing in the biofuel future.

As Medlock said, "There is a role for policy to reduce the free-rider problem of economics," because energy security accrues to the aggregate health of the U.S. economy and energy supply. To sustain a diverse economy, Medlock emphasized that there must be diversity in energy choices. But what are the forces behind changing from an ingrained energy economy based on conventional resources to an energy economy of diverse fuel options? The forces behind change include the influences of economics and politics.

Economically, prices, cost and technology limitations will determine which fuel choice is the most viable at any given time. Politically, the pretext of acting in the pursuit of energy security and/or energy independence—with policy tools such as taxes, tariffs and subsidies—can spark the necessary interest in pursuing alternative energy resources through investment in the research and development of innovative technologies.

U.S. Federal Policies

Godwin M. Agbara, assistant director of energy issues in the Natural Resources and Environment Office of the U.S. Government Accountability Office (GAO), addressed the issue of such U.S. federal policies, research funding, subsidies, taxes and tariffs. Agbara emphasized that too often "policy can be the bridge to take science and technology…to the people, but it can also actually kill or delay the actualization of all these science and technology developments." Referencing Medlock's description of a theoretical framework for an interventional policy in the market to make renewable fuels competitive in the future, Agbara regretted that unfortunately, policy in Washington, D.C., does not always follow or adhere to science and technology developments.

Rather, policies are often implemented before the science and technology is available to implement that policy. Agbara quoted a statement made by Luft to the effect that to understand the U.S. energy situation you had to understand the situation of U.S. domestic politics. Referring to the late Tip O'Neil, former Speaker of the House who said that "all politics are local," Agbara noted that indeed the modern politics of energy and certainly of biofuels is perhaps more local than most other politics in Washington, D.C.

Agbara said that in 2005, the GAO inventoried energy programs in which the federal government was involved. GAO surveyed what the federal government was doing, how much it was spending, who its collaborators were, and the results from these efforts. These key facts identified by the GAO include the following:

- Over 150 energy-related program activities identified in fiscal year 2003;
- At least 18 different federal agencies involved in these activities, from the Department of Energy to the Department of Health and Human Services;
- About $10 billion in estimated budget authority for energy-related programs;
- $4.4 billion estimated outlay equivalent for tax incentives of subsidies;
- $34.6 billion in revenue mostly from fuel excise taxes (gasoline taxes); and
- $10.1 billion revenue collection from energy-related fees (royalties, etc.).

Agbara then presented the GAO's work specifically on federal tax incentives to the ethanol industry. Tax incentives to the ethanol industry are comparatively recent, beginning with the Energy Tax Act of 1978 and amounting to $19 billion to the ethanol industry between 1981 and 2005 in 2005 U.S. dollars. According to Agbara and the GAO study, these incentives generally decrease revenues accruing to the federal treasury; in recent years, the federal revenue loss as a result of the alternative fuel production credit has increased.[xxx]

Figure 29: Summary of Tax Incentives for Petroleum and Ethanol Fuels (Dollars in millions)

See Appendix for other Tax Incentive Tables

Tax incentive	**Summed over Years**[a]	**Amount in 2005 U.S.D**
Oil and gas industry		
Excess of % over cost depletion	1968–2005	96,119
Expensing of exploration and development costs[a]	1968–2005	41,192
Alternative (nonconventional) fuel production credit	1980–2005	16,927
Oil and gas exception from passive loss limitation	1988–2005	1,311
Credit for enhanced oil recovery costs	1994–2005	2,947
Ethanol industry		
Partial exemption from the excise tax for alcohol fuels	1982–2005	18,854
Income tax credits for alcohol fuels	1981–2005	347

Source: Compiled from annual published data from Treasury

Agbara said that the ethanol industry and particularly the American Petroleum Institute (API) contact the GAO frequently to request data to support alcohol tax incentives. These organizations list several reasons why ethanol should be given tax incentives, including ethanol's infant industry status; a call to level the playing field with the petroleum industry; economic development and job creation in rural areas; environmental concerns; as well as energy security and independence.

The GAO studied the impacts of ethanol tax incentives and found that the petroleum industry does not lose profits as a result of ethanol incentives. However, the GAO investigation did find that overall the net impact on government revenue of ethanol tax incentives was a loss. Ethanol incentives can benefit either the agricultural or energy sectors depending on whether oil prices are high or low. The study found that the value of ethanol tax incentives is shared, directly or indirectly, among various groups—alcohol fuel blenders, ethanol producers, corn farmers and consumers, who would benefit from lower fuel prices.

According to Agbara, the GAO's work concludes that ethanol shows little hope of significantly altering the amount of U.S. energy obtained from imported oil. "Even if the U.S. was to devote itself to ethanol production, the oil import ration would continue to be high and to rise; and ethanol is not produced in enough quantity to mitigate oil supply disruptions and price shocks and their economic consequences," Agbara noted.

The GAO identified two key infrastructure costs associated with a major shift to ethanol:

1) Retrofitting refueling stations to accommodate E85
    - Estimated to cost $30,000 to $100,000 per station.
2) Constructing or modifying pipelines to transport ethanol
    - Potentially expensive.

The Federal government role in ethanol is broad and includes tax, mandate and legislating roles. As noted above, currently, there is a $0.51/gallon tax exemption on ethanol and a $0.54/gallon import tariff. In the EPA 2005, the government mandated the use of 7.5 billion gallons of ethanol by 2012. There are several federal agencies collaborating with industry to accelerate the technologies, reduce their cost, and assist in developing necessary infrastructure. Additionally, they are supporting the development of cellulosic ethanol.

In terms of biodiesel, the GAO study critiqued the federal role and determined that without the federal tax credit of $1 per gallon the biodiesel industry would not be cost-competitive, according to Agbara. However, efforts are being made to improve efficiency. The DOE is collaborating with biodiesel and automobile industries in R&D efforts on biodiesel utilization; and, the DOE has also been conducting biomass GTL research. Also, the U.S. Department of Agriculture has been researching feedstock options to provide new sources for biodiesel.

In conclusion, Agbara stated that "energy independence is an illusion; […] biofuels may supplement, but not substitute, oil. Government involvement in energy markets is always to be expected due to politics and market failures. Sustainable energy requires sustainable policy, meaning it affects supply as well as demand. Federal energy policy has been just as volatile as the price of oil; ideally, it should not necessarily interfere with the market."

Impact: Land Use and Large-Scale Production

In his presentation on the "Possible Impacts of Industrial Biofuels in the U.S. and the World," Tadeusz Wiktor Patzek, professor of geoengineering in the department of civil and environmental engineering at the University of California, Berkeley, presented his research that shows that U.S. government projections for ethanol production are unlikely to be met and would not represent best sustainable land-use practices.

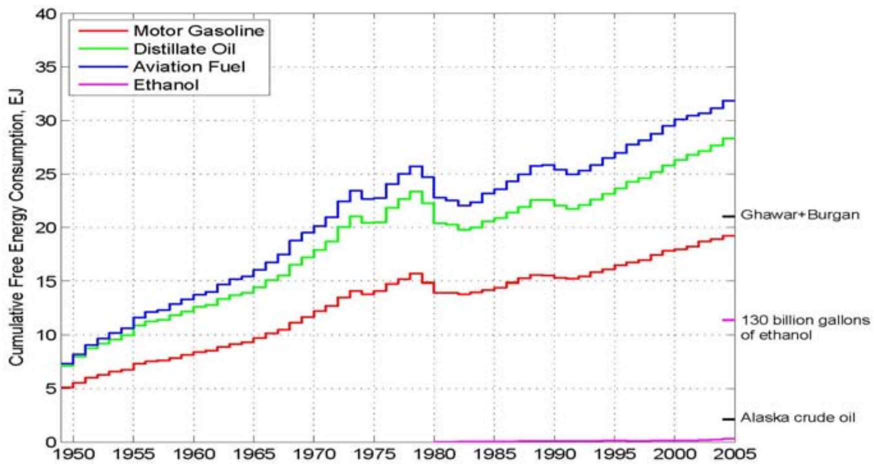
"There are many claims that biomass-derived fuels will replace traditional transportation fuels, but it is highly questionable whether this level of displacement is truly possible," Patzek told the conference.

Summary of Claims:

1) The U.S. DOE aims to have 30 percent of current U.S. gasoline consumption replaced with biofuels by 2030 (*Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda.* July 2006).
2) April 2005 U.S. DOE Report, *Technical Feasibility of a Billion-Ton Annual Supply*, "An annual biomass supply of more than 1.3 billion dry tons can be accomplished [annually] with relatively modest changes in land use and agricultural and forestry practices."

Patzek contends that inefficiencies related to the conversion of corn to ethanol will make meeting the DOE's targets with corn-based ethanol extremely difficult to meet. "In 2005 ethanol only represented 1 percent of U.S. transportation fuels, whereas the United States used over 300 billion gallons of crude oil that year," he said.

Figure 30: Transportation Fuels in the United States



Sources: US DOE EIA, Patzek (2004)
Ghawar and Burgan are the two most productive oilfields on Earth

Patzek warned that estimates of ethanol production from untilled U.S. farmland are overstated. "Current crop production is from the best agriculture land in the U.S., therefore, efficiency will decrease as additional, less-fertile land is used for agriculture. Lack of clean water will also limit opportunities for increased production," he told the conference. Patzek commented that improvements in alternative fuel systems were possible, but that the two most promising were not yet viable options; he said that "industrial cellulosic ethanol technology does not exist and biomass gasification is in an early pilot stage."

Patzek discussed the methods that need to be used predict the amount of biomass that a given amount of cropland will produce. These include the harvest index (equal to kilograms of harvested seeds divided by kilograms of biomass above ground); the root-to-shoot ratio (equal to kilograms of roots at harvest divided by kilograms of biomass above ground); the moisture contents of crops, aboveground biomass, and roots; and the high heating values of plant parts in megajoules per kilogram (MJ/kg) of dry biomass. He noted that all of these values are highly variable and uncertain.

His research concluded that when existing U.S. crop production is converted into potential energy using high heating values, about 9 exajoules (EJ) of energy is contained in all U.S. crops: 6 EJ of which is in aboveground biomass and 3 EJ in roots. Corn (at 5 EJ) provides the majority of plant green mass energy; and he noted that "the U.S.'s corn production is actually large enough to feed five times the population of the U.S. or the population of China."

Dividing this 9 EJ by the number of seconds in one year and the area of cropland produces the mass weighted average sequestration efficiency of crops, which is equal to about 0.4 watts per square meter of cropland.

According to Patzek's calculations, the average person requires the equivalent to 100 watts (W) per day to sustain life; however, the average American consumes about 11,250 W of primary energy each day and imports another 800 W (minimum) from other countries—consumed primarily through crude oil, coal, natural gas and nuclear energy, with only a small portion provided by biomass and hydroelectric power. The U.S. food system amounts to about 22 EJ per year, consumed primarily by processing, refrigeration, transportation, marketing and sales.

Therefore, since biomass stored in roots (comprising one-third of biomass) and sparse vegetation cannot be effectively harvested, all aboveground biomass from all U.S. crops, all pastureland and a large amount of forestland would have to be used to obtain 1.3 billion dry tons of biomass, using the DOE's stated 52 percent conversion efficiency. This fails to take into account that most U.S. timber is already dedicated to purposes such as lumber or paper and crops are dedicated to feeding people or livestock.[xxxi]

Energy Efficiencies of Large-Scale Industrial Biomass Systems

According to Patzek's research:

- Corn grain and corn stover contains roughly 1 W/m^2 of cropland, though as grain is converted into ethanol, only 0.25 W/m^2 can be harvested as grain ethanol and another 0.1 W/m^2 as cellulosic ethanol. These small figures are due to the consumption of energy during the production and transportation of ethanol (about 0.37 W/m^2). Patzek noted that this W/m^2 amount could increase by a degree of about 0.1 W/m^2 if certain more efficient practices were undertaken, though he found the probability of that unlikely.[xxxii] (See "Figure 31: U.S. Corn.")
- Production of Brazilian sugarcane is a more energy intensive process than that of U.S. corn, but the higher proportion of output of ethanol per unit of sugarcane compensates for this. In the final analysis, Patzek noted, Brazilian sugarcane is significantly more efficient than corn, producing an average of 0.4 W/m^2 per year. Sugar, along with bagasse (attached dry leaves) and fallen dry leaves can all be converted into ethanol; if harvested by a machine, there is a larger amount of fallen dry leaves available.[xxxiii] (See "Figure 32: Brazilian Sugarcane.")
- Indonesian acacias are highly prolific trees, having the highest stomata activity of all trees, making them the best candidates for biomass production, according to Patzek. About 2 W/m^2 of land can be captured in biomass; though, once losses due to removing and burning the branches are taken into account, only a resulting 1.2 W/m^2 can be captured. Required energy inputs include steam (for drying and chopping wood to convert it into pellets) and other harvesting processes. At most, 0.5 W/m^2 of land can be produced using these methods, so satisfying the needs of a single person requires a large amount of land.[xxxiv] (See "Figure 33: Indonesian Acacias.")

Figure 31: U.S. Corn

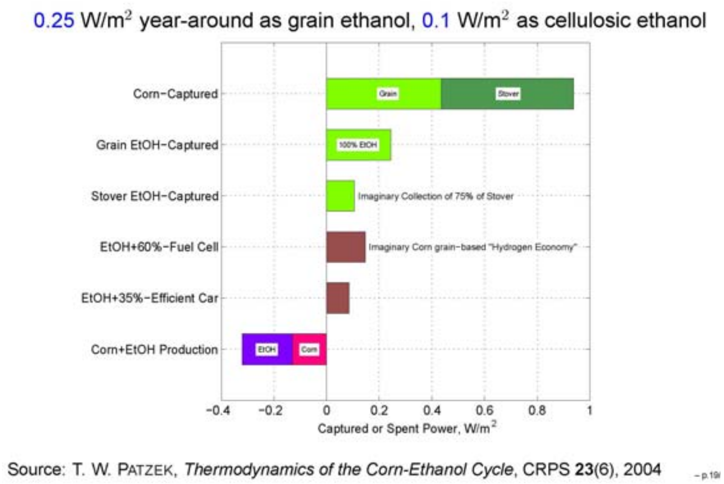


Figure 32: Brazilian Sugarcane

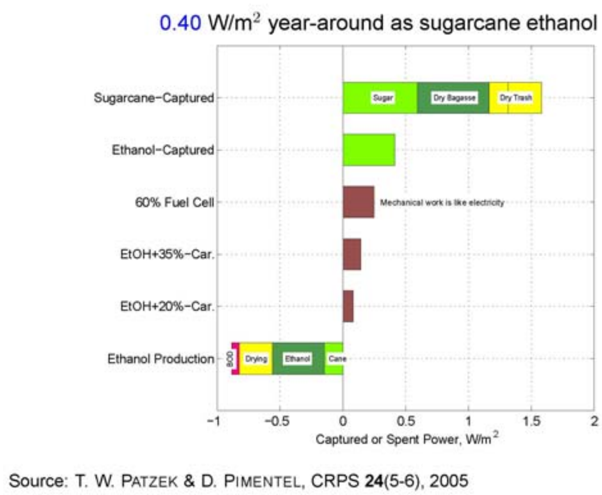
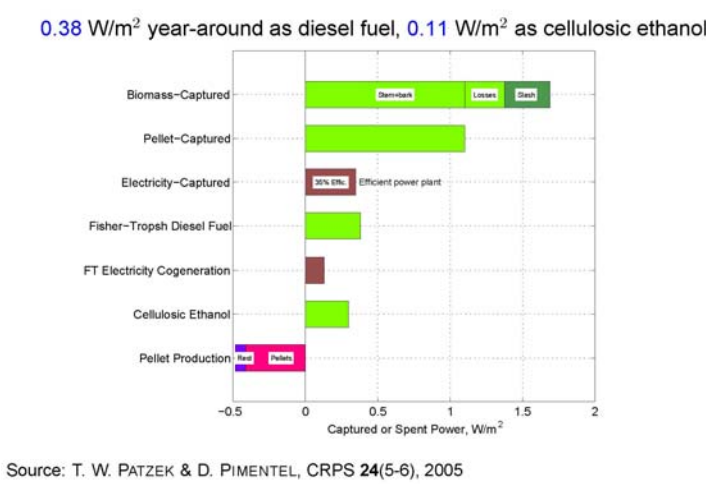


Figure 33: Indonesian Acacias



Patzek stated that "we need to invest in solar cell and electricity storage technologies, *not* in biofuels." When converted into primary energy, photovoltaic (PV) cells produce 24 W/m^2, making them about 400 times more efficient at capturing energy from the sun than the plants used in biofuels.[xxxv]

To draw these conclusions, Patzek analyzed the land area required to produce a given amount of energy fuel, and compared the fuel efficiencies of Toyota Prius hybrid (which gets an estimated 40 mpg) and an all-electric car (which is 2.5 times more efficient than the Prius)—assuming the cars will be driven 15,000 miles/year and accounting for:

1) the average energy costs of producing gasoline from crude oil (17%) and biofuels;
2) the energy costs of manufacturing and deploying PV panels (33%) and wind turbines (10%) over their 30 year lifetime; and
3) the added infrastructure needed to support each of these forms of energy; PV cells have the highest energy production costs at roughly 3.4 times the original area, followed by corn grain ethanol at 2.75 (obtained using the net energy ratio of 1.44, which is more optimistic than the DOE's estimation).

