NABC Report 20

Reshaping American Agriculture to Meet its Biofuel and Biopolymer Roles

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2008

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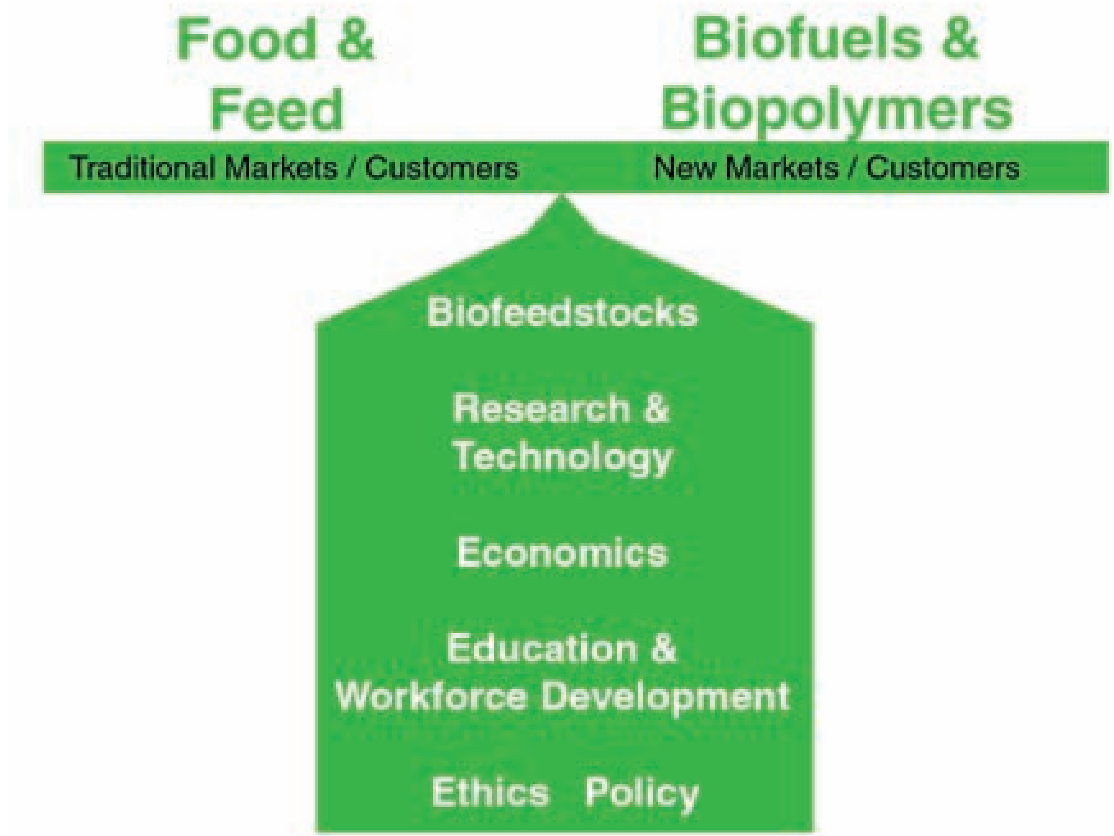

Edited by Allan Eaglesham, Steven A. Slack & Ralph W.F. Hardy

2008

NATIONAL AGRICULTURAL BIOTECHNOLOGY COUNCIL REPORT

NABC Report 20

Reshaping American Agriculture to Meet its Biofuel and Biopolymer Roles

Proceedings of the twentieth annual conference of the National Agricultural Biotechnology Council, hosted by the Ohio State University, Columbus, OH, June 3–5, 2008

Edited by
Allan Eaglesham, Steven A. Slack and Ralph W.F. Hardy

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NABC Report 20

Reshaping American Agriculture to Meet its Biofuel and Biopolymer Roles

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National Agricultural Biotechnology Council

Providing an open forum
for exploring issues in
agricultural biotechnology

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NABC's twentieth annual meeting—*Reshaping American Agriculture to Meet its Biofuel and Biopolymer Roles*—was hosted by Steven Slack at The Ohio State University (OSU), Columbus, OH, with excellent administrative assistance from Mary Wicks and Shelley Whitworth, to whom we are most grateful for a highly successful conference.

Thanks are due to the members of the planning committee[1] for an excellent agenda and first-rate choice of speakers: Steve Slack (program chair, OSU), David Benfield (OSU), Wayne Earley (PolymerOhio), Denny Hall (OSU), Alex Kawczak (Battelle Memorial Institute), Susanne Lipari (NABC), Stephen Myers (OSU), Gary Mullins (OSU), Randy Nemitz (OSU), William Ravlin (OSU), Sarah Sieling (OSU), Ken Vaughn (PolymerOhio) and Mary Wicks (OSU).

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Workshop Facilitators David Benfield (OSU), Colin Kaltenbach (University of Arizona), Bryan Kinnamon (Delta Plant Technologies), John Kirby (South Dakota State University) and Bruce McPheron (The Pennsylvania State University).

Workshop Recorders Karunanithy Chinnaduari (South Dakota State University), Sarah Kiger (OSU), Srilakshmi Makkena (OSU), Lisa Meihls (University of Missouri-Columbia), Sachin Teotia (OSU) and Thu Van Vuong (Cornell University).

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On behalf of NABC, we thank Alan Wildeman (University of Guelph) for his leadership as NABC's chair for 2007–2008.

Ralph W.F. Hardy
President
NABC

Allan Eaglesham
Executive Director
NABC

December 2008

[1]RWFH and AE also served on the planning committee.

PREFACE

The National Agricultural Biotechnology Council's twentieth annual meeting (NABC 20)—*Reshaping American Agriculture to Meet its Biofuel and Biopolymer Roles*—was the second in as many years to emphasize the importance of biofuels. The 2008 conference was built not only on the success of NABC 19 (*Agricultural Biofuels: Technology, Sustainability and Profitability*) but also on that of NABC 12 (*The Biobased Economy of the Twenty-First Century: Agriculture Expanding into Health, Energy, Chemicals, and Materials*).

The cover of this volume illustrates the challenge to agriculture to establish an equilibrium that will enable the needs of traditional markets (food, feed and fiber) to be met while also serving the needs of new markets (energy, chemicals and materials). The presentations and discussions at NABC 20 addressed the issues of food and feed, biofeedstocks, research and technology, economics, education and workforce development, ethics and policy, towards establishing this essential balance.

In 1998, NABC issued a *Vision Statement*[1] for agriculture and agricultural research in the twenty-first century. It envisioned improved food, feed, and fiber, but importantly it predicted agriculture's expansion into energy, chemicals, and materials (including biopolymers). This biobased economy, balanced with a reduced fossil-based economy, is projected to contribute to national security, sustainability, minimization of global climate change, expanded farmer-market opportunities, and rural development. Wording in the *Vision Statement* can be found in Executive Order 13134—*Developing and Promoting Biobased Products and Bioenergy*—signed by President Clinton in 1999. In 2000, NABC 12, which was hosted by the University of Florida, Gainesville, focused on these opportunities. It was the first conference to explore benefits from, and concerns about, the biobased economy. From that meeting grew the annual *World Congress on Industrial Processing and Biotechnology: Linking Biotechnology, Chemistry and Agriculture to Create New Value Chains*, the sixth of which will convene in Montreal, July 19–22, 2009[2], co-organized and sponsored by the Biotechnology Industry Organization, the American Chemical Society, the US Department of Energy, and NABC. In 2007, NABC issued *Agriculture and Forestry for Energy, Chemicals and Materials: The Road Forward*[3], an updated and expanded version of the *Vision Statement* describing opportunities for agriculture and forestry to be the basis for a hybrid bio-/petro-based economy with 100+ billion gallons of transportation fuel and value-added chemicals and materials produced from domestic biomass, and a structure for attainment.

[1] *Vision for Agricultural Research and Development in the 21st Century: Biobased Products Will Provide Security and Sustainability in Food, Health, Environment, and Economy*. http://nabc.cals.cornell.edu/pubs/vision.html.

[2] The *Summary Proceedings* from the 2008 *World Congress* is available at http://nabc.cals.cornell.edu/pubs/WCIBB2008_proc.pdf; information on the 2009 *World Conference* is available at http://www.bio.org/worldcongress/.

[3] http://nabc.cals.cornell.edu/pubs/The_Road_Forward.pdf; Hardy RWF Eaglesham A Shelton A (2007) Agriculture and forestry for energy, chemicals, and materials: The road forward. Industrial Biotechnology 3 133–137.

NABC 20's theme was biofuels and biopolymers, and Module I (*Megatrends Reshaping American Agriculture*) was held jointly with PolymerOhio. The themes of the other modules were:

II *Optimizing the Value of Co-Products and Byproducts*

III *Enhancing Productivity of Biofeedstocks*

IV *Policy Issues Impacting Agriculture and Bioenergy*

Hosted by The Ohio State University in Columbus, OH, June 3–5, 2008, NABC 20 had 107 attendees. Speakers comprised representatives of government, the agriculture and chemical industries, university administration and faculty, private companies and the US Department of Agriculture. At the conclusion of the formal presentations in Modules II–IV, panelists made brief presentations, providing alternative and complementary viewpoints, prior to Q&A sessions that included audience participation. Attendees then convened in smaller breakout sessions for further discussion of issues raised by the speakers and panelists and during the Q&A sessions.

To increase graduate-student participation at NABC conferences, the *Student Voice at NABC* initiative was launched ahead of NABC 19. Feedback from those involved was positive, therefore the program was continued for NABC 20. Grants of up to $750 were offered to graduate students at NABC-member institutions (one student per institution) to offset travel and lodging expenses. Registration fees were waived for grant winners. Registration fees were waived also for some graduate students from NABC-member institutions who agreed to act as recorders for the breakout sessions; they also participated in the *Student Voice* discussions. The student delegates attended the plenary sessions and breakout workshops and then met as a group to identify current and emerging issues relevant to the conference subject matter[4].

This volume contains an overview of the meeting, a summary of the breakout-workshop discussions and emerging recommendations, the verbal presentations—including those made during the banquet and luncheons—and the *Student Voice* report. Transcripts of the panel discussions and Q&A sessions are included.

NABC 21—*Adapting Agriculture to Climate Change*—will be hosted by the University of Saskatchewan, June 24–26, 2009, in Saskatoon, SK. Further information may be accessed via https://nabc21.usask.ca.