His research found that in terms of the land area required to produce fuel to drive the Prius, PV cells require 15 times more land area than oil, wind turbines 37 times more, acacia (including electricity produced during the process) 174 times more, and sugarcane ethanol 214 times more. Biofuels are therefore highly inefficient compared to PV cells and wind turbines, and "the only biomass sources that come close to providing a viable alternative [to petroleum-based fuel] are located in the tropics, suggesting that any attempt to switch to large-scale reliance on biomass will destroy the tropics," Patzek said.

If the United States devoted 30 million hectares (75 million acres) of land to one of the following fuel feedstocks, the respective number of vehicles could be fueled:

- **Corn =** 7 million Priuses from grain + 6 million Priuses from stover
- **Sugarcane =** 44 million Priuses
- **Solar cells =** 646 million electric cars
- **Wind turbines =** 254 million electric cars

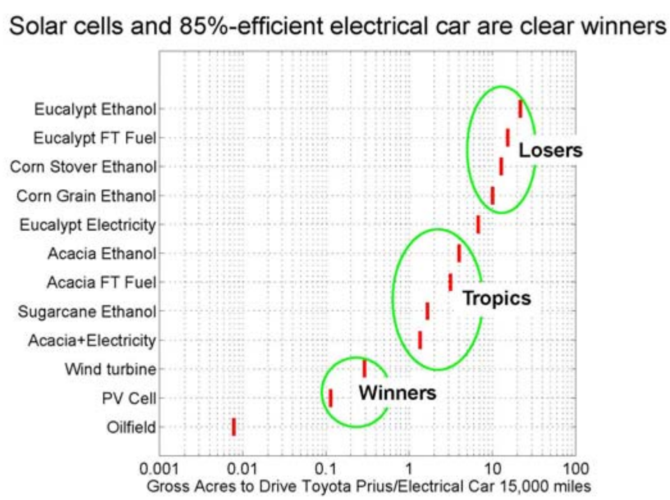
Furthermore, Patzek ended his remarks by concluding that “corn and sugarcane have the added disadvantage of limited time, as soil depletion will eventually reduce the productivity of land.” He said that this analysis suggests that “we think outside the box and pursue the development of electric cars.”

Figure 34: Areas Relative to Oilfield

Oil field area to drive the Prius is 330 square feet (30 m^2)

Technology	Net Ratio	Gross Ratio
Oilfield	1	1
PV Cell	4	15
Wind turbine	40	37
Acacia+Electricity	114	174
Sugarcane Ethanol	250	214
Acacia FT Fuel	263	403
Acacia Ethanol	333	510
Eucalypt Electricity	400	869
Corn Grain Ethanol	442	1292
Corn Stover Ethanol	1000	1641
Eucalypt FT Fuel	1000	1966
Eucalypt Ethanol	1429	2808

Figure 35: Gross Acres to Drive a Car



Source: T. W. Patzek & D. Pimentel, CRPS **23**(6), 2004, **24**(5-6), 2005

Ethanol: Energy Efficiency and Emissions

In his presentation "Ethanol Fuel," Marcelo E. Dias de Oliveira, doctoral student in interdisciplinary ecology at the University of Florida, discussed his research on two aspects of the Brazilian ethanol industry: carbon dioxide emissions and energy efficiency.

According to Oliveira, "papers and advertising from ethanol companies promise reduction in carbon dioxide emissions and improved energy efficiency." As Brazil has been using ethanol for nearly 30 years, Oliveira pursued his research by visiting sugarcane farmers and distilleries in Brazil and considering various studies to determine his own energy ratios.

Energy Efficiency Ratio

An energy efficiency ratio of ethanol can be calculated by dividing the energy embedded in ethanol by the amount of energy required for the agricultural, industrial and distribution activities associated with ethanol production. Oliveira's research found that Brazil, which uses primarily sugarcane as feedstock for ethanol, had an efficiency ratio of 3.70, while the U.S. efficiency ratio for corn-based ethanol production was 1.10. Once the energy required to clean up residues left by ethanol was considered (estimated to be 12 liters of residue for every liter of ethanol produced) these ratios dropped to 1.3 and 0.7 respectively.

"The higher energy efficiency of Brazilian ethanol production can be explained by several factors," Oliveira said, "First, the energy required by Brazilian distilleries is provided by burning bagasse [note: bagasse is sugarcane after it has been processed]; second, sugarcane yield per hectare (80 Mg) is 10 times higher than corn yield per hectare (8 Mg); and third, the process of converting corn to ethanol is a more energy intensive process, consuming about 54 percent of the biomass energy."

CO_2 Balance

According to Oliveira's research, the amount of CO_2 released by the Brazilian process of ethanol production (522 Kg/m^3), is about one-third the amount released by the U.S. process (1400 Kg/m^3). There is a basic assumption in the industry that CO_2 released as a result of ethanol combustion is not accounted for in net energy balance estimations because it will be recaptured by the plant.

When compared to the combustion of gasoline, combusting fuel with higher ethanol content—such as E85—does reduce the amount of CO_2 emitted. As an example, Oliveira compared the Ford Taurus and the Volkswagen Gol. The Ford Taurus Flex Fuel, an American car, releases 7.4 Mg CO_2 when using gasoline. When E85 is used, 5.0 Mg CO_2 is released, a 2.4 Mg CO_s reduction. In contrast, the Volkswagen Gol 1.6, a popular car in Brazil, releases 3.8 Mg CO_s when using gasohol, and when running on ethanol, only 1.2 Mg CO_2 is emitted, a 2.6 Mg CO_2 reduction.[xxxvi] Though emissions are reduced at the vehicle level, the environmental impacts of the entire biofuel industry must be considered. Oliveira remarked that "to identify the ecological footprint (EF) of various fuel types, the forest area required to absorb CO_2 and watershed area affected by production must be considered." According to his research, the ecological footprint of gasoline in the United States (1.1 acres per automobile per year) is actually lower than that of E85 (1.8 acres per automobile per year). In Brazil, the ecological footprint of gasohol (0.7) and ethanol (0.6) are very similar.

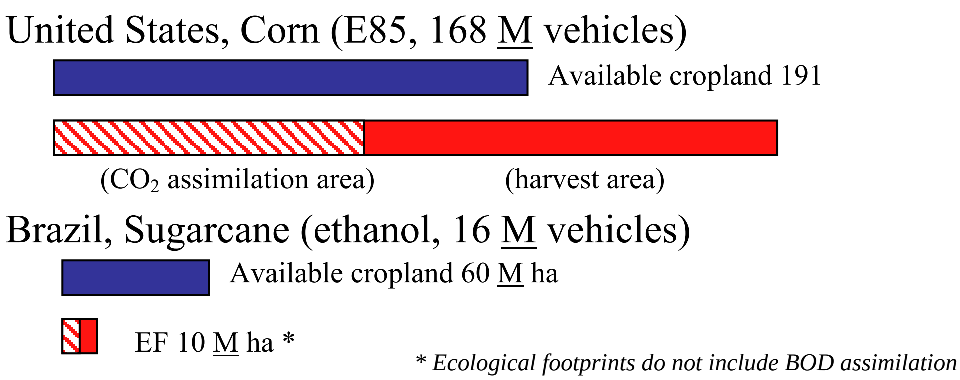
Figure 36: Fuel Acreage (in hectares) for One Automobile per Year

	For CO2 Assimilation	For Harvest Production	Total EF
United States, Ford Taurus			
Gasoline *(ha)*	1.1	—	1.1
E85 *(ha)*	0.8	1	1.8
Brazil, Volkswagen Go1			
Gasohol *(ha)*	0.6	0.1	0.7

Oliveira stated that the differences between the United States and Brazil in automobile fleet size and cropland also impact the feasibility of scaling up U.S. ethanol production. The U.S. fleet size of 138 million automobiles would require 129 million hectares of corn, or 70 percent of the cropland in the United States; whereas Brazil's smaller automobile fleet, at 16 million, when combined with the higher efficiencies of sugarcane feedstock, requires only 6 million hectares of sugarcane, equal to 10 percent of Brazil's available cropland.

"When the ecological footprint is considered, scaling up U.S. production becomes even more unrealistic, as the added area required for CO_2 assimilation brings the required land up to 292 million hectares, compared to the existing 191 million hectares of cropland in the U.S.," said Oliveira. Again, due to Brazil's smaller fleet size and the efficiency of sugarcane, only 10 million hectares are required for harvest area and CO_2 assimilation.

Figure 37: Scale Up is Unrealistic for U.S. Corn-Ethanol

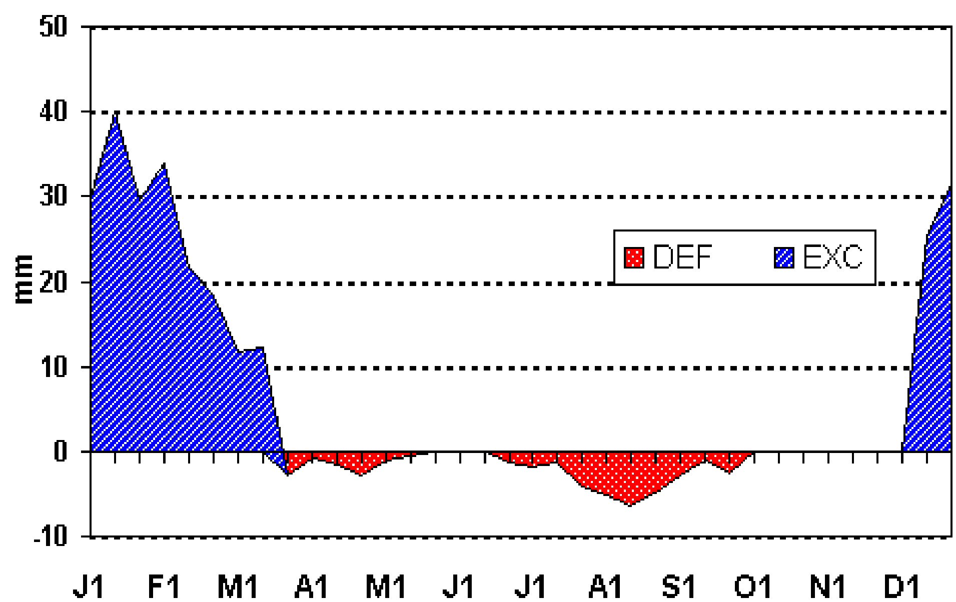


Environmental Impact

Ethanol is meant as a substitute for fossil fuels; however, Oliveira's research concluded that U.S. ethanol production requires almost as much energy input as output energy. As a result, there is almost no reduction in fossil fuel consumption, and the environmental impacts of ethanol production, when combined with the impacts of fossil fuels used to create ethanol, are higher than if no ethanol was produced.

Brazil's environment has certainly been impacted by ethanol production; most literature estimates that between 2.5 m^3 and 4 m^3 of water is used per Mg of sugarcane processed, though Oliveira observed a 3.9 m^3 of water use in his visits to distilleries. Brazilian ethanol production, averaged between 1999 and 2004, consumed 12.4 billion liters of water, enough to supply the city of São Paulo, a city of 13.8 million people.[xxxvii] Oliveira believes that this use of water is particularly upsetting to the environment because the May to November harvest season coincides with the dry season in Brazil, drawing water from rivers when they are at their lowest point, a practice which is not sustainable. Furthermore, preharvest burning increases by 3.5 percent because of sugarcane harvesting; large sugarcane plantations also decrease native vegetation and cause a loss of biodiversity.

Figure 38: Brazilian Sugarcane Harvesting Coincides with Dry Season



Source: Depto Ciencias Exatas – ESALQ – Universidade de São Paulo

In conclusion, Oliveira stated that replacing fossil fuels will take more than one source of alternative energy. Ethanol can contribute, but only if more sustainable and efficient methods of production are developed. Finally, no alternative energy source comes free from significant environmental impacts.

SCIENTIFIC RESEARCH

The plenary session on biomass science and technology featured scientists and engineers whose presentations focused on feedstocks, genomics and refinery processes. Applied genomics has the potential to increase feedstock yields, introduce or improve upon environmental condition tolerances, and optimize biomass composition for conversion, whereas advancements in refinery processes, in particular pretreatment, can significantly lower production costs. These advancements must include finding ways to reduce chemical use for pretreatment and post treatment, lower the cost of materials, reduce enzyme use, minimize heat and power requirements, and achieve higher sugar concentrations.

Applied Genomics

In order for biofuels to become market competitive, a sustainable supply system for feedstock—uninterrupted by drought episodes—needs to be developed. In his presentation on “Plant Biotechnology and Feedstock Engineering,” Bill McCutchen, deputy associate director at the Texas Agricultural Experiment Station, discussed the importance of genomics in improving productivity and resiliency in a feedstock crop, particularly sorghum, for energy.

The DOE Bioenergy Roadmap aims to increase performance and systems integration for cellulosic biofuels production over the next 15 years distributed in three phases as follows: an initial phase with focus on research on bioenergy crop and bioconversion processes; a second phase beginning in the fifth year focusing on technology deployment; and a final phase consisting of integration of sustainable agriculture, consolidated processing and fusion of value chain.

McCutchen noted that genomics will play an important role in the future of biotechnologies. Important advances can be achieved in terms of yield, nitrogen utilization, insects, disease and drought tolerance. Genomics for bioenergy include feedstock engineering, feedstock cell wall deconstruction and fermentation microbe development. He discussed work being done on sorghum feedstock, which is a logical biofuel input for Texas. Grain sorghum is grown today at high concentration in Texas, Oklahoma and Nebraska.

According to McCutchen, sorghum can serve as a dual feedstock for livestock and biofuels within the existing planning and harvesting infrastructure; additionally, sorghum has the potential to produce twice the biomass with one-third of the water when compared to corn, and is especially suited for areas prone to drought or that have dropping aquifers. Based upon this research, sorghum lignocellulose yields equal 15–20 dry tons/acre (high biomass and sweet sorghum), and could be increased with certain advances. The fossil energy ratio (FER) projected for cellulosic ethanol is 10.3, versus current 1.36 for corn ethanol, 0.81 for gasoline and 0.45 for electricity. It is a high return crop, with up to 3 harvests per annum and a simplified agricultural process.

Figure 39: Planted Acres of Sorghum by U.S. County (2005)

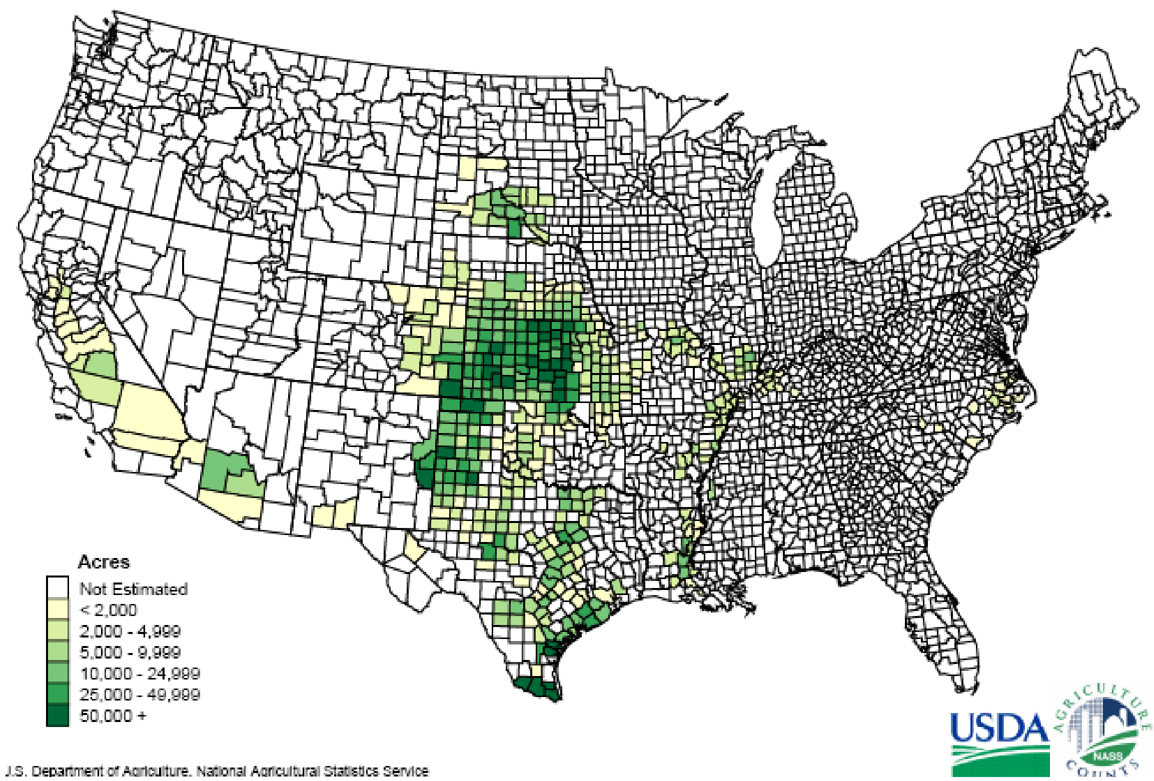
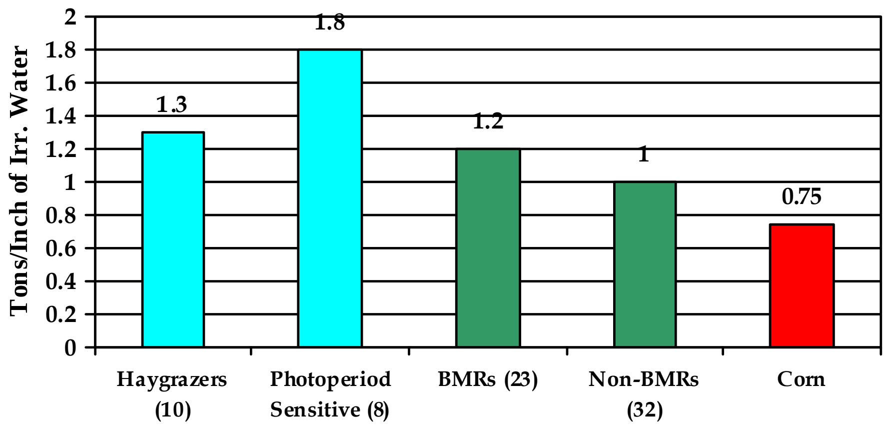


Figure 40: Drought tolerance and water-use efficiency

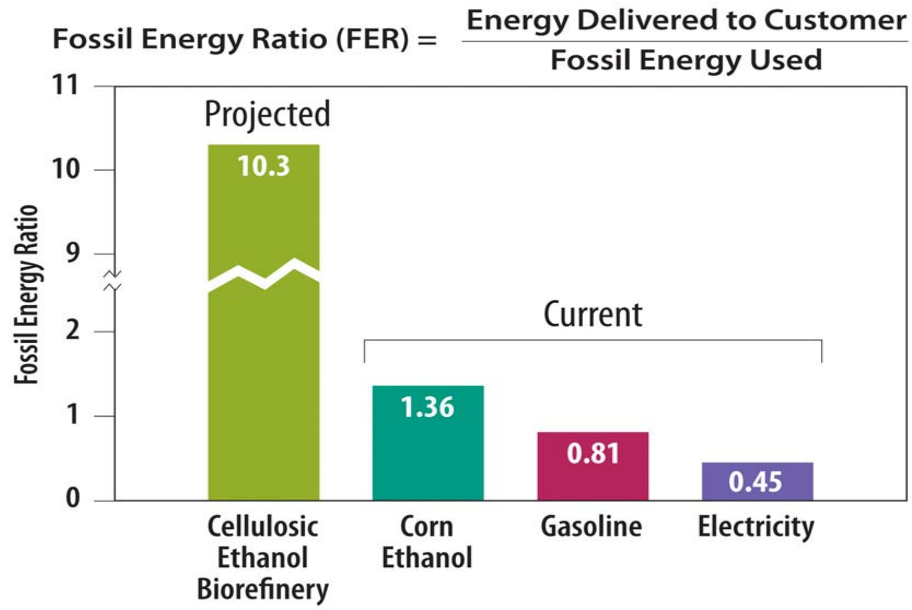
Sorghum produces more biomass than corn, using 33 percent LESS water



McCutchen emphasized that the genome technology platform for sorghum is established and biochemical pathway engineering is now possible. The platform for sorghum assembled at Texas A&M University and other institutions is researching the genetic, physical and cytogenetic maps. The Genetic by Environment (GXE) studies are a combination of genetic microarrays and phenotypic studies. Genes for drought, biomass yield, and insect resistance can be elucidates and comparisons with corn and arabidopsis can be made. Sorghum has a high drought tolerance; it is a low fertilizer input crop; it has fairly good characteristics for insect and disease resistance and is in a much better position over corn and switchgrass in terms of potential of producing biomass.

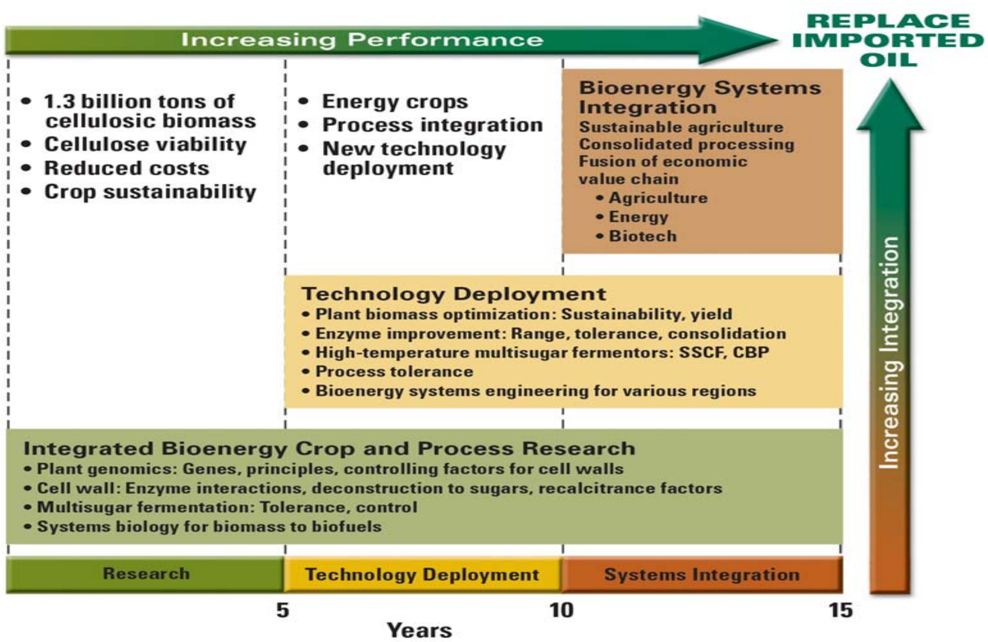
Sorghum´s genetic diversity will facilitate its adoption as a premier bioenergy crop. There is a lot of potential to develop sorghum as lignocellulosic biofuel though molecular breeding, and hybrids will be released within the next two to three years.

Figure 41: Environment-Feedstock Fuel Energy Ratio



Source: DOE Genome Program (http://doegenomes.org)

Figure 42: DOE Bioenergy Development Plan



Source: DOE Genome Program (http://doegenomes.org)

Cellulosic Biomass

Cellulosic biomass conversion can be categorized into four steps: pretreatment, hydrolysis of cellulose and hemicellulose, fermentation of sugars, and distillation of alcohol. Hydrolysis of cellulose and hemicellulose can be carried out by three different catalysts: dilute acid, concentrated acid and enzymes.

In his presentation on "Biomass Pretreatment: A Vital Interface between Plant and Conversion Systems," Charles Wyman, the Ford Motor Company Chair in Environmental Engineering at the University of California, Riverside, discussed the benefits of cellulosic biomass as a feedstock for ethanol. Environmentally, cellulosic ethanol has advantages over gasoline, including very low net CO_2 emissions. Cellulosic ethanol reduces solid waste disposal and provides a sustainable fuel. Economically, cellulosic biomass is abundant, inexpensive and domestically available. But Wyman noted that there are still needs, including lowering the costs of pretreatment (necessary to realize high yields of fermentable sugars) and of enzyme production (necessary to release sugars with high yields and thereby lower costs).

Existing cellulosic biomass resources include agricultural wastes (sugarcane bagasse, corn stover and rice hulls), municipal solid waste (paper and yard waste) and industrial wastes (pulp/paper sludge). Other additional cellulosic biomass sources are dedicated crops of grasses and trees, like switchgrass, hybrid poplar and willow coppice.

According to DOE, over 1.3 billion tons per year of biomass could be available for making fuels and other products, with about 368 million dry tons being from forests and 998 million dry tons from agriculture. These have the combined potential to be converted to about 130 billion gallons of ethanol.

Wyman said that tremendous cost reductions have been realized that may be grouped in two categories. The first is through overcoming the recalcitrance of biomass. "We did this by improving pretreatment to increase yields, improving cellulase enzymes to increase yields from cellulose, reducing enzyme use, and by integrating systems," he told the conference. The second set of advances can be viewed as overcoming the diversity of sugars. In particular, cellulosic biomass contains five different sugars whereas corn contains just glucose, and according to Wyman, "the development of recombinant organisms starting in about 1990 make it possible to now ferment all five sugars to ethanol with high yields." As a result, cellulosic ethanol is now reaching competiveness, as witnessed by the growing interest in commercializing the technology.

Even lower costs are possible through advances in pretreatment and biological processing, according to Wyman. Right now, pretreatment is projected to be the most costly process step, and options that might significantly lower costs include reducing the need for corrosive chemicals, using lower pressure, eliminating hydrolyzate conditioning and the losses associated with it, minimizing heat and power requirements for the process or achieving higher sugar yields at the end of the process. Because pretreatment cuts across almost all of the other operations it is a key to enhancing yields and lowering costs, Wyman pointed out.

Wyman's presentation discussed how costs could be reduced to about $0.50/gal to $0.60/gal through advanced technology. Recently, the DOE announced plans to provide $250 million over 5 years to each of its three Bioenergy Research Centers to help achieve this goal, and BP announced the award of about $500 million for biofuels research at UC Berkeley over 10 years through the BP Energy Biosciences Institute.

As a closing remark, Wyman said that not all pretreatments are equally effective in all feedstock and that looking at just the biology of plants and the process without addressing their interface (i.e., pretreatment, etc.) will not sufficiently lower costs.

Figure 43: Projected Cellulosic Ethanol Costs

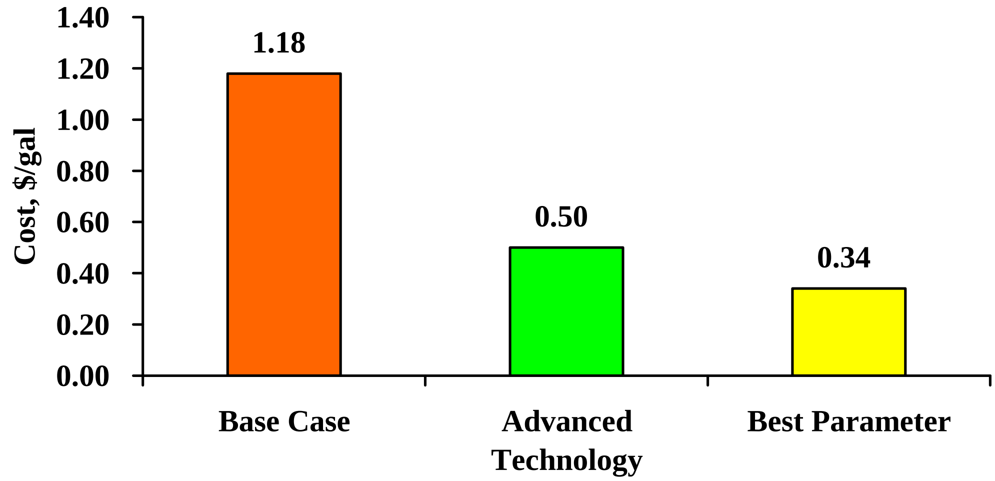


Figure 44: Key Processing Cost Elements I

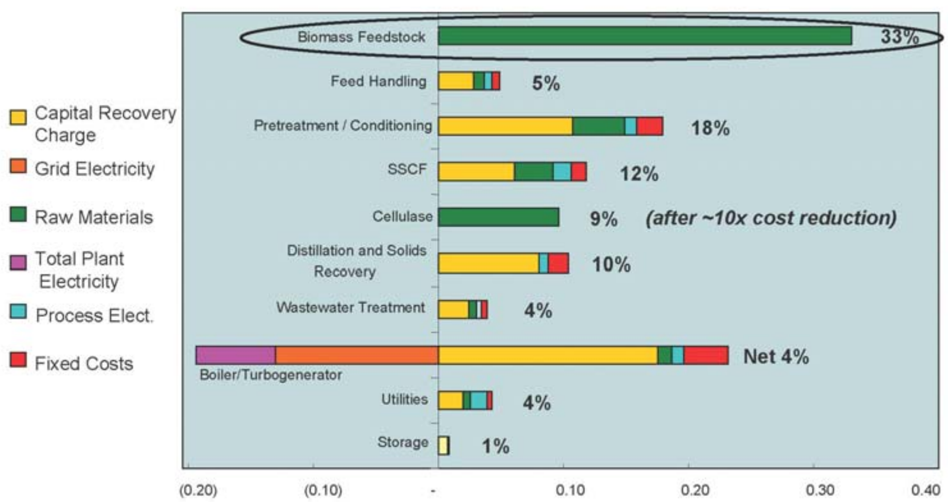


Figure 45: Cost of Cellulosic Biomass vs. Petroleum

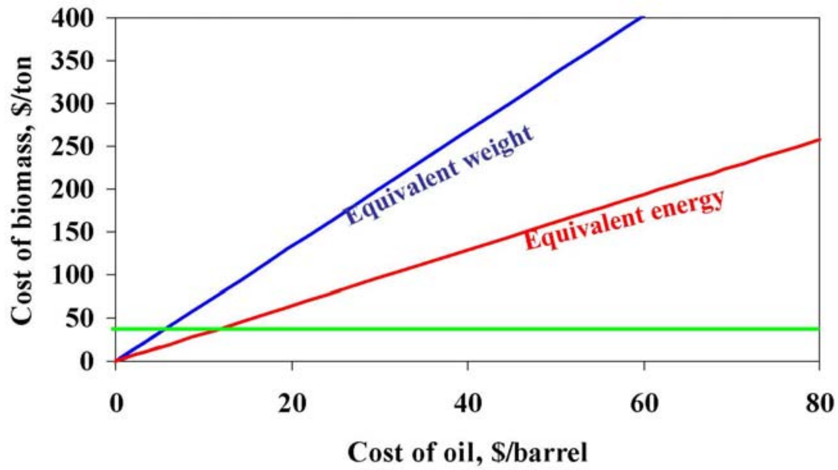
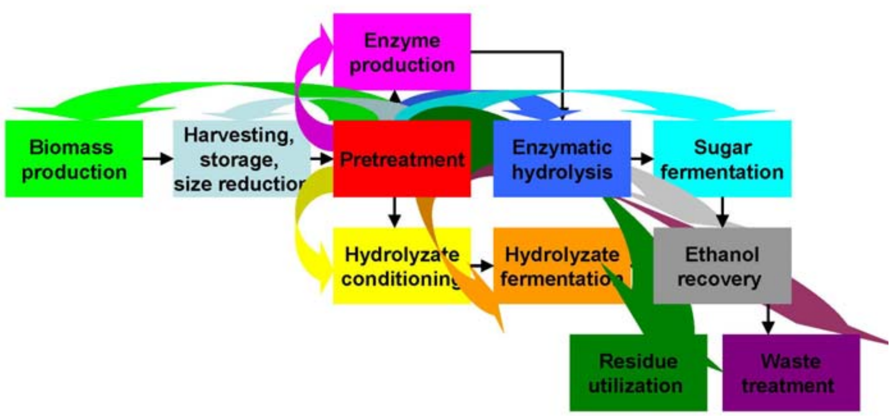


Figure 46: Central Role and Pervasive Impact of Pretreatment for Biological Processing



In his presentation on the "Potential of Designer Cellulosomes for Biomass Conversion," Edward Bayer of the Weizmann Institute of Science in Israel discussed the composition of cellulosic compounds and their role in ethanol production.