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The Ohio State University

Ralph W.F. Hardy
President
NABC

[4]Information on the *Student Voice at NABC 21* is available at https://nabc21.usask.ca/student%20studentscholarships/student_index.htm.

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Reshaping American Agriculture to Meet its Biofuel and Biopolymer Roles

Steven A. Slack & Mary Wicks
Ohio Agricultural Research and Development Center
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Wooster, OH

NABC's twentieth annual meeting—hosted by The Ohio State University—convened in Columbus, OH, June 3–5, 2008. Delegates were welcomed by the senior author (associate vice president for agricultural administration and director of the Ohio Agricultural Research and Development Center, OSU), Bruce McPheron (NABC chair 2008–2009) and Ralph Hardy (NABC president). The conference attracted 107 delegates from twenty-seven US states, two Canadian provinces and Nigeria. Plenary sessions were held on the afternoon of June 3, the morning and afternoon of June 4, and the morning of June 5.

For the June 3 luncheon, delegates were joined by participants attending the Ohio Polymer Summit with Ohio Governor Ted Strickland as the keynote speaker. The keynote speaker for the evening's banquet was Ganesh M. Kishore (Burrill & Company, San Francisco, CA, *Agriculture: The Foundation of the Bioeconomy*). On June 4, the two luncheon keynote speakers, Christiane Deslauriers (Agriculture and Agri-Food Canada, Charlottetown, PEI, *Supporting Cross-Cutting Research: The Agricultural Bioproducts Innovation Program*) and Irwin Goldman (University of Wisconsin, Madison, WI, *Energy Transformations in a Land-Grant College: The Great Lakes Bioenergy Research Center*), shared efforts by Canada and the United States to enhance bioproduct and bioenergy research. The Ohio State University President Gordon Gee (Columbus, OH) provided the final keynote address at the June 5 luncheon.

Module I—*Megatrends Reshaping American Agriculture*—comprised presentations by John Pierce (DuPont, Wilmington, DE, *Renewable Fuels and Materials*); Steven Pueppke (Michigan State University, East Lansing, MI, *Megatrends Reshaping Agriculture and Agricultural Universities*); Benson Lee (Technology Management, Inc., Cleveland, OH, *Energy Independence: On-Site Fuel Cell Systems Operating on Biofuels*); and Peter Ashcroft (Environmental Defense, Washington, DC, *What Future Role for Biofuels?*).

In Module II—*Optimizing the Value of Co-Products and Byproducts*—presentations were made by Stephen Myers (Ohio BioProducts Innovation Center, Columbus, OH, *Renewable Polymers and Advanced Materials*); Robert Fireovid (USDA/ARS, Beltsville, MD, *ARS Research on Bioenergy and Co-Products*); and Joseph Bozell (University of Tennessee, Knoxville, TN, *Biomass as a Source of Carbon: The Conversion of Renewable Feedstocks into Chemicals and Materials*).

The speakers in Module III—*Enhancing Productivity of Biofeedstocks*—were Stephen Long (University of Illinois, Urbana, IL, *Opportunities for Enhancing the Productivity of Biofeedstocks and Minimizing Inputs: Theory and Practice*); Bill McCutchen (Texas A&M University, College Station, TX, *High-Tonnage Dedicated Energy Crops: The Potential of Sorghum and Energy Cane*); and David Bransby (Auburn University, Auburn, AL, *Synchronization of Biofeedstocks and Conversion Technologies: Current Status and Future Prospects*).

Presentations in Module IV—*Policy Issues Impacting Agriculture and Bioenergy*—were given by Paul Thompson (Michigan State University, East Lansing, MI, *Agricultural Biofuels: Two Ethical Issues*); Harry de Gorter (Cornell University, Ithaca, NY, *The Social Cost and Benefits of US Biofuel Policies*); and Kenneth Cassman (University of Nebraska, Lincoln, NE, *Scientific Challenges Underpinning the Food-Versus-Fuel Debate*).

The conference theme—agriculture's biofuel and biopolymer roles—was comprehensively covered with high-quality presentations that stimulated thoughtful feedback from response panelists, lively Q&A sessions with the audience and active discussion within three breakout sessions. Points of interest made by speakers and which emerged from the Q&A sessions with audience participation included:

Food & Feed

- There is considerable misinformation about how food prices are impacted by ethanol production from corn; better understanding is needed of the variables that impact food pricing.
- More time needs to be committed to considering multifunctionality of systems, *e.g.* food and fuel and ecosystem services. Intensive use of land for production of both food and fuel crops needs consideration.
- Researchers need to adapt interdisciplinary approaches to solve food-availability and, thus, rising food-cost issues. A focus on genetic improvement of traits such as disease and pest resistance, adaptive changes to climate or soil-fertility differences and improvements in products for end-users is needed. Large-scale, real-world field tests will be critical for validation.
- Farmers will grow what the market demands. They have always been adaptable to changing societal needs as long as the market is sustainable.

Biofeedstocks

- Ideal feedstocks will likely be region-specific.
- The top feedstocks today are native forests, crop residues, paper that would otherwise go into landfills, food-processing wastes, and energy crops like *Miscanthus*.

- Perennial grasses utilizing C4 photosynthesis likely come closest to meeting the concept of an ideal biomass crop. Sustainability experiments to provide actual data on greenhouse-gas balance will be important as future cropping and policy decisions are considered.
- The development of multiple crop-production systems tailored to meet local climatic, biotic and soil stresses and to economically deliver year-round supplies is essential for a successful bioprocessing industry.
- Growing crops for energy requires the same attention to production issues—rotation, soil erosion, pest management, *etc.*—as food crops.

Research & Technology

- Biomass is a relatively new raw material for the chemical industry with current conversion technologies limited and, thus, continued investment in research and development for bioprocesses, potential products and economic production is critical. To meet this challenge, biorefining must integrate the production of high-return feedstocks with high volumes of fuel to meet energy and economic goals.
- All aspects of bioenergy need to be synchronized, from production to processing to profitability. Converting biomass to heat energy or liquid fuel requires process technologies that maximize production and minimize environmental impacts.
- Academic and industry partnerships will be critical to solving national and international energy needs for society.
- Bioconversion technologies have significant implications for landfills and gas generation and utilization of municipal waste streams, but consideration needs to be given to the fact that agriculture and municipalities have their own cultures in terms of waste collection, separation, *etc.*
- In an era of limited resources, it is critical to prioritize goals; biotechnology will be one of the critical tools available for possible solutions.

Economics

- Economic trade-offs are overriding forces that will ultimately dictate the comparative advantages of fungible commodities in different regions and countries.
- Rural communities have an opportunity to benefit from the development of bioenergy and bioproducts industries, especially to the degree that they can develop in a decentralized environment; however, the economics of business will drive final decisions.
- We need to allow room for innovation, *e.g.* there will be entrepreneurs who will figure out the "opportunity space" for feedstocks and land utilization if given the opportunity to compete for markets.
- Intellectual property and technology licensing can be deal-breakers in part because the models are not uniform from state to state nor institution to institution,

but systems can be managed effectively either by working out the fundamental parameters upfront or by developing long-term relationships that enable partners to work through issues.

Education & Workforce Development

- The twenty-first-century land-grant university must evolve to incorporate changes in access to information, diversity of competition, demands of consumers, and changing faculty and student needs.
- It is critical to develop public-private forums to enhance understanding of what is happening in different sciences that may impact the feasibility of product development from energy-balance and value-chain perspectives.
- High-risk investments to propel new technology development have been an effective tool in various settings, but workforce development needs to be a core consideration in order to get and keep government engaged.

Ethics

- As the emphasis on the development of biofuels increases, so do ethical concerns regarding perceived tradeoffs between food, fuel and the environment. However, this is a complex paradigm that cannot be easily teased apart and will require a democratic public exchange of views.
- An interesting dichotomy exists between industrial and agrarian perspectives of agriculture; only 1.4% of the population is involved in agricultural production, whereas many others have a romantic view of what agriculture should be. However, the latter agrarian perspective can have considerable policy impact and may foster different pathways to market (*e.g.* local food networks).
- Subsistence farmers produce food for their own existence without infrastructural access to broader markets. Issues beyond science are the primary barriers in these cases.

Policy

- The net result of the current combination of tax credits and mandates negates the tax credit and subsidizes gasoline consumption. It was argued that consumption mandates alone are more efficient.
- The renewable fuel standard is critical to drive innovation and investment as it sets the goals that industry will strive to meet.
- Markets created by subsidies or other artificial means make these markets inherently risky as policy changes may eliminate them unless there is an inherent underlying demand. Renewable energy from "free" sources like the sun and wind are not limited and are, therefore, more likely to be viable over time. However, the technologies utilized to harness them are still subject to public review.

- Effective policy for developing alternative fuels must answer questions regarding integration into the existing transportation-fuel infrastructure and the implications for meeting fuel-vs.-food demands.
- The rate of technology change poses a critical catch-up problem for policymaking processes.
- Unintended consequences of policy in this nascent industry are sometimes exploited. The tax credit gained by blending in a small amount of biodiesel with normal diesel has resulted in profiteering.

Response panels followed the plenary speakers in Modules II–IV and breakout sessions were held as small-group discussions of specific questions (see pp. 11–21) with reports made back to the entire group of attendees, a process that enriched the exchange of information considered. In addition, the *Student Voice* delegates met as a group and reported on their discussions, again of specific questions (see pp. 229–232).

The discussions and interactions of all participants helped to identify significant questions and to pose relevant perspectives to an emerging land-use issue in which energy generation and food production—two critical issues for society today and for the foreseeable future—will need to be considered by all as we seek to maintain a precarious balance in a world with increasing population and the concomitant accompanying pressures.

PART II–BREAKOUT SESSIONS

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Allan Eaglesham & Ralph W.F. Hardy

Workshops Summary

Allan Eaglesham & Ralph W.F. Hardy
National Agricultural Biotechnology Council
Ithaca, NY

Three breakout workshops were held, under the following general topics:

- *Optimizing the Value of Co-Products/Byproducts*
- *Enhancing Productivity of Biofeedstocks*
- *Policy Issues Impacting Agriculture and Bioenergy*

Four groups, each with a facilitator and recorder[1], met for 1-hour sessions to discuss predetermined questions. This is a synthesis of key points[2] that emerged from those discussions.

Workshop I – *Optimizing the Value of Co-Products/Byproducts*

Question 1: What economic and social issues need to be considered as industrial products are made from bioresources instead of from petroleum?