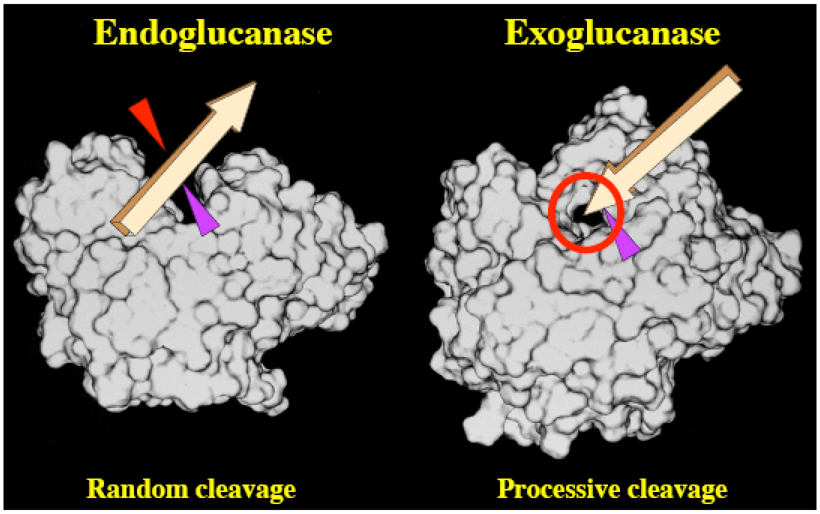
Bayer explained that in nature, microbes decompose and recycle cellulosic organic matter. Human action has resulted in a great proliferation of landfills, which are predominantly filled with industrial solid waste, much of it cellulosic. According to Bayer, organic matter in a landfill is very stable; cellulosic waste (which constitutes 50 percent or more of landfill content) even more so.

Cellulose is the main component of the plant cell wall. Cellulose is formed by fibers of beta-linked glucose residues embedded in a colloidal matrix composed of hemicellulosic compounds (xylans, mannans, etc.), pectins, lignin—mostly polysaccharides. The beta-1,4 glucosidic bonds of the cellulosic chains are arranged in parallel and solidly linked together by many H-bonds, which makes it very stable, Bayer explained.

Cellulases are enzymes that degrade cellulose, and they can be divided into two major groups: endoglucanases and exoglucanases. The actions of the endoglucanases and exoglucanases complement each other.

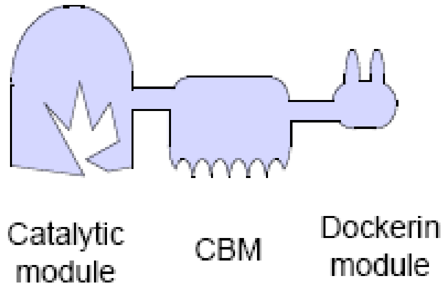
- Endoglucanases have a cleft-like active site which is exposed. It is able to cleave the beta-1,4 glucoside bonds of the cellulose chain at random sites. This creates more loose ends for exoglucanase action.
- Exoglucanases' active site is a tunnel-like path inside the protein that can accommodate the end of a cellulose fiber. It performs a processive cleavage, starting at one end of the chain and, progressing from there, releasing disaccharide cellobiose units along the way in a systematic (processive) manner.

Figure 47: Different Types of Cellulase



Bayer said that there are many different types of cellulases, all of which have cellulose-binding modules (CBMs), catalytic modules (which perform the actual cleavage of the cellulose chain) and other motifs such as protein-binding domains (dockerins and cohesins) in the case of cellulosomes. "The dogma used to be that cellulases are secreted from the cell in the free form and bind to and act individually on cellulose extracellularly," said Bayer. But after the study of the cellulose-binding *C. thermocellum*, which binds strongly to the cellulose crystals, it became clear that they do not use free cellulases but rather a protein complex with a number of subunits, some of which show enzymatic activity. This complex, which is bound to the cell surface, binds to the cellulose substrate and mediates its enzymatic digestion, was termed the cellulosome.

Figure 48: Cellulases are Multi-Modular Enzymes



The cellulosome is composed of a scaffolding subunit, dockerin-bearing enzyme subunits and anchoring proteins:

- The scaffolding subunit, termed “scaffoldin,” is comprised of a number of linked cohesin motifs, a dockerin motif and a CBM.
- The enzyme subunits: different from free enzymes in that they show a dockerin module besides the catalytic subunits. Cohesin-dockerin interactions link a number of enzyme subunits to a single scaffoldin subunit. The complex then binds to cellulose because of the scaffoldin protein’s CBM. There are over 70 different enzymes or dockerin-containing proteins that can bind to the scaffoldin unit, the majority of which display catalytic activity.
- The anchoring scaffoldins: via another cohesin-dockerin interaction (with the dockerin motif of the scaffolding unit), it binds the scaffoldin subunit together with its dockerin-containing complement of enzymes to an anchoring protein on the exterior of the bacterial cell wall.

The arrangement of the cellulosome can vary from bacterium to bacterium, with different types and number of scaffoldins and catalytic components, which confers the system a great variability and versatility. Ethanol is produced from the fermentation of sugars (obtained, for instance, from cellulose). Cellulosic compounds are a great source of sugars (glucose), if they can be successfully degraded. Bayer’s work focuses on investigating whether designing these arrangements can favorably alter the properties of the cellulosomes to increase their efficiency in degrading cellulose. (See “Figure 49: The *C. thermocellum* Cellulosome.”)

According to Bayer, “designer cellulosomes” can be obtained by engineering chimeric cohesins and binding them to scaffolding proteins to create custom-made artificial cellulosomes. Using recombinant methods, a specific cohesin can be positioned at every binding site of a chimeric scaffoldin. In parallel, matching catalytic subunits can be constructed with the appropriate dockerins to bind to the desired cohesins. Bayer noted that with this method, total control can be exerted over the identity of a specific cellulosome; therefore, many different combinations are possible.

Figure 49: The *C. thermocellum* Cellulosome

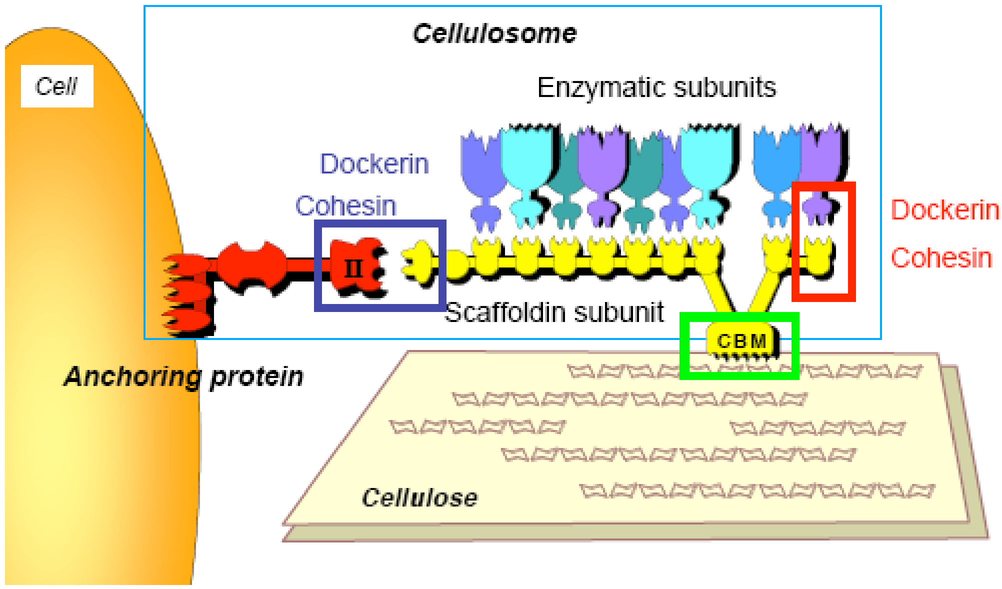


Figure 50: Designer Cellulosomes

Chimeric scaffoldins enhance the catalytic activity of the bound enzymes by bringing them closer together and favoring interaction between products. There is a great diversity of scaffoldins with different binding sites, which provides versatility when dealing with different celluloses, such as bacterial, algal, etc.

Bayer concluded by outlining the efficiencies of cellulosomes:

1. The cellulosome is very efficient in degrading cellulose: A 2 percent cellulose solution takes two days to obtain 100 percent solubilization. A 20 percent cellulose solution takes five days to obtain 60 percent solubilization. That number can be boosted to 96 percent in eight to nine days if a second cellulose batch is added.
2. Cellulosome compares very well to fungal enzymes. *T. reesei* (the standard fungal free-cellulase system) is much slower (16 h) than *C. thermocellum* cellulosome (2 h) and degrades from a half to only one-tenth the amount of cellulose.
3. What are the practical applications of cellulosomes?
    - Engineering larger scaffoldins and determining the optimal enzyme combination to produce custom cellolosomes that degrade cellulose in situ.
    - Tranferring selected cellulosomal genes into an appropriate host (i.e., *Bacillus*, *Aspergillus*, *Clostridium*, yeast) that would then be able to produce sugars or even ethanol after being fed cellulose.

Biochemical Conversion

In his presentation on "Biochemical Conversion of Cellulosic Feedstocks," James McMillan of the National Renewable Energy Lab (NREL) contended that cellulosic biomass represents "the most abundant renewable carbon material in the planet." DOE calculates that there is 1.3 billion tons of cellulosic biomass available, which would displace 30 percent of U.S. petroleum consumption; this includes any aboveground residue left after harvest, including corn stover, wheat straws and rice hulls. [xxxviii] In the United States, corn stover is the most often discussed feedstock because corn is the largest single crop. However, other interesting cellulosic feedstocks are switchgrass and short-rotation, hard, woody materials such as poplars. These materials are very different physically, but when they are broken down into compositions, three-fourths of their mass consists of sugars.

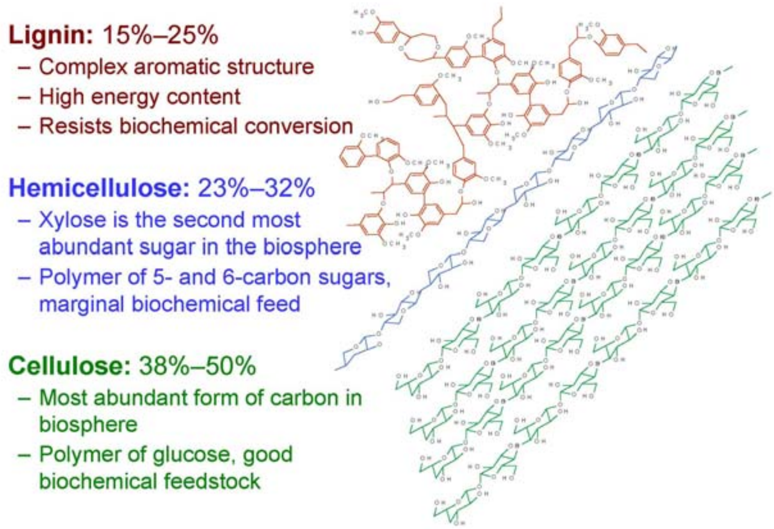
Cellulose, like starch, is glucose-based, but with different bonding. Cellulose uses hydrogen bonding that acts like a molecular Velcro. Hemicellulose is basically composed of xylose (which is the basic constituent of the polymer xylane), a five-carbon sugar which is presenting one of the greatest challenges in cellulose conversion. Lignin is an aromatic based molecule, energy rich and very recalcitrant to biochemical hydrolysis but an excellent feedstock for thermochemical conversion. Proteins and oils also exist in biomass. Future bioenergy crops will be raised for recovery of several of these molecules.

Figure 51: Composition of some feedstock – Grain vs. Cellulosic

Constituent levels can vary by roughly ± 5 percent dry weight due to environmental and genetic factors

Component	Corn Grain	Corn Stover	Switch-grass	Poplar
Starch	72–73	Trace	Trace	0
Cellulose/Hemicellulose	10–12	63–74	60	73
Lignin	0	14–18	10	21
Other Sugars	1-2	3–5	6	3
Protein	8–10	1–3	5	0
Oil/Other Extractives	4–5	2	13	3
Ash	1–2	6–8	6	0.5
Total	96–104	90–110	100	100

Figure 52: Cellulosic Biomass-Major Constituents



Biochemical Conversion Routes

In his talk, McMillan focused on two types of biochemical conversion routes:

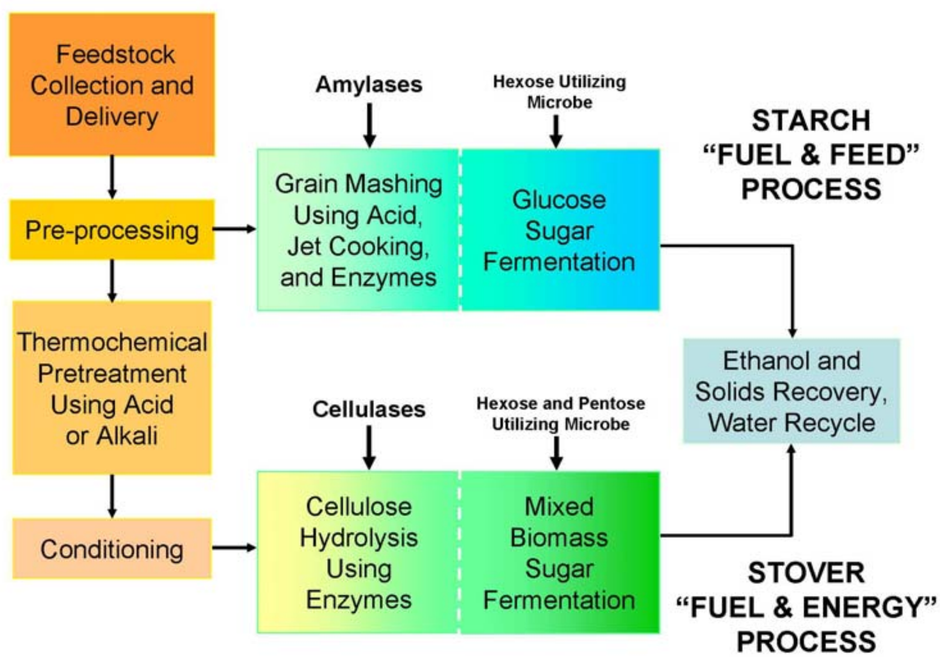
- Fermentative conversion of syngas (CO and H_2) resulting from gasification.
- Fermentation of hydrolysis sugars, the conventional brewing route, which can be categorized based on the method used for breaking down cellulose.

Break down of cellulose has historically been achieved by diluted and concentrated acid hydrolysis. These methods have been around for over 50 years, but now the enzymatic route is being emphasized due to the potential to reduce production costs, McMillan said. Commercial processes based on enzymatic hydrolysis of cellulose do not yet exist, but "they are believed to offer the best long-term potential for minimizing ethanol production costs," McMillan asserted.

The only constraint is that the enzymatic hydrolysis alone is not sufficient to break down the biomass. "You need to activate, to make the cellulose and hemicellulose accessible to the enzymes, and typically a pretreatment is used with acid or alkali solutions, which may inactivate the enzymes and require condition prior to the next step," he explained.

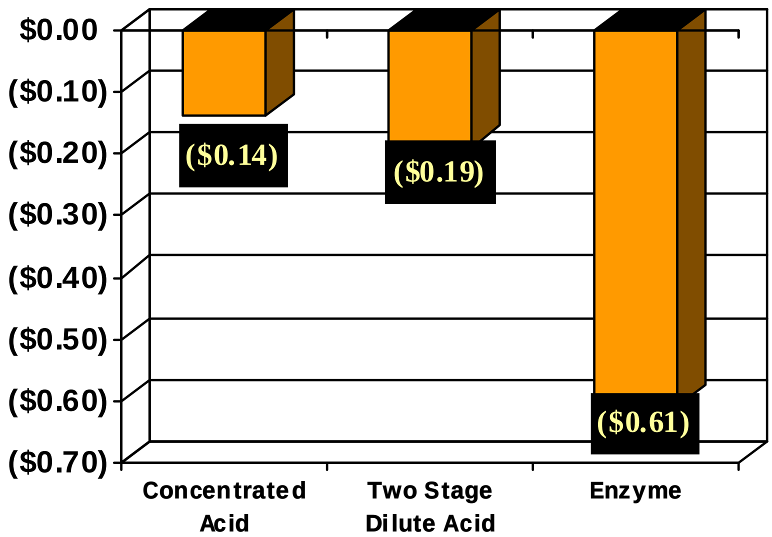
Figure 53: Carbohydrate Conversion Steps

The technology exists but the challenge is making it economical.



Typically, McMillan explained, the electricity co-product envisioned from corn stover utilization is small compared to the co-products resulting from using grain corn as feedstock. He noted that there is potential for "novel higher value co-products in the stover process" if new process streams are developed. The challenge, according to McMillan, is to make co-product market scale in parity with the scale of the fuel market. "We have higher costs associated with chemicals and enzyme use and higher fixed costs in the case of stover," he said. "We also use longer concentrations of chemicals, and as consequence of that we have higher capital cost." Capital cost is in the range of \$2.50–\$4.00/annual gallon for stover versus \$1.00–\$1.50/annual gallon for grain, but the operating costs are potentially 20 percent to 40 percent lower in processing cellulosics than corn. The cost of cellulosic ethanol production has dramatically dropped in the past few years. Projections for 2020 are based on feedstock price of \$30/ton, but that could be reduced if the price of production could be lowered, McMillan said.

Figure 54: Why Emphasize the Enzymatic Route?



McMillan noted that there are still a few techno-economical barriers in the United States to making cellulosic biofuels competitive with starch (grain)-based fuels (like corn-ethanol). To do so, the recalcitrance of cellulosic biomass must be overcome. Also, a better integration of these processes in the biorefinery is required. According to McMillan, "It is necessary to prove processes at industrial scale and to validate societal/environmental benefits rigorously."

The first barrier, cell wall recalcitrance, is challenging because lignocellulose cell walls contain intermeshed carbohydrate and lignin polymers among other minor constituents. The major structural polymers (cellulose, hemicellulose and lignin) exhibit different reactivity to thermal, chemical and biological processes. By natural design, cell wall polysaccharides are more difficult to break down than storage carbohydrates like starch. Ongoing research on high solids pretreatment has demonstrated that pretreatment is key to high sugar concentrations and hence to lower the costs. Past research has helped bring down enzyme costs sharply, and McMillan believes that further research will result in significant cost reductions. Other advances in science such as imaging at scale of cell wall ultrastructure allow understanding of how molecules move in biomass.

Figure 55: Comparative Economics – Biomass Program Goal is Market Competitiveness

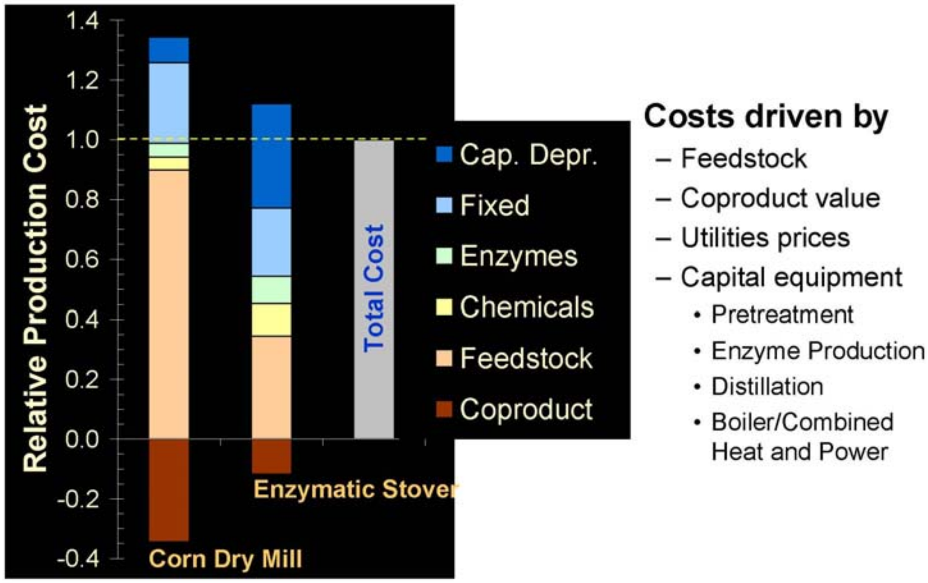
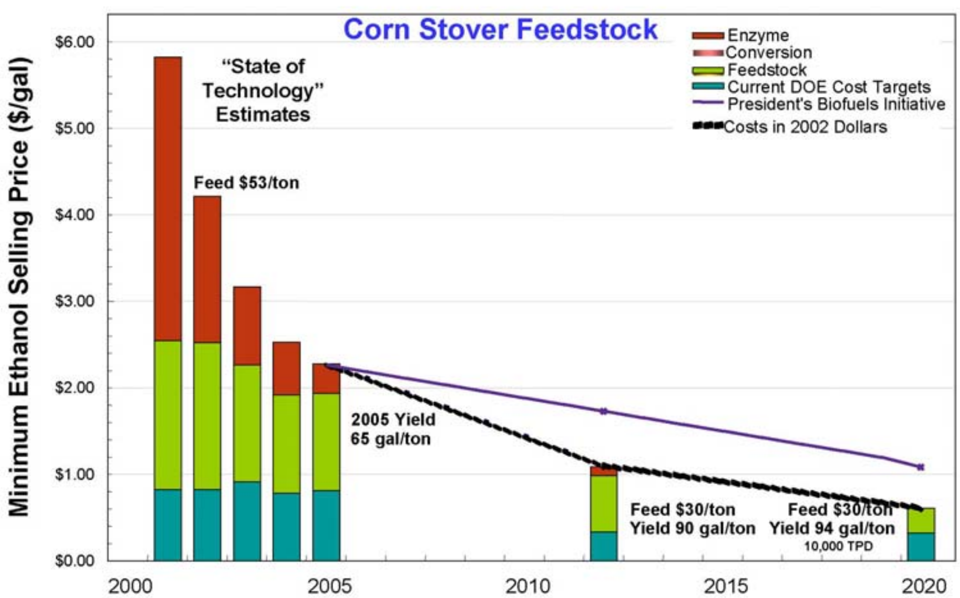


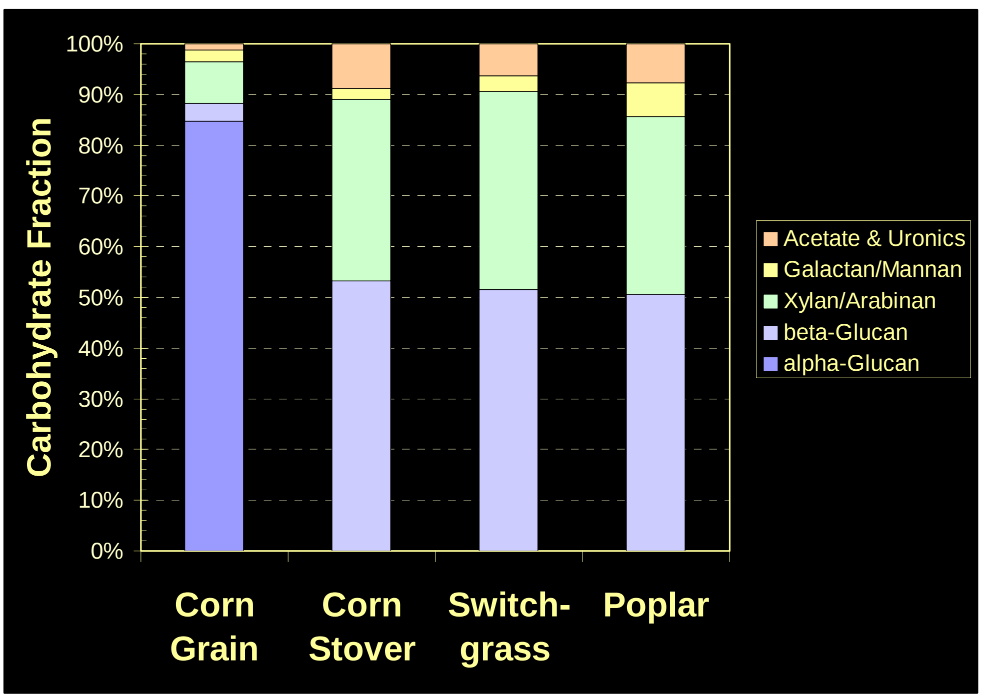
Figure 56: Cellulosic Ethanol Cost Reduction Progress and Goals



The second barrier is pentosan utilization. The percentage of pentosan in biomass affects the yield of ethanol and exists in different composition in the different feedstocks.

Pentosans are not metabolized through glycolysis in the cell. McMillan explained that there are some organisms that metabolize pentosans, “but they do not have the robustness that we require in industry and are used with brewers yeast.” *Saccharomyces cerevisiae* have a typical fermentation yield 50 percent alcohol and tolerance to system contamination. Pentosan-metabolizing organisms produce 4 percent to 7 percent ethanol at half the rate of a typical glucose fermentation process.

Figure 57: Second R&D Barrier – Pentosan Utilization



The third barrier is process integration. This area requires much work, as there are many different feedstocks, many different pretreatment processes, many different enzymes, and they all affect the way the others work.

"Although major progress is being made in all the above mentioned areas, more is needed to achieve market competitiveness, especially for more costly feedstocks," McMillan said. More specifically:

- Sustainable feedstock supply systems must be developed
- Processes must be proved at scale
- Societal/environmental benefits must be rigorously validated.

Breakthroughs that allow overcoming biomass recalcitrance, development of robust ethanologens (organisms that can generate more than 10 percent ethanol on pentose and mixed sugars) and finding new value-added commodity products will spur deployment, which is key to achieving a leap forward in economic viability.

Thermochemical Conversion Technologies

In his presentation on "Thermochemical Conversion Technologies," Richard Bain, principal research supervisor of the Biorefinery Analysis and Exploratory Research Section at the National Renewable Energy Laboratory (NREL), discussed the importance of integrated biorefineries to promoting the potential of biofuels in the United States.

Future integrated biorefineries will involve both biochemical and thermochemical processes, according to Bain.

He noted that if a particular feedstock is amenable for biochemical conversion it will probably be used for ethanol; but he added that other feedstocks like lignin that do not have the appropriate properties for high ethanol yield, or feedstocks or intermediates with mixed properties, may work well for thermochemical conversion.

Thermochemical Routes and Products

There are three traditional thermochemical conversion routes: combustion, gasification and pyrolysis, all of which produce different intermediate products. Combustion produces a hot gas, gasification produces an intermediate syngas (CO and H_2), and pyrolysis results in intermediate oxygenated oils (pyrolysis oil).

Bain noted that intermediate products can be further converted to final products. The hot gas from combustion can only be used to make electricity, steam and hot water, but intermediates from gasification and pyrolysis can be converted to final products using traditional synthesis chemistry. Syngas can be converted to H_2, alcohols (including ethanol), Fischer-Tropsch liquids (gasoline and diesel), olefins, oxychemicals and more. Oxygenated oils can be converted to H_2, olefins and specialty chemicals.

Figure 58: Integrated Biorefineries Involve both Biochemical & Thermochemical Processes

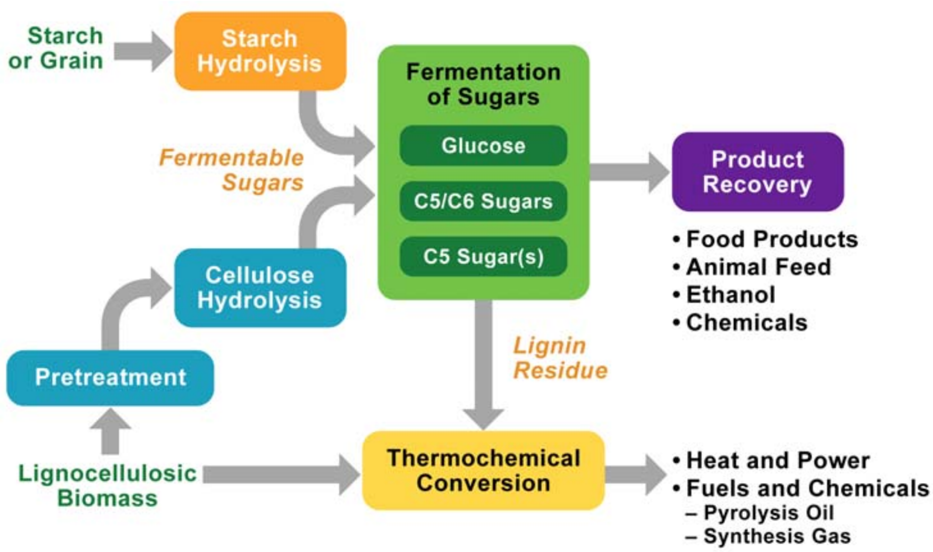


Figure 59: Primary Conversion Routes Give Different Types of Products

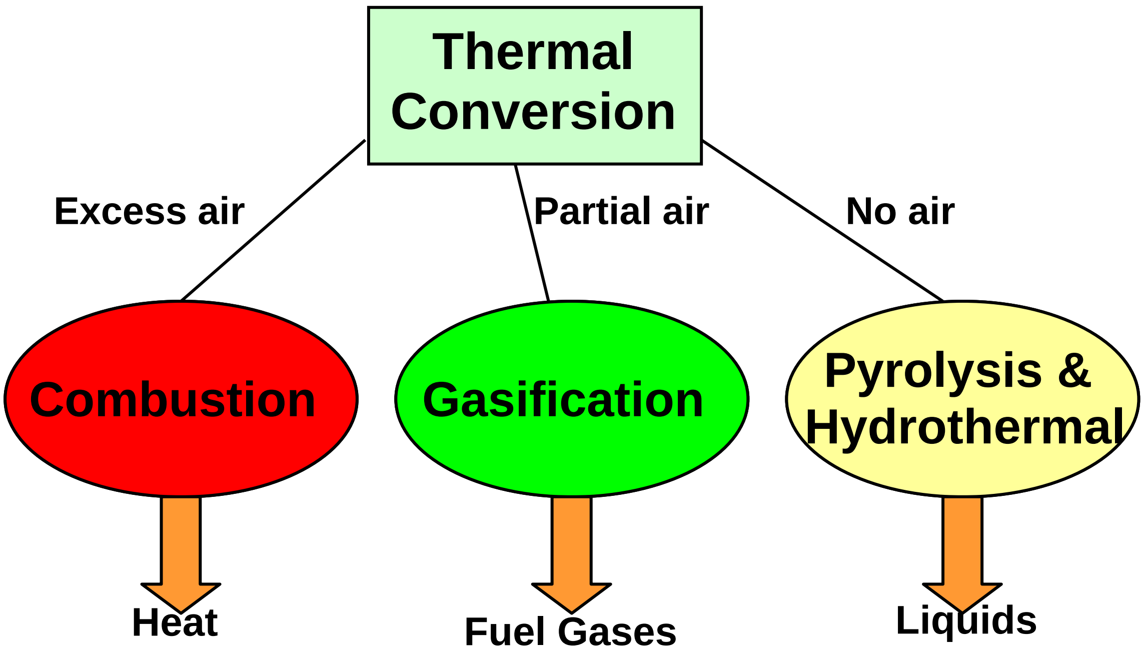
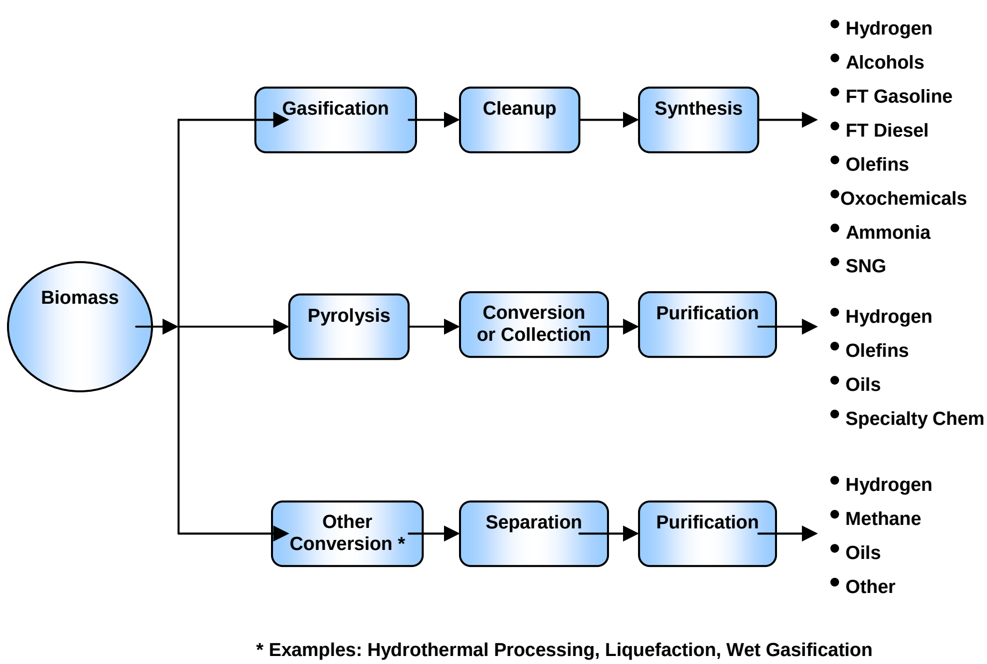


Figure 60: Fungible Fuels and Chemicals are Major Products

New classes of products (e.g., oxygenated oils) require market development



Importance of Biomass Properties

"Physical and thermal properties influence the choice of thermochemical conversion route," Bain explained. He noted that biomass feedstock properties are different from traditional fossil feedstocks. There are four aspects to take into account: the proximate analysis, the ultimate analysis, the heating value and the ash composition.

"The proximate analysis shows the relative abundance of fixed and volatile carbons, which will determine the temperature that we can use," said Bain. Coal contains 50 percent fixed carbon while biomass contains 80 percent volatile matter and only 20 percent fixed carbon; therefore, higher temperatures need to be used in coal gasification than in biomass gasification.