- Good market analysis of costs, demands, *etc*. of co-products.
- Positive aspects of biotechnology—resulting from solid science—should be emphasized in published articles.
- Effective communication and management of risk are important. Perceived risk and real risk should be differentiated.
- There is the possibility of a wealth-shift in the US economy as it transitions to being biobased rather than petro-based.

[1]These duties were shared as follows:
Facilitators—David Benfield, Colin Kaltenbach, Bryan Kinnamon, John Kirby and Bruce McPheron.
Recorders—Karunanithy Chinnaduari, Sarah Kiger, Srilakshmi Makkena, Lisa Meihls, Sachin Teotia and Thu Van Vuong.

[2]Comments more relevant to workshops other than those in which they were raised have been reassigned accordingly, and comments not related to the theme of the conference are not included.

Question 2: What elements are necessary to develop a systems approach (value chain) to predict best end-uses of biobased industrial products (*e.g.* biofuels and co-products)?

- New systems infrastructure will be needed as we transition to second-generation biofuels.
- Distillers dry grains (DDGs) are a by-product of corn-starch conversion to ethanol. It is not widely understood by the public that DDGs are a valuable component of animal feed.

Question 3: How can life-cycle greenhouse-gas impacts (footprint) be minimized for the biobased economy

- Accurate life-cycle analyses are needed to understand energy gains/losses and waste generation associated with biofuel production.
  - A sound scientific basis is needed on which to make lifecycle analyses of biofuels and fossil fuels.
- Lifecycle analyses can be used by technology developers to improve sustainability and minimize waste.
- Renewable fuels should not be held to stricter standards than non-renewables.
  - The risks inherent in the biobased economy should be compared to risks inherent in a petro-based economy.
- Broader studies of carbon sequestration by plants are needed; such plants should be chosen on a regional/climate basis.
  - Land use for maximum carbon sequestration should be encouraged.
- New technologies should be developed to capture carbon and re-use it.
  - CO_2 produced during yeast fermentation can be captured by microalgae, for use, in turn, as a feedstock for biofuel production.
  - The regulatory framework should encourage introduction and adoption of new technologies.
- A comprehensive approach to reducing the carbon footprint and the focus should not be wholly based on energy consumption. There should be economic incentives, laws and policies, moral imperatives, education, introduction of new social norms, and technological/mechanistic changes aimed at reducing the carbon footprint.
- A carbon tax would raise revenue to make people realize how much carbon they use and increase their desire for efficiency.
  - The effect of rising fuel prices on driving habits shows that consumer behavior can change.

Workshop II – *Enhancing Productivity of Biofeedstocks*

Question 1: What are the economic, environmental and social issues that should be considered in the selection of biofeedstocks?

- Government should provide a financial safety net for farmers growing new crops.
- Increasing productivity per unit area will be necessary as arable land is limited. Availability of new, productive crops will be key, *e.g.* switchgrass.
- Profit and risk factors—including disease, insect predation and drought—should be considered.
- Maintenance of ecosystem services is vital by using production systems that support natural and managed ecosystems.
  - Consideration of ecosystem services should be built into the feedstock-decision-making process.
- Regional and local factors will influence choice of biomass feedstocks. In the Northeast, for example, there is emphasis on woody biomass. Pennsylvania about 750,000 private forest landowners with an average woodlot area of <19 acres. Whether these will be available becomes a sociological issue.
- There is concern over cultivating land that hasn't been intensively farmed before.
  - Land conversion can have long-term effects on the ecological footprint.
  - Perennial systems should not be converted to annual systems.
  - Systems that store large amounts of carbon should not be converted to those that store minimal amounts of carbon.
- The ultimate measure for a biofeedstock might be that the production system has to be carbon neutral.
  - Biofeedstock standardization is problematic.
  - Not all feedstock/bioproducts solutions are equal.
- We need to help people understand that we already affect ecosystems—it is just a matter of degree and intensity.
- A likely consequence of increasing biofuel production is the cultivation of more land with implications for wildlife habitats and environmental quality.
- Land on which corn is productive should not be planted to switchgrass. Illinois, for example, should stay in corn, whereas switchgrass might be usefully grown in parts of Tennessee. It might be most useful to grow cellulosic feedstocks on land no longer used for agriculture. Also, pasture land may be well suited for switchgrass production.
- The emphasis on switchgrass as a perennial feedstock for cellulosic ethanol may not be feasible on an industrial scale due to costs of transportation from the field to the biorefinery.
- Feedstock-resource owners will need education on economic and sociological issues.
- The advancing average age of farmers is a factor in receptiveness to new ideas. Young farmers are more attuned to emerging opportunities.

- Inappropriate infrastructure can be a hindrance to switching to new crops and new technologies.
- It is necessary to understand the market.
  - Industry won't build an ethanol facility without having buyers for ethanol and DDGs.
  - The Farm Bill emphasizes cellulosic ethanol rather than alternative fuels, responding to public perception that rising corn prices result from diversion to biofuel.
- A bridge will be needed between industrial and agrarian considerations as they relate to advanced biofuels.

Question 2: Where are the greatest opportunities for genetic and agronomic productivity enhancement of biofeedstocks to provide sufficient supply to meet demand?

- Emphasis on plant breeding is needed, with incorporation of biotechnological innovations.
  - Because the germplasm base of biofeedstocks like switchgrass is narrow, genetic engineering will play a key role in achieving genetic improvements.
  - Hybrid technologies may play an important role.
  - Genome sequencing should be a component of the appraisal of new crops to maximize understanding of their biology.
- Crop rotations should be encouraged; in recent years, corn and soybean have been increasingly sole-cropped.
  - Although not initially affected by pests, biomass crops may be affected in the future. Vigilance is required.
  - Growing feedstocks in polyculture will help minimize pest problems.
  - Companies and farmers will make feedstock choices.
- Over-seeding biomass crops with nitrogen-fixing cover crops should explored.
- Multiplication of seed material will be needed in anticipation of cellulosic ethanol becoming economically viable.
- Water is an important resource for crop production and access to irrigation will be an increasing challenge.
  - Breeding for increased drought resistance will be important.
- At this stage, we should embrace the complexity that solutions are not equivalent.
- It has been suggested that marginal lands may be recultivated to produce biofeedstocks. However, if productivity is relatively poor, increasing transportation costs may make this strategy unfeasible.
- Studies are ongoing on the genetics of algae.
  - The use of algae for production of biofuels and for carbon dioxide sequestration faces scale-up problems.

Question 3. What are the primary systems obstacles/opportunities for utilization of new biofeedstocks?

- The biofeedstocks discussed include the current production crops of corn, soybean and sugar beet. In the short term, we should focus on these traditional crops—for which production systems are in place—and then in a few/several years overlap with cellulosic feedstocks, which will assume the increasingly greater role.
  - There is need to educate people that woodland resources are renewable. Somewhere in the ethical debate there needs to be understanding of plant lifecycle.
  - A niche will exist for academia to educate on ecosystems and plant processes.
  - As we move into cellulosic solutions the definition of "agrarian" becomes different from what it is now.
- There is need to capitalize on previously unused components. Before considering new biofeedstocks, we should examine the possibility of using corn and soybean more efficiently, including straw, stover and cobs as sources of carbon.
  - More research is needed on how much straw and stover can be removed from the field without compromising soil organic matter replenishment.
- It doesn't make sense to convert the corn belt into the energy belt because infrastructure for the former industry is already in place.
- Financial investments in corn ethanol are large, will take years to pay off and may delay the transition to cellulosic ethanol.
- More than feedstock development, vertical integration is needed, involving harvesting, in-field processing, transportation, storage, in-factory processing, co-product catchment and utilization, *etc.*
- Vertical integration is likely; as with food producers, fuel producers will buy the land they will need.
  - On the other hand, forest-product companies also bought woodland but later sold it and now buying their wood.
- Papermill waste and wood chips may be good candidates as feedstocks for ethanol production.
- If bio-oil can be produced economically it would solve many problems.
- Important scale issues underpin production of significant quantities of biomass feedstocks to support a cellulosic ethanol industry.
- The type and cost of feedstock, its transportation, storage and processing all affect the value chain.
- In-field feedstock preparation may be necessary; in the future, farming may involve more than production.

- The area available for planting biofeedstock crops will depend on the processing-plant location; "capture zone" size will depend on many factors including the energy content of feedstock on a per unit weight basis.
- Through research, we may be able to guide farmers on their land use.
- Aesthetic value: increasingly, the appearance of "pretty" farmland has implications for decisions that non-farmers make about land use with the growing interface between rural and urban communities.
  - Couched in appropriate terms, animal-waste conversion to energy could be an important factor in improving acceptance of the livestock industry by exurbanites.
- To a large extent, the petroleum industry controls development in biofuels. If oil companies decrease the price of petro-fuels, interest and investment in biofuels could suffer.
- New construction is likely to be more robust with built-in capability to adjust to new technologies.
- Farmers have the potential to steer the momentum towards cellulosic biofuels.
- The support of environmental groups is needed. Industries are investing profits in ecological restoration.
- Opportunities for revitalizing rural economies are important.
  - Use of marginal, or underutilized, land for production of biofeedstocks represents potential new income for farmers.
- Cellulosic ethanol will also be transitional. The future lies with a combination of fuel cells and batteries.
  - The transition time will be influenced by the marketplace.

Workshop III – *Policy Issues Impacting Agriculture and Bioenergy*

Question 1: What primary economic, environmental and social perspectives should be considered in making effective public policy to encourage adoption of bioproducts?

- Much of the public policy on biofuels needs to be re-examined.
- "Biobased" certification would give bioproducts a preferred status for government purchase. This would assist achievement of production at the scale necessary for companies to provide bioproducts commercially.
- Risk-management incentives should be available to farmers growing new biofeedstock crops.
- Incentives should be available to encourage farmers to form cooperatively owned processing plants.
- Introduce incentives for dairy farmers to install manure digestors to capture the energy content of biogas and minimize methane release as a greenhouse gas.