Compared to fossil fuels, traditional biomass is very high in oxygen and low in sulfur, with the exception of some particular cases of biomass, like chicken litter and black liquor, which can have increased nitrogen and sulfur content. Ash composition is important in gasification because at high temperature the ash will melt and can foul heat exchange surfaces and interfere with downstream catalytic processes. Bain said it was also important to look at the alkaline content and sodium and sulfur composition, among others "as indicative of what kind of temperature we can use."

Status of Gasification

Bain noted that gasification is 200 years old. During World War II, 1 million vehicles in Europe were equipped with biomass gasifiers. Gasification has also been used extensively in South Africa for production of typical refinery products and it has the potential to make hydrogen in the future.

Gasification technologies from coal and petroleum coke are commercially practiced at large scale. The syngas market is approximately 6 exajoules per year, which is comparable to the total renewable energy produced in the United States. Primary products are ammonia, hydrogen (for use in refineries) and methanol (for MTBE and formaldehyde production).

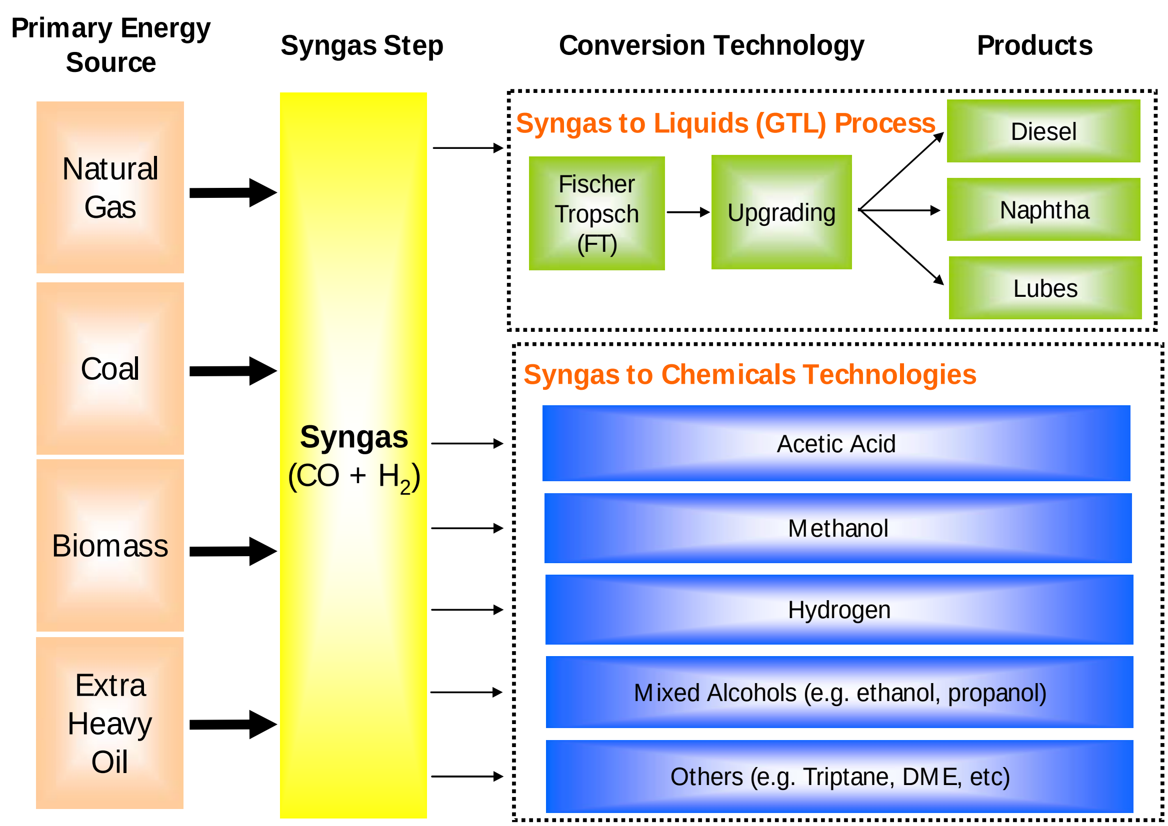
The production of liquid fuel by gasification has several steps. The primary conversion step is a heating process that results in syngas and tar. Then tar is removed and syngas conditioned. Finally the molecule is recombined to produce the fuel.

Gasification technologies are tailored to the feedstock. The first heating process is conducted at 1300 ºC to 1400 ºC in traditional high-temperature coal gasifiers. Under those conditions ash melts and for that reason, they are sometimes called “slagging” gasifiers. Those high temperatures can be used for gasification of biomass, but due to the high volatile carbon content, these temperatures are not required. New low-temperature steam gasifiers that generate dry ash have been designed to work at 800 ºC for biomass. Using coal-based gasifiers for biomass has other constraints as well. Coal-based gasifiers need small particles, which are expensive to achieve for biomass, or they require a pretreatment process that typically involves pyrolysis to make the material easier to feed to these high-temperature gasifiers. The second step is syngas conditioning, which includes different processes depending on whether there is need to eliminate residual particulates, sulfur, to achieve the appropriate $CO:H_2$ ratio, or to remove hazardous components detrimental to the catalyst, like mercury and cadmium. The final syngas obtained will be the same regardless of the feedstock used.

A large number of companies are interested in developing biomass gasification for fuels and chemicals, Bain said. Traditionally, small- and medium-scale for combined heat and power (CHP) is a good process for businesses. The Colorado-based Community Power Corporation is using CHP at the 25 kW electric scale for institutional use or for uses in developing countries. CHP for district heating is also attractive in Europe because of incentives given for systems in the scale of 5 MW electricity. In Minnesota, a 15-million gallon per year (gpy) corn-ethanol facility is including a CHP system that uses 300 tons of wood a day to produce electricity and heat the process. But Bain noted that “transportation fuels production will need larger scales because the process is substantially more complicated. There may be opportunities for smaller modular facilities, but what most people are looking at is central facilities."

Bain said that the key to success will be fungibility. Syngas will be the same regardless of the feedstock use. "The gasification route gives flexibility for the future since the feedstock can be changed depending on the existing environmental constraints," he said. "If you are in a carbon constraint world biomass is the answer; if you are not, you can emphasize fossil fuels."

Figure 61: Hydrocarbon fungibility will be a key to success



Bain noted that the DOE emphasis has been on ethanol via a mixed alcohol synthesis process, which takes a Fischer-Tropsch catalyst and adds a reactant to produce alcohol instead of traditional diesel. A product of interest in Europe and Japan is dimethyl ether

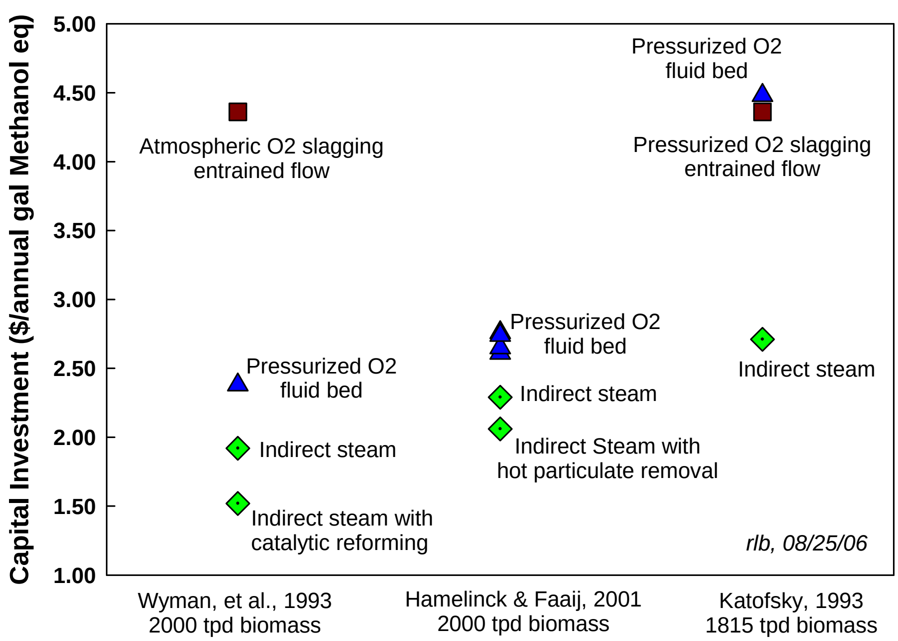
(DME), which can be used as a cold fuel diesel, but is currently used mainly as a propellant for hair spray.

According to Bain, a second- or third-generation integrated biorefinery could consist of biochemical conversion of biomass to ethanol as the primary process, with a portion of the lignin diverted to CHP, and the rest of lignin used to produce gasoline through selective thermal processes.

Costs

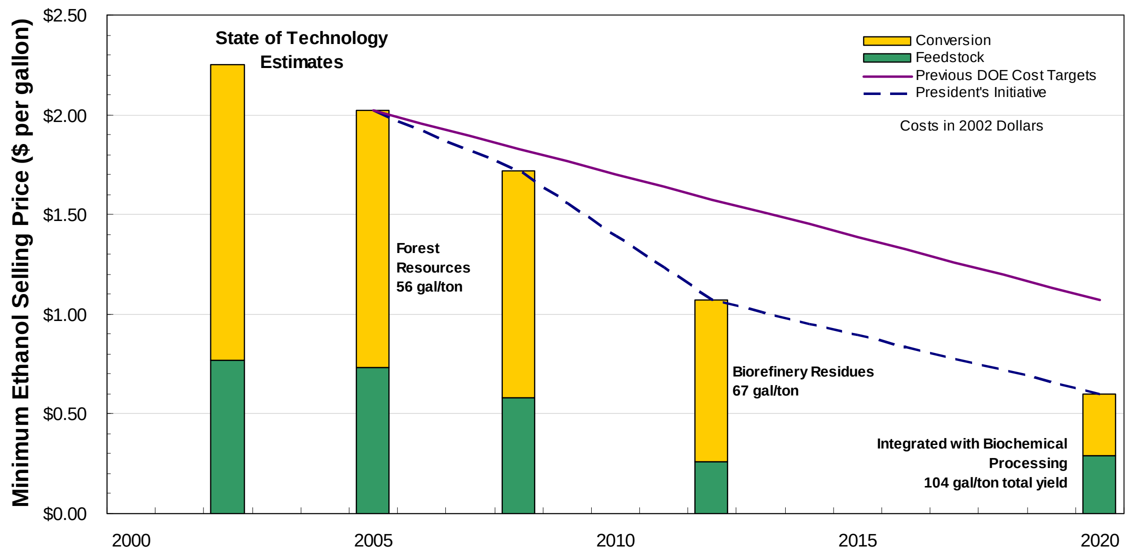
The cost of ethanol through the mixed alcohol process using the thermochemical route is comparable in magnitude to the biochemical route. Many variables affect the cost independent of the process: feedstock cost, cost of utilities, etc. Yields are around 75 gal/ton (lower than those of an ethanol-only process), but there is another 20–25 gal/ton of higher alcohols like butanol and propanol coming out in thermochemical process. Although ethanol and Fischer-Tropsch liquids are presently preferred products, previous work on methanol can help guide analysis.

Figure 62: Methanol from Biomass: Comparison of Capital Investment (2002 $)



Bain explained that analysis of ethanol for thermochemical mixed alcohols shows the potential to reach the DOE goal of $1.07/gal in 2005 dollars in 2012. "It is a capital-intensive process," he said. "There is a projected capital investment of about $1.50-$2.00 per annual gallon based on previous calculations made for methanol; however, this can vary depending on the system configuration."

Figure 63: Ethanol Selling Prices



About 2000 tons of biomass per day produces 45,000 gallon per day of methanol. Coal slagging gasifiers are being optimized for scales that are 30,000 gallons per day. Bain told that conference that "scaling down those systems would bring them below the optimal point. For developing second-generation gasifiers, economists say that it is better to go with gasifiers made specifically for biomass instead of retrofitting coal gasifiers to make ethanol right now."

Status of Pyrolysis

Pyrolysis is a thermal decomposition process of organic matter in absence of oxygen at 350 ºC–500 ºC. It has been known for thousands of years and traditionally used to produce charcoal. Now it is used to produce a water-miscible biocrude, comprised of many oxygenated organic chemicals, with basically the same composition as the starting biomass but with much higher density. It sinks in water, is very acidic (pH 2.5), ages with time, and has a distinctively strong odor.

Figure 64: Distribution of Products Depends on Temperature and Residence Time

	Liquid	**Char**	**Gas**
FAST PYROLYSIS	**75%** ***moderate temperature*** ***short residence time***	**12%**	**13%**
CARBONIZATION	**30%** ***low temperature*** ***long residence time***	**35%**	**35%**
GASIFICATION	**5%** ***high temperature*** ***long residence time***	**10%**	**85%**

Source: Bridgewater and Czernik

Bain noted that while small pyrolysis units primarily produce boiler fuel, there has been some success at producing diesel fuel from biomass (green diesel). There is also some interest in extracting phenols (for phenol formaldehyde resins), or in using the pyro-lignin, the lignin rich fraction, or to make a gasoline blend stock.

Fatty acids from feeds such as soy oil can be used to make high quality diesel blend through hydrotreating. The quality is higher than traditional biodiesel as it has a lower density than biodiesel, a heating value higher than biodiesel, NO_x emissions lower than traditional diesel, a cloud point in the desirable range for diesel, and a cetane number in the 80-100 range. A disadvantage is posed by the higher oxygen content, which would need to be removed because petroleum-derived fuels do not have as much oxygen.

Figure 65: Green Diesel's Attractive Properties

	Biodiesel (FAME)	Green Diesel
% Oxygen	11	0
Density g/ml	.883	.78
Sulfur content	<10ppm	<10ppm
Heating Value (lower) MJ/kg	38	44
% change in NOx emission	0 to +10	0 to -10
Cloud Point oC	-5	-5 to -30
Distillation 10%-90% pt	340-355	265-320
Cetane	50	80-90

Source: Marinangeli, R., et.al. (2005). "Opportunities for Biorenewables in Oil Refineries: Final Technical Report," UOP, Des Plaines, IL; DOE Report No. DE-FG36-05GO15085

A number of petroleum companies are investing in this type of technology. Neste Oil is building a plant for 170 tons of product per year in Finland. It has also been tested at commercial scale in Ireland. It is not happening in the United States because of the lack of a tax credit for green diesel.

Hydrothermal Treatment

Bain concluded by discussing hydrothermal treatment. In this process, biomass is mixed with water and an alkaline catalyst and heated at 300 ºC for several minutes. It is a capital-intensive process because it requires high pressure. An ultralight distillate is obtained, which is not a fungible product but can be upgraded to standard products. Changing World Technologies, Inc., has successfully processed poultry waste to make oil.

Microbial Fermentation of Butanol

In his presentation on "Butanol Production by Microbial Fermentation," George Bennett, professor in the department of biochemistry and cell biology at Rice University, discussed the advantages of butanol as a fuel. Butanol has a low vapor pressure and a high-energy content (comparable to gasoline), has low water adsorption (making transport in pipelines feasible), blends over wide concentrations, and requires no engine modifications.

Figure 66: Comparison of Solvents for Fuel Use

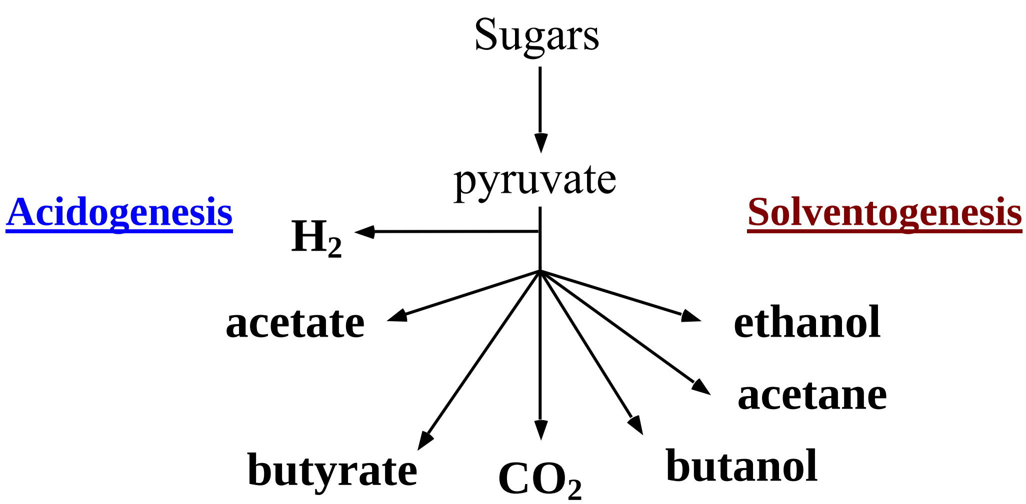
Solvent	**methanol**	**ethanol**	**butanol**	**gasoline**
Formula	CH_3OH	C_2H_5OH	C_4H_9OH	many
Energy	63 k Btu	78 k Btu	110 k Btu	115 k Btu
Vapor press.	4.6 psi	2.0 psi	0.33 psi	4.5 psi
Octane	91	92	94	96
Air to fuel	6.6	9.0	11.1	12 – 15

Source: W. Schwarz, Technical University of Munich, 2004

The U.S. butanol market is 370 million gallon per year. Butanol is currently produced via the petrochemical route and can be used as a fuel and as feed into production of other chemicals. However, Bennett emphasized that the biochemical route via microbial fermentation for butanol production is possible. There are many organisms and pathways from a variety of feedstocks that are capable of producing butanol. "Many natural butanologenic strains, mainly Clostridia, have been isolated and through microbial fermentation under anaerobic conditions butanol is formed," Bennett said.

Clostridia is a class of bacterium that can generate many solvents, mostly butanol but also some ethanol, and can utilize many feedstocks, such as starch (grains), sugar (sucrose and molasses), pectin (fruit waste), pentose-xylan (hemicellulose hydrolyzate), whey (dairy product processing), glycerol (biodiesel production byproduct), and DDGS (distillers dried grains and solubles, residual from corn processing).

Figure 67: Fermentation by *C. acetobutylicum* Makes Acids then Solvents



An example of the industrial scale of butanol production existed in Evremovo in Russia from 1960 to 1990 in a biorefinery-type operation as described in Zverlov, et al. "Bacterial acetone and butanol production by industrial fermentation in the Soviet Union: use of hydrolyzed agricultural waste for biorefinery."[xxxix] It used starch, molasses and biomass hydrolyzate. Every year it used 40,500 tons of starch equivalent as input to produce 15,000 tons of solvent (approximately 4 million gallons) and 8.7 million cubic meters of H_2 and 13.1 million cubic meters of CO_2 and other useful byproducts were recovered.

Bennett noted that performance of biological butanol production can be improved by "genetic manipulation of regulatory processes or pathway alternatives that affect the proportion of products or substrates used." Scientists have identified the genes of butanol formation by cloning and sequence analysis, additional genomic sequencing can give a more complete picture of the genes involved in solvent production. Clostridial genomes that have been sequenced are those of solvent producers, *C. acetobutylicum* 824[xl] and *C. beijerincki* 8052,[xli] cellulolytics *C. thermocellum* and *C. phytofermentans*, and several pathogenic clostridia.

"We also need to analyze gene expression and protein levels, using microarrays and proteomics, to identify genes whose expression correlates with solvent production and tolerance in order to improve levels of solvents, butanol proportion, rate of production and extend the productive operating phase," according to Bennett. Proteome analyses can allow identification of regulatory, metabolic and stress genes. "We can alter regulation and expression of genes by homologous insertion of plasmid into the microbial chromosome," Bennett told the conference. "Overall high solvent production has been achieved in regulatory mutants. Metabolic mutations increase the concentration of butanol and lower the concentration of other products." Overexpression of key genes (e.g alcohol dehydrogenase) from plasmids increases the rate of solvent formation. Controlling other genes, like *SpollE*, to keep cells from sporulating may prolong the solvent production phase in the life of the microbe.

Besides genetic advances, Bennett noted that butanol production can be integrated into existing infrastructure and based on the variety of feedstocks utilized it can be used in many localized situations. "This is the case of glycerol generated in biodiesel production, which can be used by some clostridial strains, to make butanol," he said. "Clostridia can also use residue solids from corn processing (DGGS) or wheat straw hydrolysate (WSH). In addition, clostridial cellulose degrading systems have the potential for utilization of plant biomass since some strains can digest crystalline cellulose and genes and enzymes of the cellulosome complex have been analyzed."

According to Bennett, "There is enormous potential for clostridia in bioconversion of biomass to biofuels, and the more we find about global cell processes enhances our ability to modify the cell characteristics for applications." For example, a number of clostridial strains can digest cellulose as they possess cellulosomes, but cellulosomes are difficult to work with because they are cell-bound large enzyme complexes produced in relatively small amounts (although they are ca. 50 times as efficient as fungal cellulases) and they produce cellobiose and cellotetraose instead of glucose. However, advances in cellulosome knowledge are occurring and will impact positively the use of cellulosic biomass for butanol.

In conclusion, Bennett summarized the current and future themes in the production of butanol via biochemical route:

- Organisms and pathways to produce butanol are now known.
- They require industrial technology that is proven at large scale.
- A wide variety of feedstocks can be used.
- Genetic and metabolic engineering tools can be used to improve production.
- There is need to scale up pilot experiments with engineered strains.
- Experiments should be undertaken to expand suitable feedstocks to include cellulose.
- Industrial plant engineering needs to be optimized for separation of the desired product from other coproducts.
- Integration with existing chemical industry infrastructure is desirable.

Emerging Platforms for Biomass

In his presentation on the "Emerging Platforms for Biofuels and Biochemicals: The Role of Metabolic Engineering and Systems Biology," Ramon Gonzalez from the department of chemical and biomolecular engineering at Rice University, discussed how the combined use of metabolic engineering and systems biology can enhance profitability and efficiency in the biofuels industry.

Metabolic engineering is the manipulation of metabolic processes (DNA recombination) to improve cellular activities. Systems biology involves the use of two new technologies (high-throughput genomics and mathematical modeling) for quantitative measurements at systems/cellular levels. In Gonzalez's opinion, a system-biology based approach can be used to link the petrochemical and biobased industries.

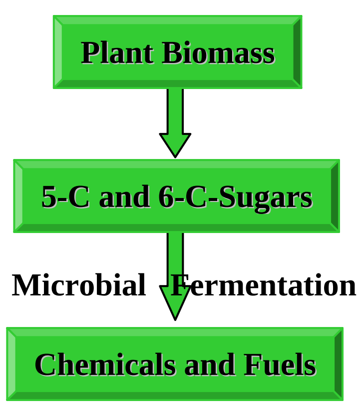
There are three main platforms for fuels from biomass:

- Sugar platform: sugar from biomass to produce fuels via fermentation.
- Syngas platform: plant biomass processed via thermal processing to obtain heat, power and a gas mix (syngas) that can be further processed via chemical processes or fermentation to produce ethanol.
- Oil platform: vegetable oils are used as biodiesel via conventional refinery technology.

Part 1. Optimization of Ethanol Producing Metabolism

In Gonzalez's opinion, "although the most important U.S. feedstock today is corn, in the future lignocellulosic biomass is predicted to take the predominant role." Lignocellulosic feedstock is hydrolyzed with enzymes to produce sugars that are then fermented to produce ethanol (biofuel) and byproducts. Gonzalez's research focuses on microbial fermentation of these sugars to produce fuels and chemicals.

Figure 68: Conversion of Plant Biomass Sugars into Fuels & Chemicals via Fermentation



Attempts to optimize ethanol production utilize the previously mentioned tools, which include metabolic engineering, systems biology via mathematical modeling, and systems biology via high-throughput genomics.

1. Metabolic engineering

E. coli and other microorganisms are used as platforms for metabolic engineering (ME) in order to construct biocatalysts capable of processing sugars or feedstocks in a profitable way. A typical problem in the use of microorganisms to ferment lignocellulosic sugars is that glucose inhibits the utilization of other sugars, resulting in a sequential processing of different sugar species. Gonzalez told the conference that a bacterium must be engineered in order to avoid this and to achieve simultaneous degradation; this is achieved via the modification of regulatory pathways mediating this metabolic process. The goal, according to Gonzalez, is to "engineer genotypes via systems biology in order to obtain a desired phenotype" (i.e. a bacterium that can degrade all types of sugars simultaneously and efficiently).

2. Systems biology: mathematical modeling

The systems biology-based approach starts with a mathematical model. First, the regulatory network that controls the way the metabolism works must be elucidated. According to Gonzalez, this is achieved "by modeling the relationship between the different components of the pathway in a technique called elementary network decomposition (END)." Building on the known interactions, the behavior of the remaining network may be inferred, permitting the prediction of the network behavior and of its emerging properties. This approach was successfully used to predict the behavior of sugar-utilization regulatory systems in *E. coli*.

3. Systems biology: high-throughput genomics

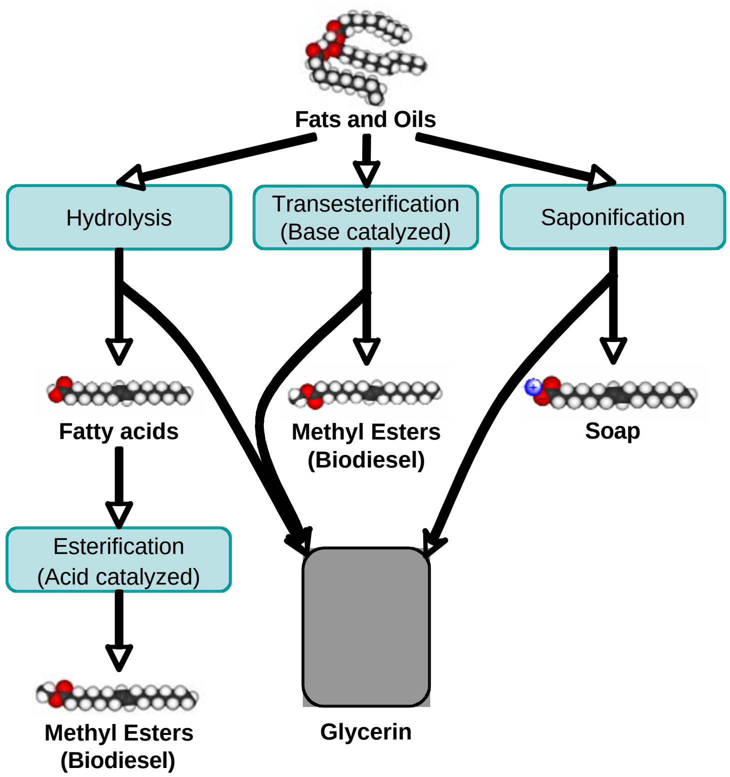
Next, the contribution functional genomics (high-throughput) approaches was illustrated through the use of DNA microarrays to analyze global gene expression changes in different conditions such as presence or absence of ethanol and use of different lignocellulosic sugars. Gonzalez presented a newly developed method in their group that allows the identification of "gene signatures" associated with each experimental condition or microorganism evaluated (the latter called assays). Using this method inferences are drawn regarding the contribution of each gene to each analyzed component (the first component being the response to ethanol) in each condition. Gonzalez explained that this allows for not only the identification of a gene signature that corresponds to the metabolic response in the presence of ethanol and a different one in the absence of ethanol, but also the identification of which genes contribute the most to a particular component (for instance, which have a bigger impact on the response to ethanol).

In summary, Gonzalez concluded that the systems biology approach provides a better understanding of the system, which can be applied to improve approaches to engineering metabolic pathways for the production of ethanol and optimum utilization of sugar mixtures.

Part 2. Integration of Oil and Sugar Platforms: Production of Fuels and Chemicals from Crude Glycerol

Gonzalez then discussed the problem of glycerol in the biodiesel industry. Glycerol is an unavoidable and abundant by-product of biodiesel production: 10 pounds (lb.) of glycerol is produced per 100 lb. of biodiesel. Gonzalez noted that as biodiesel production increases, the production of glycerol becomes a greater concern because there is currently no market for glycerol; glycerol's price has fallen to the point that it has become a liability, and people pay to dispose of it instead of selling it for profit.

Figure 69: Oleochemical and Biodiesel Industries Glycerol/Glycerin as Inevitable Byproduct



"New glycerol platforms are necessary in order to research and discover new uses for it," Gonzalez explained. A recent discovery in Gonzalez laboratory has enabled the anaerobic fermentation of glycerol by a native, nonpathogenic strain of *E. coli*. The ability to ferment glycerol and convert it to different fuels and chemicals (such as ethanol, hydrogen, formic and succinic acids) could have a big impact on the biodiesel industry as it will allow the use of this abundant and inexpensive by-product in a new path to produce biofuels and biochemicals. According to Gonzalez, utilizing glycerol is particularly strategic because of its abundance, renewability, low cost, and high degree of reduction. The advantages of the highly reduced state of carbon in glycerol are better illustrated by comparing the production of ethanol from glycerol to its production from sugars (the latter is equivalent to corn ethanol). While the fermentation of a pound of sugar results in approximately half a pound of ethanol and half a pound of CO_2, one pound of glycerol can be converted to half a pound of ethanol and half a pound of formic acid. As an alternative, the formic acid could be converted to CO_2 and hydrogen, a process in which the energy of formic is recovered as hydrogen. Overall, the production of ethanol from glycerol is more efficient because in addition to ethanol it can also generate either formic or hydrogen.

Figure 70: Crude Glycerin Prices

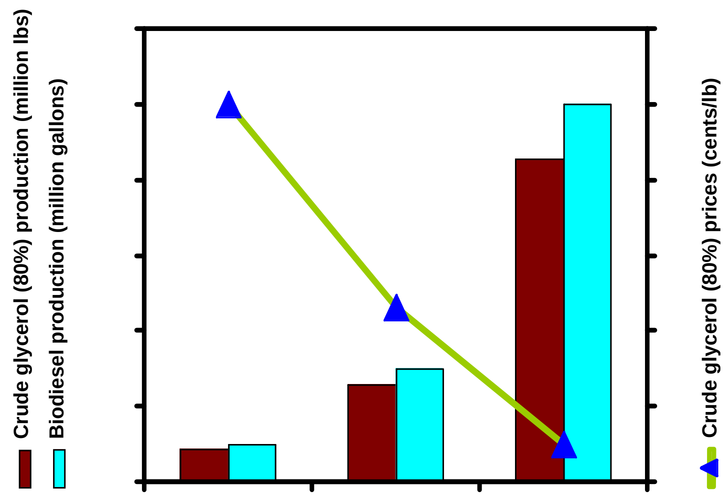
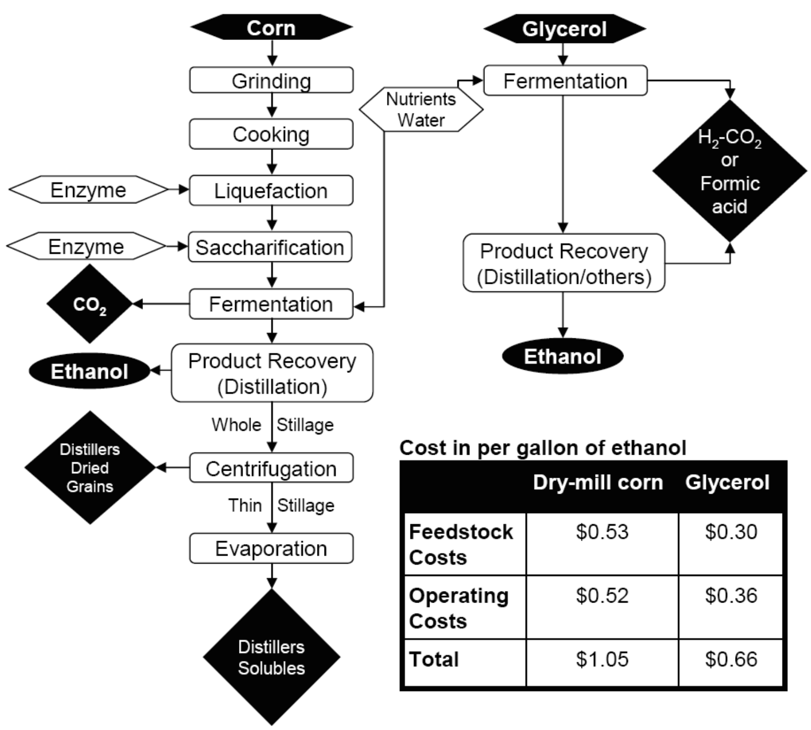


Figure 71: Ethanol → Formic and Ethanol → H_2 and CO_2 from Glycerol



	Dry-mill corn	Glycerol
Feedstock Costs	\$0.53	\$0.30
Operating Costs	\$0.52	\$0.36
Total	\$1.05	\$0.66

Source: Yazdani and Gonzalez (2007) Curr. Opin Biotechnol. 18: 213-219.

Conclusion

Conference participants concluded the session by noting that a sustainable transition to an effective national biofuels program will require greater planning to lower costs, reduce the environmental footprint, ensure efficient production and transportation logistics, safeguard fuel standardization and reliability, and manage input crop competition.

While many experts agree that biofuels will never represent a "silver bullet" solution to energy security or climate change, conference participants concluded that biomass is an important fuel diversification option to supplement other more comprehensive strategies and other alternative fuels. The energy density of biomass is low in comparison to that of petroleum. In the immediate term, ethanol is a lower-risk proposition to meet calls for alternative fuels, but many conference participants pointed out that other kinds of vehicles have greater potential long term and that U.S. policy must focus on a wider range of options rather than just take the easy short-term route to biofuels.