- Change state policies so that people with solar power are rewarded for adding electricity to the grid.
- Regulatory aspects require reconsideration, with emphasis on deregulation coupled with selective incentives.
- Policies are needed to ensure energy security.
  - The main market driver always ends the value chain. Everyone in the process has to profit.
  - One of the drivers of the USDA strategic plan is contribution to energy security.
  - Policy decisions need not be complex, largely because we don't have many working technologies.
- "Green" collar jobs will be created and, over time, policies will be shaped by endeavors that grow jobs.
- There is a disconnect between policies at the city, state and national levels. City and state policymakers are, in general, more aware of opportunities.
- States are putting renewable fuel standards in place, although they are not necessarily well located geographically for feedstock availability and ethanol production. This may lead to variation in implementation of national-scale policies.
- The government should implement a land-use policy that dictates return of organic matter to the soil to maintain its organic matter content.
- Public education is as important as introducing new ideas. The public has the right to know about new products and technologies.
- The public isn't aware of much of the policy that affects them, nor are they aware of the effects of public policy on them.
- Institute a system for paying for ecosystem services.
- Maximize efficiency of biofuel-powered vehicles.
- The negative public perception of private companies holding ownership of varieties and genes should be addressed. It is important that the public understands that, without the profit motive, much of the expensive research that will be needed to improve food production will not be done.
- There is need for funding that encourages skill integrations, such as plant breeding and molecular biology.
- US energy consumption is 25% of the amount consumed globally. If the United States were to reduce consumption, developing countries might use that energy to become developed. The United States should use all possible resources (including corn) to become energy-sufficient.
  - The United States needs a national energy policy.
  - There is pressing need for energy conservation in the United States.

- The petroleum industry is centralized at ports for shipping. In contrast, food comes from a variety of places. Production of biofuels is likely to benefit people in rural areas.
  - More than 50% of the population is in cities; if subsidies keep people in rural communities, it may be worth the cost.
- Wealth generated from ethanol production will accrue mainly to landowners.
- Eventually a tipping point will be reached at which the cost of waste disposal will become more than the cost of recycling.
- The new Farm Bill $1.01 subsidy on blending ethanol could be a disincentive to developing new technologies beyond cellulosic ethanol.
- As developing nations become more affluent, there is increased demand for meat in the diet making agricultural sustainability more difficult to achieve.
- In creating fuel to replace foreign oil, co-products can bring benefits in creating new sources of income for local communities.
  - It's important to support the agricultural strengths of a given region.
- This issue is often viewed from a national perspective, whereas the focus should be regional.
- There is a perception that the bioeconomy will be "green," which is not necessarily so.
- Durable products can be economic disincentives; in that case we will have to change the view of what constitutes a successful economy.

Question 2: What key issues must be resolved for the discussion to move beyond the "food versus fuel" debate to encourage consumer acceptance of "food and fuel"?

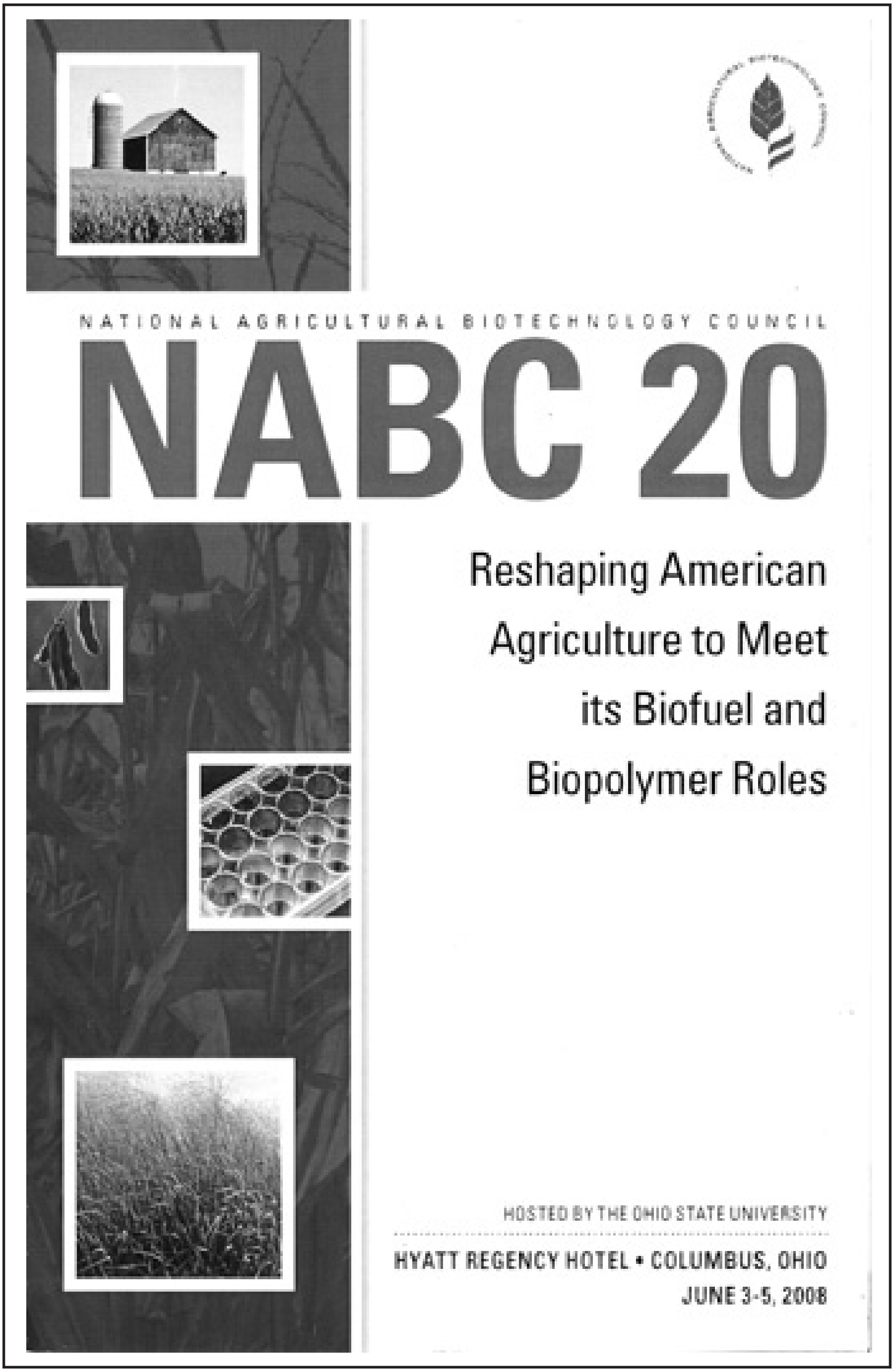
- There is much media coverage of direct adverse effects on food prices of using corn as a feedstock for biofuels and bioproducts. This subject needs more study and the degree to which it is perception rather than reality needs to be conveyed to the public.
  - Public forums should be initiated to address key issues.
- There is need to develop and publish concise white papers on food-versus-fuel and fuel-versus-nature. These should include all cost elements.
- Food security concerns should be addressed. Bioenergy policy should take food security into account such as to secure our food first.
  - Bioproducts can contribute to food security.
- Public understanding of the food-versus-bioproducts issues is needed; Outreach programs could be aimed at high-school students and consumers in general.
- Land-management issues need to be resolved.
- A white paper on food versus fuel and food versus nature should be produced and circulated.

- The debate over food versus fuel may never go away. Good science doesn't always carry the day in the public perspective.
- We must seek economic fuel solutions that are not in direct competition with food production.
- Will we have a sufficient natural-resource base to produce the food needed to support an increasing global population and demands for higher living standards?
- As alternative fuel scenarios are developed and tested, we must not compromise the natural resource base necessary for increased food production.
- Soybean and corn may not provide the best feedstocks for biofuels. The new Farm Bill will encourage farmers to switch to new crops such as native species like switchgrass.
  - Why make corn-starch ethanol at all, if it's only a temporary fix? It's immoral to use food to make fuel, when people are hungry.
- Technologies are being developed for growing microalgae as a source of biomass feedstock for fuel and polymer production. Relatively little land mass need be involved. The liquid fuel needs of Ohio could be met with an area equivalent to one and a half counties. There is room for optimism that we can solve our energy needs without affecting food production.
  - Algal ponds could be placed adjacent to coal-burning power plants, to utilize CO_2 and provide biofeedstock, on otherwise unproductive land.
- The increasing global population dictates the need for long-term alternatives to cellulosic biofuels.
  - In the long term, agriculture will be unable to keep pace with growing demands for food, fiber and fuel without impingement on the ecosystem services—clean air and water, fertile soil and biodiversity—that human survival depends upon.
- Woody crops can provide feedstock without impinging on food production.
  - In terms of woodchips as feedstock, use of fruit-crop trees would help sustainability.
- Countries like China don't want food *or* fuel; they want one crop that can serve as both in case of food shortage.
- High food prices are an incentive to farmers to produce, but will the consumers buy?
  - US food prices were relatively higher in the 1960s and 1970s.
- Farmland continues to be used for building. If we are to achieve a biobased/renewable economy, policies should be instituted to keep land in agricultural production. One approach would be to subsidize land rather than crops.

Question 3: What unresolved technical issues are impeding progress toward sound biofuel policies?

- The major issue is technology availability.
  - Familiarity with the current technologies may constrain adoption of new technologies. The corn-starch process is so well known, that there will be inertia to change to more complex processes.
- Several technical issues remain unresolved. Conversion of cellulosic biomass to ethanol is not yet economically viable. Furthermore, biomass transportation and storage systems are not ready to deal with large-scale production of cellulosic biofuels.
- Missing technologies may constrain policy.
  - Cellulosic ethanol production has its attendant technologies, but breakthroughs are needed.
  - Policy lags behind technology.
  - Many technical issues are unresolved, but not all have policy implications.
  - Lack of profitability of the current technologies is driving incentives for new technologies.
- Regulations should facilitate the implementation of novel developments. Unfortunately, the current federal regulatory framework is inhibitory to the adoption of new policies.
  - Improved technologies are sitting on the shelf because implementation is encumbered by regulations and cost of negotiating the regulatory process.
  - These technologies are disruptive and may be difficult to regulate.
- Facilitation is needed of technology transfer from the university (discovery) to companies (marketing).
  - Collaboration among industry, university, and government is needed.
  - With adoption of the Canadian model—*i.e.* with federal funding to encourage the uniting of efforts from academia, industry, and government—more rapid progress would be possible in terms of advancing agriculture and its contributions to energy security, the biobased economy, and human health.
- Modification of educational systems is needed at the high-school and undergraduate levels to put greater emphasis on cellulose-based chemistry as well as petro-based chemistry. Greater emphasis should be placed on plant biology across the educational system. For example, chemical engineers should have at least a grounding in plant biology.
- Graduate students need to learn how to implement their molecular and cellular studies at the economic and ecological levels.
- A key component of ethanol-production technology should be capture and recycling of water.