In order for biofuels to play a more important role in the U.S. energy equation than they do today, conference participants agreed that new policies and new technologies would be needed. Many biofuel alternatives currently under study are far from cost-effective using present technology. Conference participants agreed that corn-based ethanol, currently the focus of U.S. biofuel policy, is among the least efficient biofuels with a marginally positive net energy value and questionable net reduction in GHG emissions. Thus, new alternatives must be developed to create a sustainable, sensible biofuels program in the United States. Even the U.S. Department of Energy acknowledges this problem and aspires to develop means to make cellulosic ethanol commercially viable in a conversion plant by 2012. Other conference speakers noted the potential of methanol, biobutanol and biodiesel.

Commercial participants noted that the biofuels industry needs to be able to stand on its own and that government-backed incentives should not be the only driver that keeps the industry growing. Industry needs to be able to make technological progress to make biofuels cost-competitive with traditional fuel options and to ensure that biofuels will have the same reliability and quality standards as existing fuels.

Industry speakers noted that larger economies of scale will be needed to make biofuels a commercial business that can contribute large scale supply in the United States. This will likely mean changing the crop basis for producing biofuels, but it will be difficult to convince farmers to change to alternative crops, which may different cash flows and rotate on different time scales than those to which they have become accustomed to growing.

Scientists are working to overcome the recalcitrance of lignocellulosic biomass. There are several ways to do this including improving pretreatment to increase yields, improving cellulase enzymes to increase rates from cellulose, reducing enzyme use, and by integrating systems. Additionally, to make the cellulosic industry commercially viable, scientists must come up with ways to overcome the diversity of sugars. Cellulosic biomass contains five different sugars whereas corn contains only one. One breakthrough could be a recombinant organism that ferments all kinds of sugars to ethanol at high yields and productivities.

Options that might significantly lower costs would include finding less-corrosive chemicals that can operate under lower pressure, eliminating hydrolysate conditioning and the losses associated with it, reducing the use of enzymes, minimizing heat and power requirements for the process or achieving higher sugar yields at the end of the process. Scientists are also looking at other ways to degrade cellulosic compounds including designing arrangements which can favorably alter the properties of the cellulosomes to increase their efficiency in degrading cellulose.

Another key to increasing the cost-effectiveness of the biofuels industry is to create more sophisticated biorefineries that make better use of input materials. Several speakers noted that the biorefinery industry must focus on adding value to the agricultural inputs and exploit the many types of biomass resources. Biomass, for example, has a strong potential as the feedstock for the production of fine chemicals and polymeric materials.

Finally, conference participants emphasized that further study is needed on the long term environmental impacts of large scale use of biofuels, the likelihood of crop failures or agricultural market competition, as well as the logistical and economic issues involved in extending biofuels beyond their current role as a 10 percent additive in the existing gasoline pool. Industry experts warned that if a drought occurred in the U.S. heartland, the biofuel industry, supported by subsidies, would win over the agricultural feedstock and agro-food industries in a competition over supply and prices, which would then drive food inflation to the public detriment.

Scientists also warned that sound biofuels policy is needed to ensure that the ecological footprint of scaling up U.S. biofuels production can be properly managed to reduce negative environmental consequences. Conference presenters noted that massive production of biofuels, such as currently being undertaken in Brazil, creates immense pressure created on water supply that needs to be considered. New processes that minimize water use need to be developed. In addition, biofuels production practices need to consider how to best minimize the use of fertilizer and to avoid the potential impacts that large scale biofuels production and use poses in terms of water pollution of rivers and streams as well as groundwater. Furthermore, more study is needed on the greenhouse gas effects of development of large scale crop resources for the production of biofuels, including the impacts of deforestation that might occur in the conversion of land use from tropical forest to cultivated land.

Transition to an effective national biofuels program will require greater research and planning to ensure that a sustainable and reliable fuel system is promoted. Many examples abound in modern U.S. politics of fuel and energy policies that had unintended consequences despite initially promising goals. These situations forewarn us that a holistic analysis is needed to develop effective and sustainable implementation to changes in our transportation fuel sector.

APPENDIX – RICE BIODIESEL INITIATIVE

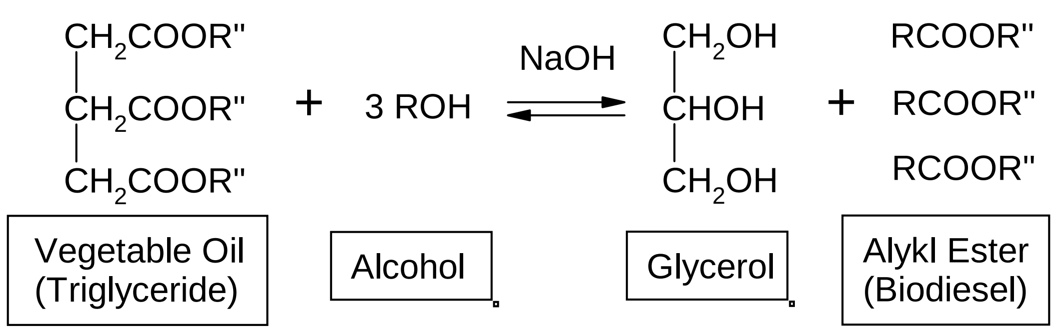
In his presentation on the "Rice University Biodiesel Initiative," Guyton Durnin, master's candidate in civil and environmental engineering at Rice University, discussed the biodiesel program at Rice University. The biodiesel program was initiated in 2005 as a means to produce a locally grown substitute for oil, less susceptible to price fluctuations and with lower emissions than those from gasoline consumption.

<u>Biodiesel: The Molecule</u>
Chemical name: Fatty Acid Methyl Esters
Formula: C14-C24 Methyl Esters

- Designated Alternative Fuel by U.S. DOE
- Registered as a fuel & fuel additive with U.S. EPA
- Specification set by ASTM 6751

Biodiesel varies greatly depending on the feedstock input to production. To produce biodiesel, vegetable oil (triglyceride) and alcohol are combined with a catalyst to produce glycerol and alkyl ester (biodiesel) in a process called transesterification. The biodiesel is then 'washed,' removing both excess methanol—reducing flammability risks—and any remaining catalyst—eliminating engine damage. The methanol is then recovered in order to reduce vaporization and ground water pollution.

Figure 72: The Process of Transesterification



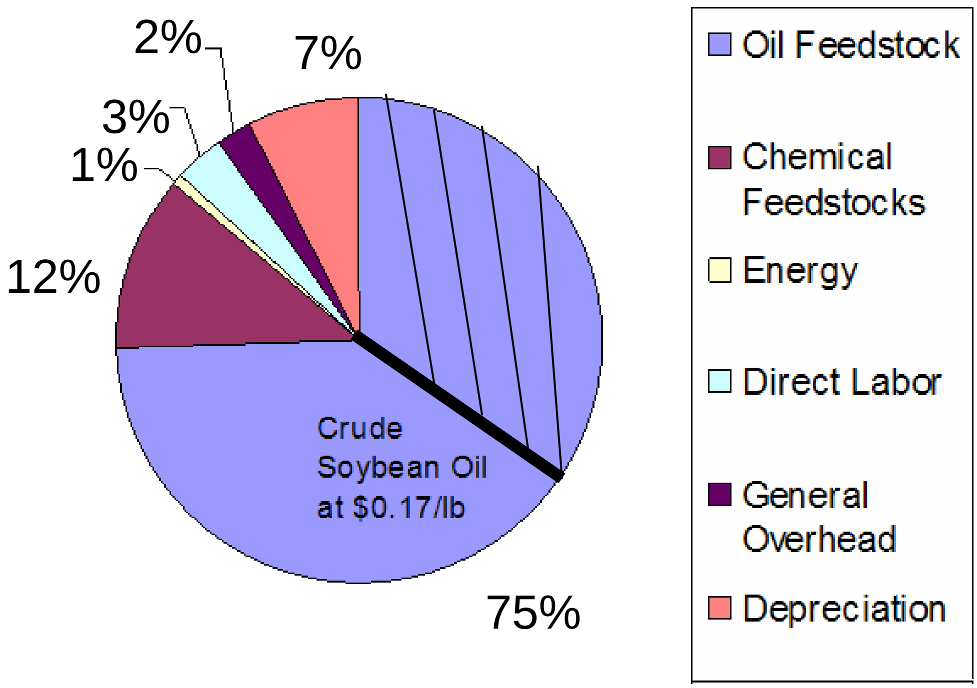
A group of Rice undergraduates, graduate students and faculty formed the Rice University Biodiesel Initiative (RUBI), to convert the 1,300 gallons of waste oil per year generated by the university's kitchens, combined with fresh canola oil, to cut the expense of diesel fuel for the campus shuttle fleet, which requires 8,000 to 10,000 gallons per year. RUBI started production slowly, producing biodiesel in 200 mL batches to test the system before moving to progressively larger batches, with a final goal of 70 gallons per reaction; their small reactor can produce 100,000 gallons per year if operating at maximum capacity. The RUBI program is a closed loop system in that most of their inputs are recycled cooking oil and waste grease, they produce a final product (biodiesel), and most of the by-products can also be used for other purposes, such as compost or soap.[xlii]

Durnin remarked that cooking oil and waste grease are suitable feedstocks for biodiesel because of the vast supply of these inputs in the United States; this supply represents an economic opportunity as well. "About 300 million gallons of waste grease is produced per year [in the United States]. If all of that were converted into biodiesel, it would create a $250 million to $1 billion per year industry. Using waste oil to produce biodiesel, rather than using soybeans, causes the cost to drop from $0.08 to $0.09 from $0.17 per pound," stated Durnin. (See "Figure 73: Waste Grease.")

According to Durnin, quality control and decentralized production are the keys to a successful biodiesel industry in the United States. He stated that "in-house production provides an especially strong incentive to maintain quality control; in a closed loop system, such as a university, universal regulations and standards can be less severe than in the open market." To maintain quality, RUBI found that if batches are poorly produced, they can be reprocessed by adding more catalyst.

Regarding decentralized production across the United States, RUBI found that biodiesel can be successfully produced from small reactors using relatively simple technology, while maintaining quality control. "Though the initial capital investment is high in order to purchase the necessary equipment, the final product and by-products provide enough savings to pay for the initial investment and generate profit," Durnin said, and that a "decentralized production network could overcome infrastructure and distribution barriers that exist for large centralized plants." There may be limitations to the extent which the energy industry may be decentralized, Durnin warned. For example, methanol production poses some dangers in large quantities (in terms of flammability and ground water control), and there are scalability issues involved: each facility would need extra tanks for storage, equipment to recover alcohol produced, and the ability to dispose of wastewater in an environmentally friendly manner.

Figure 73: Waste Grease



Used Vegetable Oil Container from Rice Kitchens (left) and the Rice Shuttle (right)

Reactor Growth at RUBI

From 200 mL reaction, to 1 Liter reaction, to 1 Gallon reactor, to a 70 Gallon reactor

The RUBI Pilot Plant

[i] DOE. Alternative Fuels and Advanced Vehicles Data Center: "Alternative Fueling Station Total Counts by State and Fuel Type." http://www.eere.energy.gov/afdc/fuels/stations_counts.html (Dec. 6, 2007).
[ii] United Nations Environment Programme (UNEP) report. "Global Trends in Sustainable Energy Investments, 2007." Released 20 June 2007. ISBN: 978-92-807-2859-0.
[iii] Energy Information Administration. February 2007. "Biofuels in the U.S. Transportation Sector."
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[v] "Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda," DOE Report DOE/SC-0095U.S. Department of Energy, (6), 2005.
[vi] DOE/EIA, December 2005.
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[xxi] Tokgoz, Simla & Elobeid, Amani (2006).
[xxii] The U.S. Energy Bill of 2005 requires a scheduled production of renewable fuels, beginning with 4 billion gallons in 2006 and reaching 7.5 billion gallons by 2012. Renewable fuels are defined as motor vehicle fuels and include cellulosic biomass ethanol, waste derived ethanol, biodiesel and any blending components derived from renewable fuel. However, 1 gallon of cellulosic biomass or waste derived ethanol is counted as the equivalent of 2.5 gallons of renewable fuel.
[xxiii] "How much bioenergy can Europe produce without harming the environment?" EEA Report No 7/2006 European Environmental Agency (2006, June 8).
[xxiv] According to a Fox news report, "Iowa has 28 ethanol refineries and 19 under construction or expanding." As of August 2007, presidential candidates Mitt Romney, Rudy Giuliani, Hillary Rodham Clinton and Barack Obama have toured ethanol plants ("Ethanol-Loving Candidates Pay Lip Service to Corn Farmers." August 30, 2007, Fox News).
[xxv] Annual Energy Outlook 2007 With Projections to 2030. DOE-EIA-0383 (2007). "Biofuels in the U.S. Transportation Sector." February 2007, Washington, D.C. and DOE Alternative & Advanced Fuels.
[xxvi] "Recent EIA estimates for replacing one gasoline dispenser and retrofitting existing equipment to carry E85 at an existing fueling station range from $22,000 to $80,000 (2005 dollars), depending on the scale of the retrofit. Some newer fueling stations may be able to make smaller upgrades, with costs ranging between $2,000 and $3,000. Investment in an E85 pump that dispenses one-half the volume of an average unleaded

gasoline pump (about 160,000 gallons per year) would require an increase in retail prices of $0.02 to $0.07 per gallon if the costs were to be recouped over a 15-year period. The costs would vary, depending on annual pump volumes and the extent of the station retrofit. The installation cost of E85-compatible equipment for a new station is nearly identical to the cost of standard gasoline-only equipment." (Annual Energy Outlook 2007 With Projections to 2030. DOE-EIA-0383 (2007). February 2007, Washington, D.C.).

[xxvii] Louis Dreyfus Energy specializes in the merchanting of agriculture and energy products, dealing with the transport, storage, trading and capital investment in these commodities. Their competitive advantage comes from merging agriculture's physical and financial markets.

[xxviii] Runge, C. Ford and Benjamin Senauer, "How Biofuels Could Starve the Poor" Foreign Affairs, Volume 86, No. 3. p. 41-53.

[xxix] Groundwater contamination associated with blending MTBE into gasoline has essentially eliminated this source of gasoline, oxygenating and octane from the gasoline pool.

[xxx] This data was compiled using treasury numbers, rather than those provided by the Joint Committee on Taxation.

[xxxi] Patzek on green land area in the United States**: "**Taking into account Alaska and Hawaii, there are roughly 165 million hectares of cropland in the United States, 130 of which is actually in production, with the remaining either idle, pastured, or filled with failed crops. A large portion of this land is dedicated to soybean and corn production, at about 30 million hectares each, followed by hay, at 25 million hectares, and wheat, at 20 million hectares. Additionally, 160 million hectares is currently in use as pastureland. Thirty million are currently woodland. Three-hundred million are currently forest or timber, much of which is committed to lumber production."

[xxxii] According to Patzek, some means to increase the amount of W/m^2 harvested from corn grain and stover include the following: If 75 percent of stover was collected from the field, an additional 0.1 W/m^2 can be captured (however, collecting this percentage of stover is highly inconsistent with current agricultural practices); if ethanol is run through a 60 percent efficiency fuel cell, about 0.18 W to 0.185 W will be used as mechanical work (however, most current fuel cells operate at about 40 percent efficiency, resulting in the use of about 0.1 W/m^2).

[xxxiii] According to Patzek's research on Brazilian sugarcane as a feedstock for ethanol, if the resulting ethanol is used in a 60 percent efficient fuel cell engine, 0.25 W/m^2 will be captured; if used in the typical American car, which uses a very low percentage of ethanol, a very low value will be captured.

[xxxiv] If converted into Fischer-Tropsch diesel fuel, about 0.4 W/m^2 can be captured, along with co-generation of electricity. If cellulosic ethanol is produced, about 0.3 W/m^2 can be captured.

[xxxv] For comparison, Patzek's research shows that in a standard oil field, between 100 and 300 W/m^2 of primary energy can be captured per year, with expected life of the field being 30 years.

[xxxvi] According to Oliveira, fuels in the United States and Brazil are slightly different. Pure gasoline is not available at the pumps in Brazil, but a mixture of gasoline and anhydrous ethanol is available, with the ethanol proportion varying from 20 percent to 25 percent; on the other hand, neat-ethanol engines use hydrated ethanol, without gasoline, so mixtures like E85 or E10 are not available.

[xxxvii] www.ibge.gov.br

[xxxviii] DOE and DOA. Biomass as Feedstock for a Bioenergy and Bioproducts Industry: the Technical Feasibility of a Billion-Ton Annual Supply. April 2005.

[xxxix] Zverlov, et al. "Biofuels from Microbes." Applied Microbiology and Biotechnology. 2006. 71:587-97.

[xl] DOE, Rice University strain 1995–2001.

[xli] DOE, 2003–2006.

[xlii] According to RUBI biodiesel production, 10 lbs. of glycerol are produced for every 100 lbs. of biodiesel produced. Fermentation experiments have shown some promise for expanded uses of glycerol, which will provide additional profit for the biodiesel production process.