- Corn-grain production is dependent on water and inputs; it has required subsidization.
- The public is more open to rational discussion on biotechnology than it was 5 years ago.
- We need to establish collaborative worldwide efforts scientists in India, China, *etc*. to share research and technological information.
- A policy group should evaluate and define what bioproducts are, to facilitate uniform legislation among states.


NATIONAL AGRICULTURAL BIOTECHNOLOGY COUNCIL
NABC 20
Reshaping American Agriculture to Meet its Biofuel and Biopolymer Roles
HOSTED BY THE OHIO STATE UNIVERSITY
HYATT REGENCY HOTEL • COLUMBUS, OHIO
JUNE 3-5, 2008

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Renewable Fuels and Materials

John Pierce
DuPont
Wilmington, DE

I'll give my views on how I see the evolving fuels and materials areas, but I'll start with a historical perspective with some slides used in 1996 in discussions with upper management at DuPont on why we ought to focus on bioproducts. Enormous quantities of materials are available from agriculture and though prices fluctuate over time, they're cheap on a per-pound basis (Fig. 1). Supplies tend to exceed demand even though distribution is problematic. Biotechnology, of course, provides tools to start converting agricultural feedstocks into various types of materials.

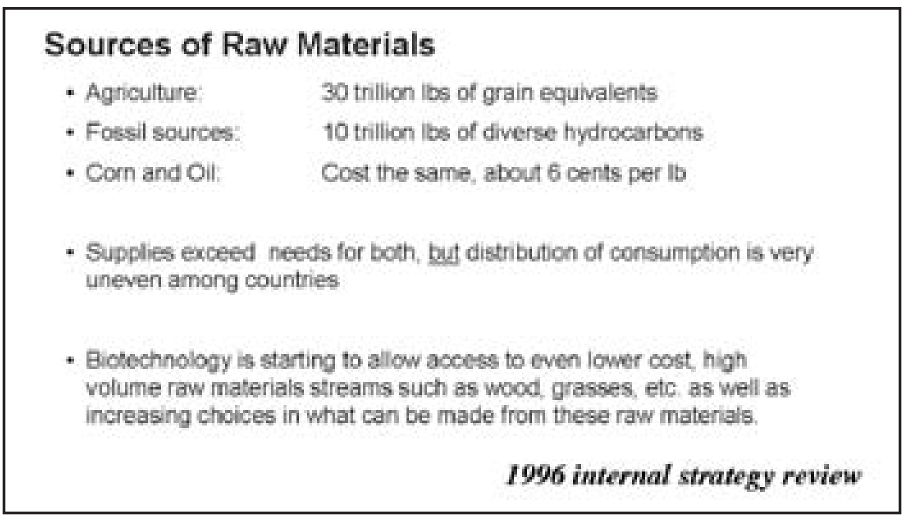

Figure 1. Sources and costs of feedstocks, 1996.

Figure 2 shows the relative price of corn versus oil. For most of last century, oil was cheaper on a unit-weight basis than corn. That has become less and less true. Today, even with corn prices at record highs, on a per-pound basis the corn versus oil ratio is at a historic low. This brings into focus the factors that can drive new processes and new feedstocks.

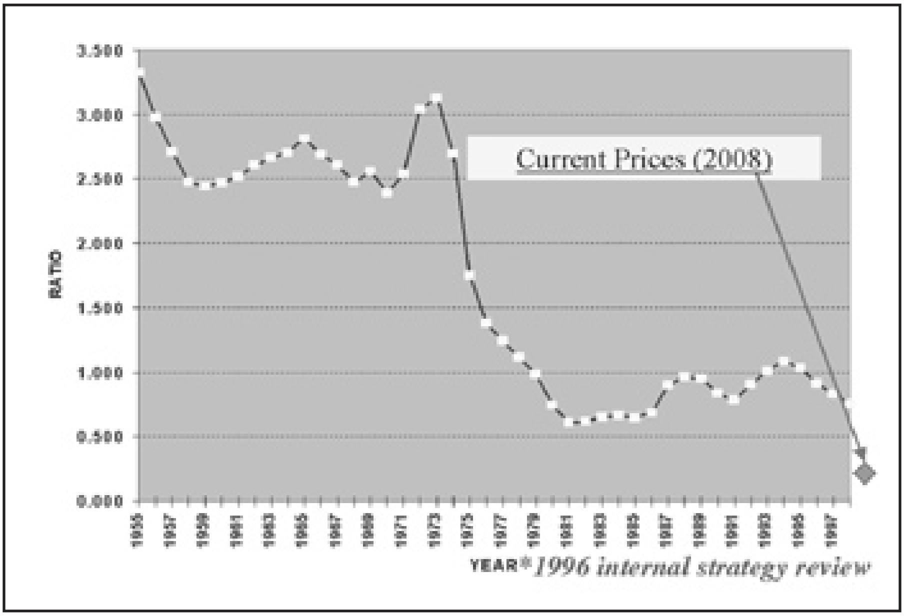

Figure 2. Price ratio, corn: oil ($ per lb).

Historically, we've had two separate industries (Fig. 3). You had the folks like Dupont who take a barrel of petroleum and do some fancy chemical engineering with it and make a better thing for better living, such as a nice polymer. That continues to be important. The other group, who hardly interacted with the polymer side of the house, grew and sold raw agricultural materials for various purposes. And then along came biotechnology and the idea that you can start doing something purposeful with the products of agriculture, and the two groups started eyeing each other. We started understanding more about companies like ADM, Cargill and Tate & Lyle, and they started understanding more about the chemical industry.

At Dupont, this perspective caused us to look hard at what we were doing and to make commitments about our future (Fig. 4). I remember at the time our chairman announced the plans, I thought, "I don't know how we're going to do that." However, we've made some strong moves in terms of sustainability. Now, most of these have been "mindset" related; once you decide you are going to be sustainable and renewable, you find all kinds of ways to achieve that. Some are agriculturally based and some are process-based involving normal chemical approaches.

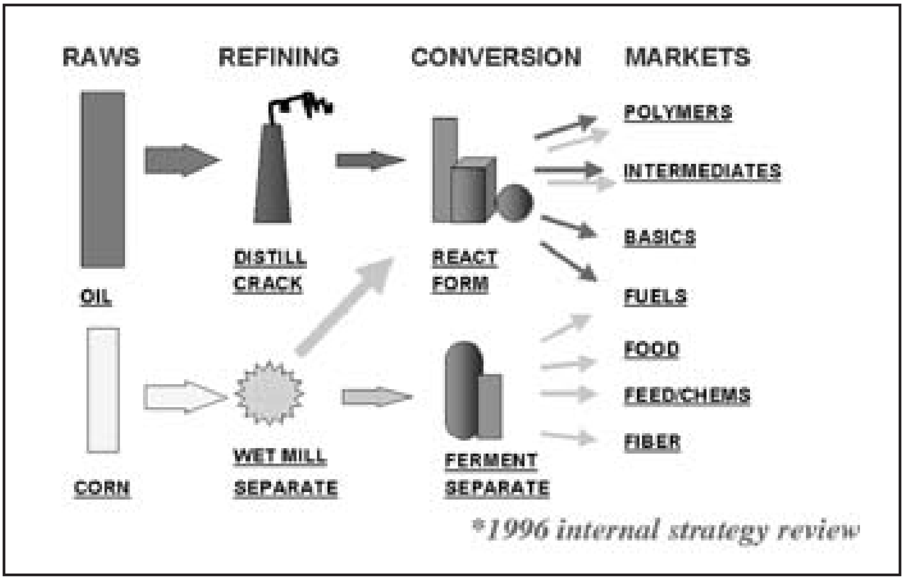

Figure 3. Two industries starting to partner and compete (1996).

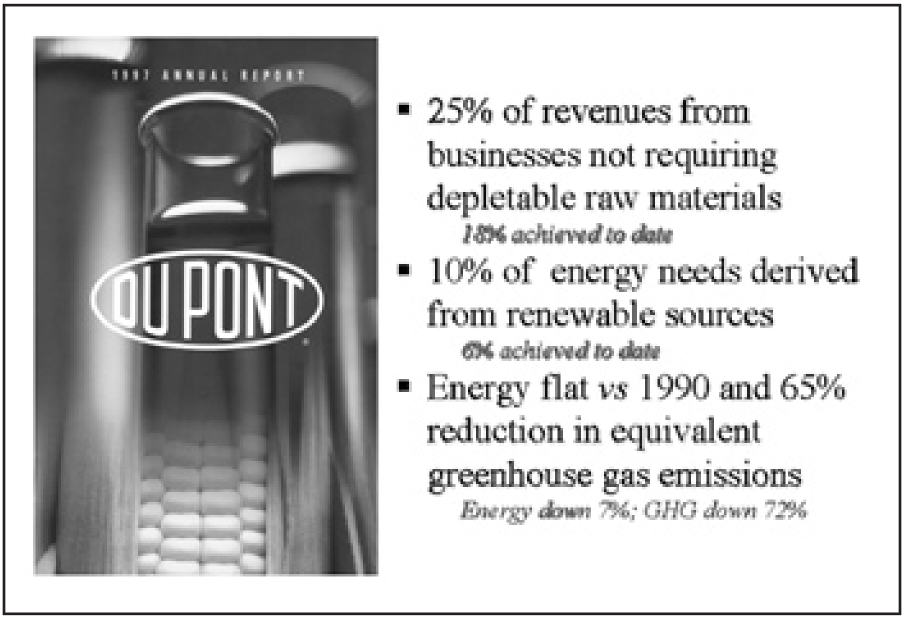

Figure 4. DuPont's commitments by 2010.

Biobased Economy

Today we can convert agricultural feedstocks into intermediates like starch, cellulose and sugar and, with the appropriate enzymes and biocatalysts, convert these into chemicals, materials and fuels (Fig. 5).

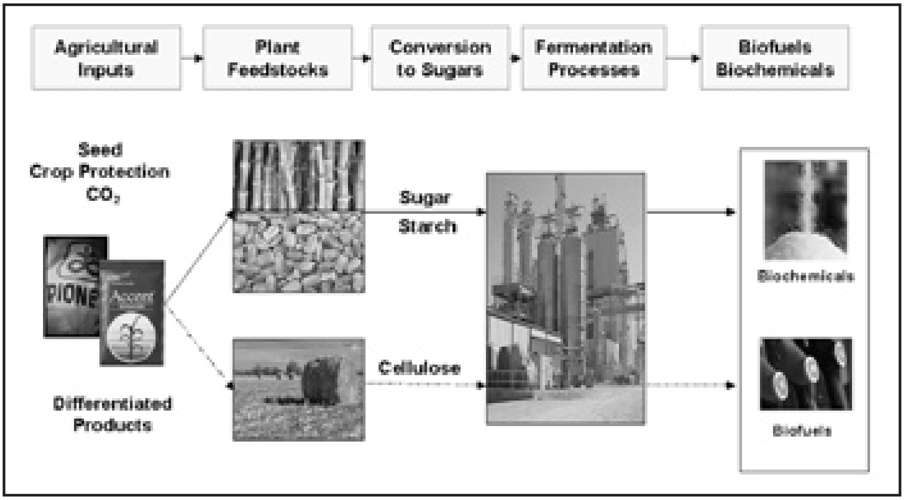

Figure 5. The biorefinery value chain, the foundation of the biobased economy: carbohydrates to fuels and chemicals.

Now, a few thoughts to bear in mind: it was one thing back in 1996 to say, "This is how it's going to be," but it was quite another thing to actually do something about it. This is a complex, large volume, long value-and-process chain. A lot of cost constraints are involved and everything must be kept in balance. Technology is complex; therefore, even though we are a large company with a long history of technological innovation, we also form partnerships to bring in various pieces of the puzzle. When you go into a new area you may have government incentives to get you over some of the humps, such as the famous "valley of death" between research and commercialization. However, I would make the point that proper thermodynamics *and* kinetics are required if you are going to be successful. You must have the right view of the picture, but there may be many paths to an end-point. Some of them may land you in jail and some will take you where you want to go.

Conversion of Biomass

What about biomass conversion today? Cornstarch plus enzymes make glucose, or you can use cane sugar. Processing comprises wet- and dry-grind corn mills in the United States, and cane-processing facilities in Brazil. Standard yeast conversions to ethanol occur at high volumes. Numerous other processes involve a variety of microorganisms—most of them are unimproved, some of them have been evolved and a few of them engineered—to make a variety of molecules. And, fundamentally, this takes advantage of existing infrastructure, to get raw materials to the plant.

Now, what might be the thermodynamically ideal system? It starts with high, sustainable yields of biomass per acre. At this conference, we'll hear more about new, high-yielding biomass energy crops. You want to use the things that are made all over the place. You don't want one-off facilities at each location. You don't want to have too much work with this material; you want flexibility. You want to minimize capital outlay and you want flexibility also in plant size. This is bread-and-butter manufacturing. The next questions is, "What's the best way to get there?"

New Platform Chemicals

A few years ago, scientists at the National Renewable Energy Laboratory published a treatise on top value-added chemicals from biomass. The objective was to identify the intermediates to synthesize from complex biomass. Figure 6 lists those top sugar-derived building blocks—molecules that have end-groups and "handles" that chemists know how to work with and convert into other compounds—a very different group of chemicals from the corresponding top ten for the petrochemical industry, *i.e.* ethylene, propylene, *etc*. Maybe we could make other simple intermediates that could then be converted into more valuable things.

- 1,4 diacids (succinic, fumaric and malic)
- 2,5 furan dicarboxylic acid
- 3 hydroxy propionic acid
- aspartic acid
- glucaric acid
- glutamic acid
- itaconic acid
- levulinic acid
- 3-hydroxybutyrolactone
- glycerol
- sorbitol
- xylitol/arabinitol

Figure 6. Top sugar-derived building blocks.

We focused on a new three-carbon molecule called propanediol (PDO). Dupont had known since the 1940s that a wonderful polyester could be made from this. We could never find a way to make it cheaply enough from petroleum, so we started experimenting with biological approaches. We achieved it and embarked on a metabolic engineering program. It was a complex project to genetically engineer *E. coli* to convert glucose at high yields, high rates and high titers into propanediol. We learned that the complex metabolic engineering was possible and we also found that it was commercializable. Our first shipment of bio-PDO was delivered in late 2006. We are now beginning to match the technology with the feedstock. This process taught us is that it is possible to use biological raw materials to make heretofore inaccessible chemicals that have industrial applications.

Market Entry

Using the Porter model of competition (Fig. 7), I want to talk about what you *should* make. If you are making a new material like PDO, there is a high barrier to entry. If you

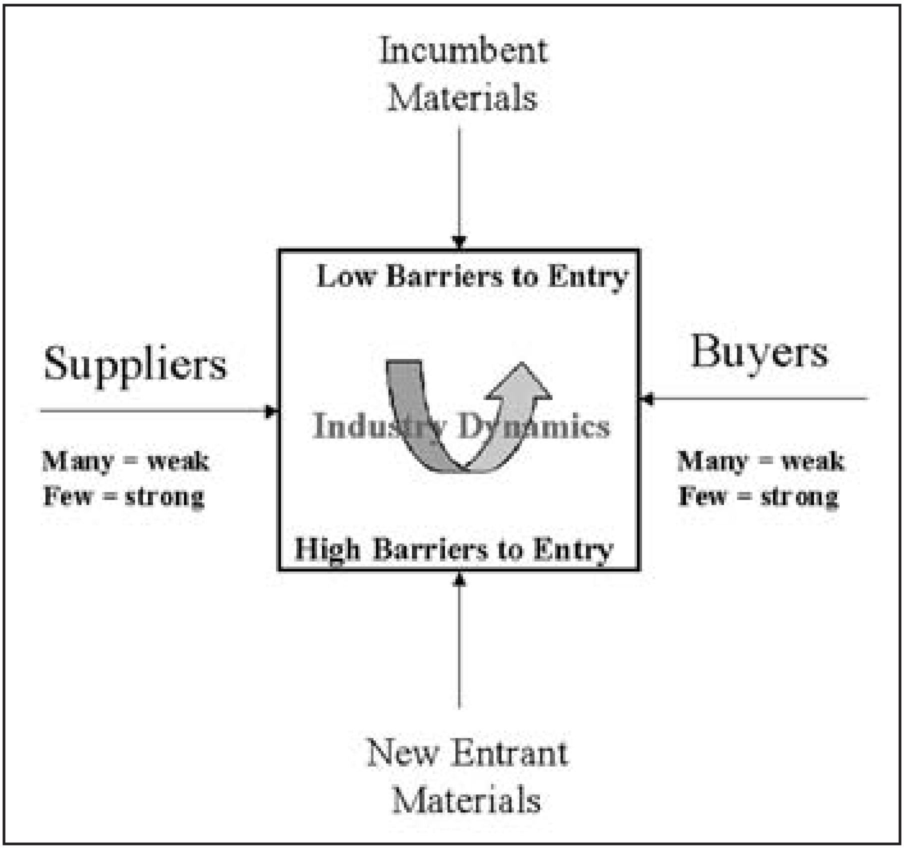

Figure 7. The Porter model of competition.

are making an incumbent material, the barrier to entry is low, and you have to decide if the market you are focusing on has many suppliers or many buyers. The choices you make determine whether it will be difficult or easy. Figure 8 shows idea-process steps for men's cotton slacks. Between the farm and the store, many people "touch" the item being purchased, each of whom must make a profit. It's a complicated value chain, and to enter it you need to change something within it and you have to talk to a lot of people along the way to make that happen. It can be valuable if you can do that, but it's not simple.

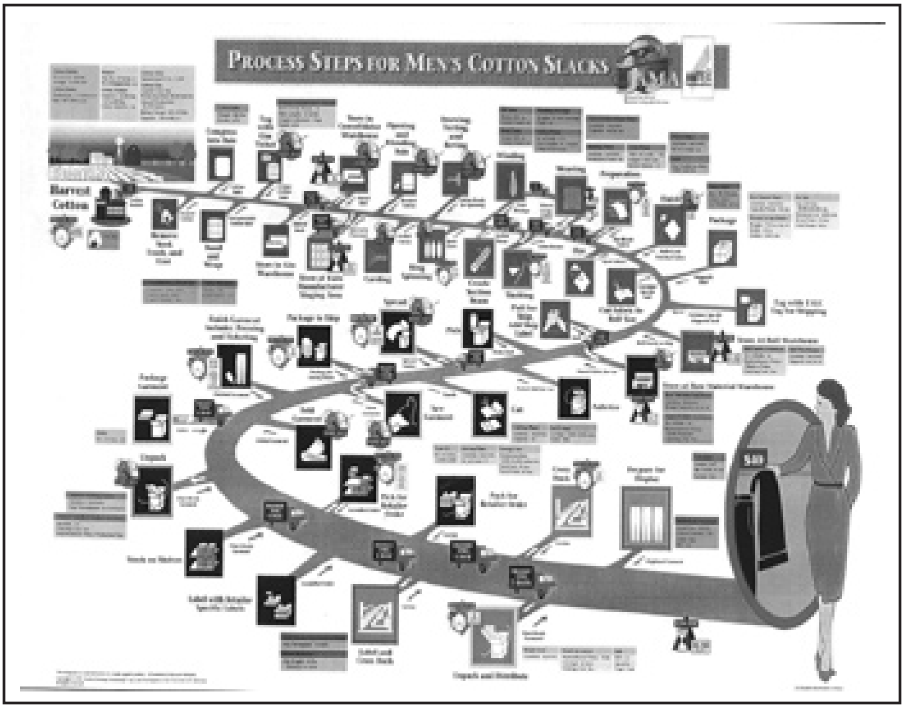

Figure 8. The complicated process of manufacture and delivery of cotton slacks.

The polymer we make—Sorona® (Fig. 9)—has utility in fabrics. I have a suit made of a wool blend and, again, if you track that PDO from Tennessee, a complicated process led to it getting into that suit. By comparison, the North American carpet industry is simple; the polymer comes in and the carpet goes out (Fig. 10). Within such a concentrated industry, those involved care a lot about price and performance, *etc.*, so you have to be very careful to supply the right materials. So, here we have the same product, but two very different value chains.

In a highly fragmented many-step value chain with many decision-makers along the way, it can take a long time for a new technology to diffuse through it. With the carpet example, if you make the right sale, you may quickly induce a major change in the market and soon be running to keep up with demand; can you make the polymer fast enough?

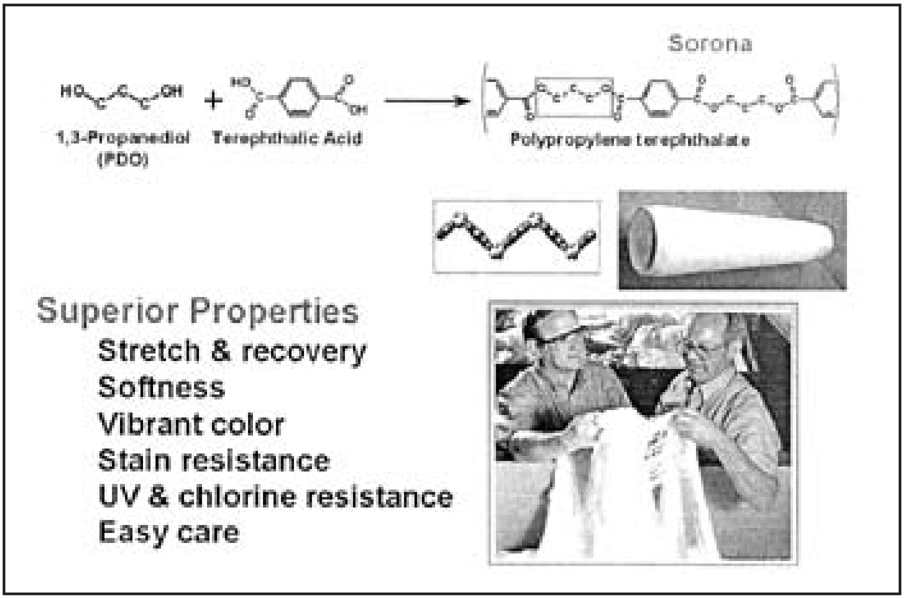

Figure 9. Sorona®: an advanced polymer/fiber.

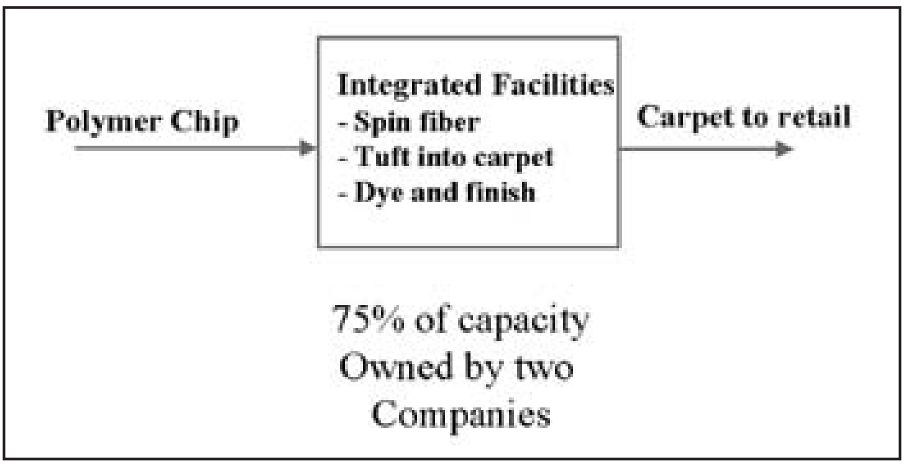

Figure 10. Structure of the North American carpet industry.

All you need is one "yes" from a particular person and you may soon need to expand capacity. Those two very different worlds can result from the same innovation.

What shall we make? With an existing material or chemical you have low market risk, but price is paramount. In our experience, there is generally lower capital intensity and you can get profitability at smaller scale with biological processes than with chemical processes. So that can be a helpful thing, depending on the market. With a new material or chemical, you have a high market risk. You have to explain to the market how it works. It's a significant technological risk especially if the only way to make this material is biologically and you can't make a little chemically to test the market. Then you have much high-risk R&D before you have enough material to fully test your hypothesis. And you need to offer the new attributes at the right price. One thing to consider with a new chemical, is extending existing markets through lower-cost routes especially for a medium-volume chemical. You can get higher margins if you can reduce cost. You have life-cycle-analysis benefits and environmental benefits. As mentioned, there is often an advantage in the biological approach at the smaller scale. You can build more quickly than if you have to wait until the demand is sufficient to justify building a large petrochemical plant. But this requires integrated science and collaboration among people who normally don't interact.

I don't have a list of the molecules to make, but if you have any, call me. Deciding what molecule to make is the single most important thing. The second most important consideration is what feedstock to use, and the third most important decision is the biocatalyst. If you have any ideas—I'm serious—please be in touch.

Biofuels

Biofuels have elicited enormous interest around the world. There are aspects of greed, politics, national security, economics and environment—there's an issue for everyone—which is partly why it has garnered so much attention. Biofuels are *the* alternative to liquid transportation fuels, almost all of which come from petroleum, whereas several options exist in the other areas for stationary power or electricity .

The power density with biofuels fits well with the current infrastructure. There's an enormous market, and it's growing (Fig. 11). How many hundred-million-gallon facilities will need to be built at $200 million per facility, to get to these enormous numbers? It's a huge undertaking.

Venture capitalists are funding new technologies. The Department of Energy has established three large centers to examine a variety of approaches. With oil at $140 a barrel, technologies that hitherto were not competitive then look interesting. There are chemical approaches, thermochemical approaches and biological approaches, all of which are being developed. Scores of companies and institutions are trying various technological permutations to make biofuels. From our perspective, the current biofuel solutions are inadequate to address needs, and our approach is to work on:

- higher-yielding feedstocks through our Pioneer subsidiary, and
- alternative fuels that fit well with current infrastructure.

We are big believers in products that work in existing infrastructure. When a society spends billions of dollars to establish an infrastructure, you must take it into account. Although infrastructures do change, they change slowly. This isn't "dot com" stuff. Such change is a real-world, heavy-lifting activity.

Our cellulosic ethanol method is a standard mill / pretreat / saccharify / ferment / separate process, but making it work requires utmost integration. We recently established a joint venture with Genencor to help achieve this integrated activity and we look for-

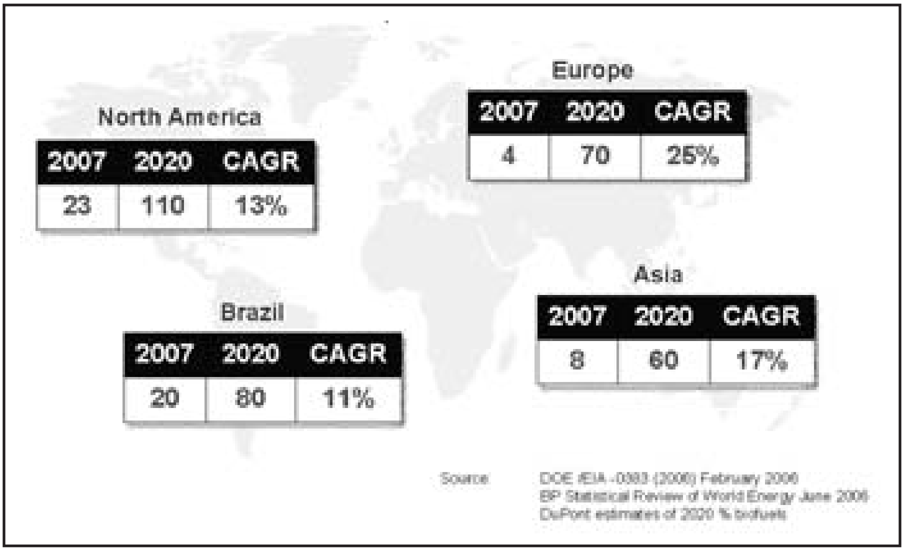

Figure 11. Biofuels: a high-volume, high-growth market
(billions of liters and compound annual growth rates for 2007–2020).
The 2020 market is projected at >$200 billion.

ward to having a commercial process in the near future. Again, regarding infrastructure, we intend to pay attention to the many plants that are already sited in prime farming locations. Currently, they take corn grain and grind it—either wet or dry—and make glucose. From a standard yeast fermentation, they make ethanol. Right next door, we'll erect a cellulosic facility that will take the waste parts of the corn plant to produce more ethanol as well as PDO (Fig. 12). Our analyses suggest that we can take off about 50% of the stover for our process without affecting soil fertility. On some soils you can take more, and on others you can take less. The process on the right of Fig. 12, turns the mix of sugars into ethanol. The current "waste" products of the wet- and dry-mill processes become further substrates for the cellulosic side and enough energy is left over from the lignin and other unfermented materials to energize the whole process. Figure 13 provides a representation of the fermentation process. We use a strain of the bacterium *Zymomonas mobilis*, manipulated to co-ferment five- and six-carbon sugars. We get high titers of ethanol; essentially all of the five- and six-carbon sugars are converted to ethanol. We still want to move the xylose line in Fig. 13 a little to the left to complete the fermentation more quickly. And we need to improve sugar production, which is why we've entered the joint venture with Genencor.

Biobutanol

Biofuels are more than just ethanol and biodiesel. Ethanol and biodiesel are important because their production technologies have been available for some time. Yeasts have been used for a long time to convert glucose to ethanol, and people have been saponify-

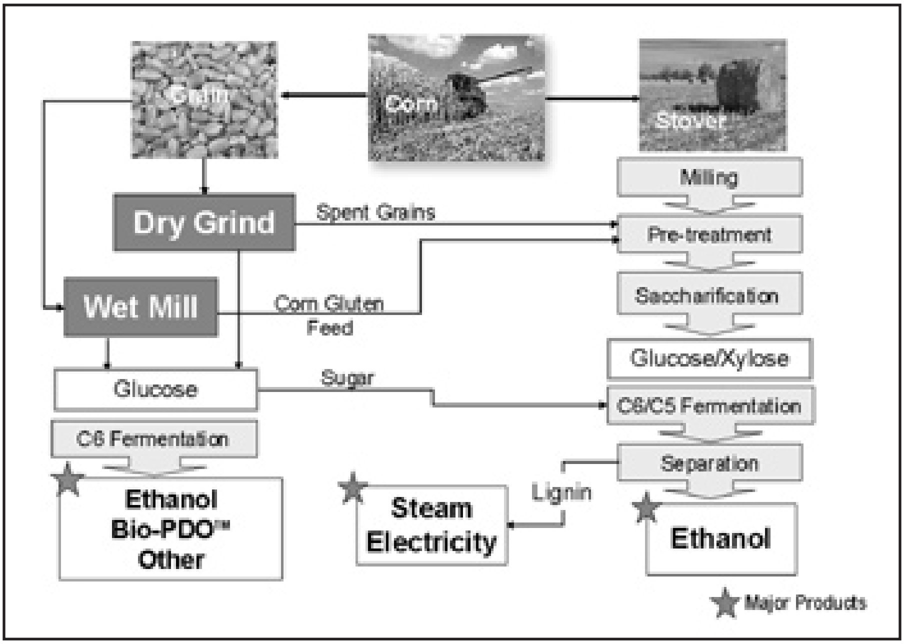

Figure 12. The integrated corn biorefinery.

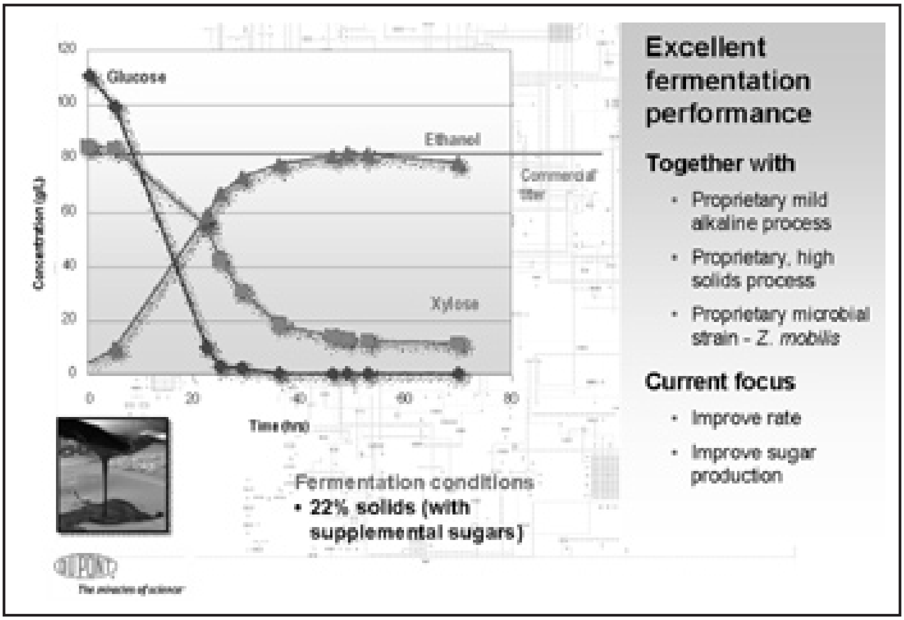

Figure 13. Fermentation performance of genetically engineered *Zymomonas mobilis*.

ing fats for a long time. A number of companies are trying to use thermochemical and biochemical technologies, to make various kinds of materials. Some years ago, we sat down with BP representatives to try to figure out an optimal space in which to operate: what are good fuel properties versus what is achievable biologically? We came up with biobutanol, which has several good features. It can be blended completely flexibly. You can run it through pipelines and it gives more miles per gallon. Also, importantly, it helps ethanol use—it's not an either-or situation with respect to ethanol. With a little butanol in the gas tank you can add more ethanol and keep the vapor pressure down. Thus, it contributes to current infrastructure.

The Weizmann process for butanol synthesis has been available for many years, named after the first president of Israel. This natural so-called ABE process produces acetone, butanol and ethanol (Fig. 14). Although used commercially around the world, it is not economical as a fuel. Our approach has been to make butanol for transportation use. There are four isomers, all of which have good fuel values: high energy density, easy to blend, and less corrosive than ethanol. We have been working on iso-butanol and 2-butanol, which have higher octane values than normal butanol (Fig. 15), using biochemical techniques to engineer pathways into microbes and we've been able to produce microbes that can convert glucose into either butanol or isobutanol or 2-butanol. We're working to increase the rates, titers and yields so they can be competitive. We have exceeded the ABE commercial standard, but wish to do better before declaring success.

I suggested the need to have thermodynamics and kinetics on your side. So, what might be a kinetically feasible path? Again, my belief is that improved corn and sugar-cane yields will continue to make these crops important for years to come. Other kinds of energy

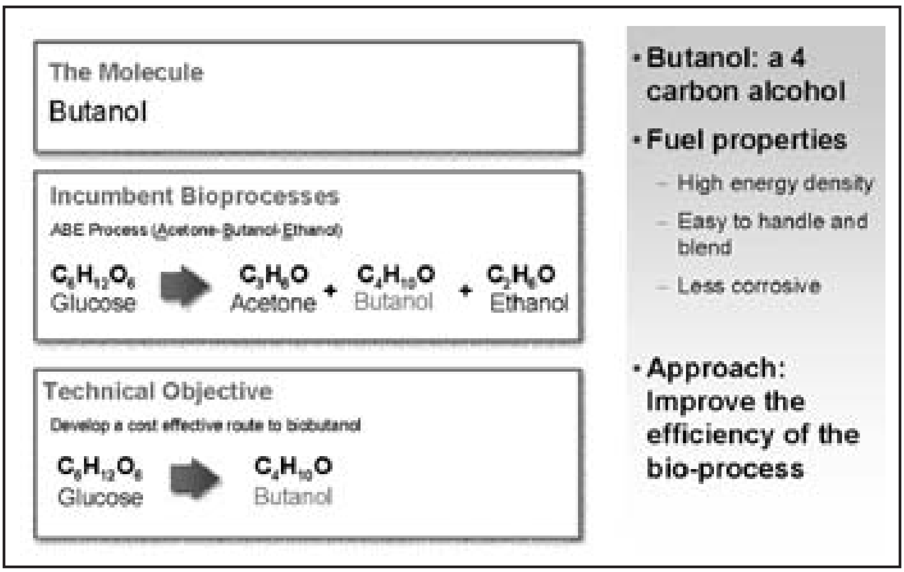

Figure 14. Biobutanol.

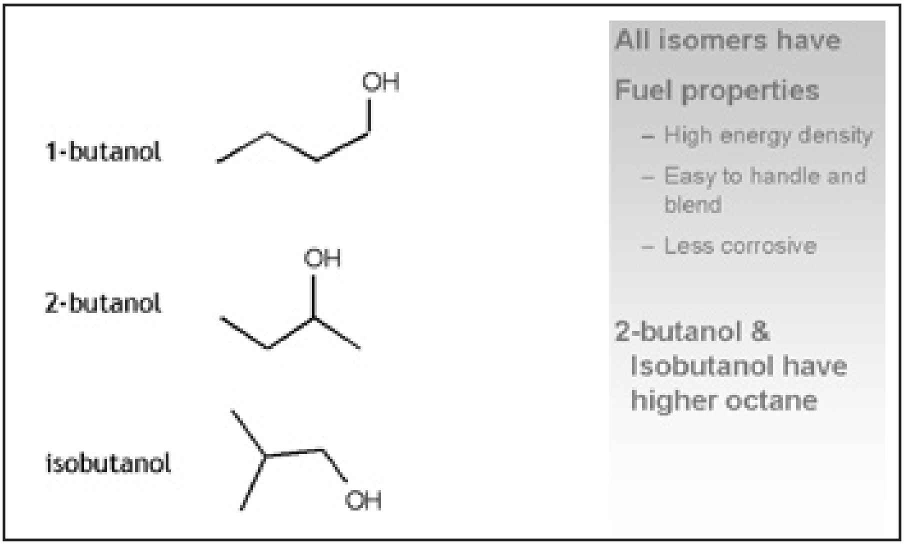

Figure 15. Isomers of butanol.

crops—high-yielding biomass feedstocks—will also be important. Approximately 90 million acres of corn were planted in 2007 in the United States, and every year there are likely to be yield increases of a few percent. Processing improvements will foster movement to significant production of cellulosic-based biofuels over the next 10 years. We'll start seeing cellulosic facilities this year, next year and the year after, but it will take several years before those volumes are significant. Breeding for biomass will redefine harvestable yield, both in standard crop plants and energy crops. Existing ethanol-production plants will initially be retrofitted to take advantage of their prime locations and synergies between current and future processes. We're getting better at making the biocatalysts and integrating biocatalytic processes and we will continue to set the pace for innovation. We will have the ability to produce microbes that synthesize many different types of molecules. It's getting faster and faster. What used to take 10 years now takes 8 and a little while from now it will take 6. We are on a steep learning curve with this technology.

Integration is Key

It's not just about biotechnology and it's not just about fuels. It really is all based on agriculture and if you take the three ratios in Fig. 16 and multiply them by each other, you get revenue per land area. There's a finite area of land and you need to maximize the revenue from it. To do that, you need to have all the tools in hand for agriculture, engineering, chemical engineering and distribution and you also have to make sure you don't fail once you have made the product and now you are trying to market it. It's complicated but exciting to contemplate.

Integrated approaches are necessary, partnerships are essential and you have to make sure that you are working on the right thing and in the right fashion.

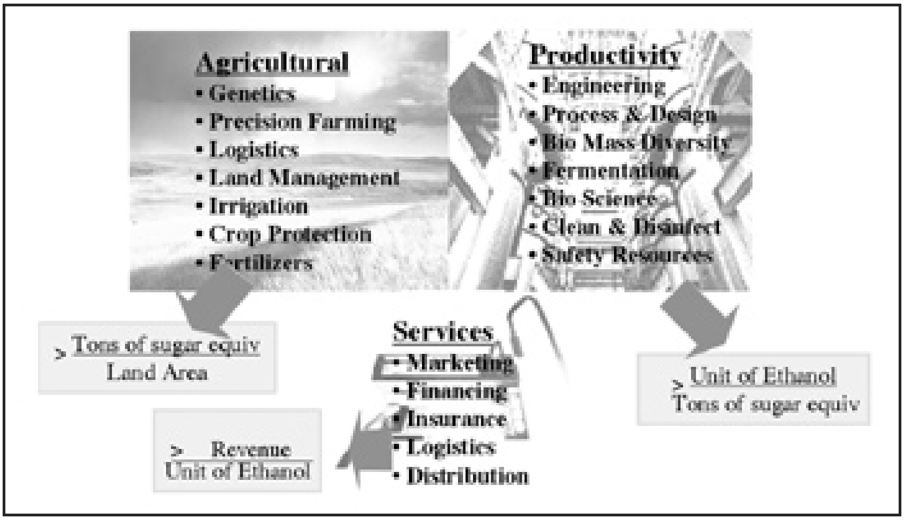

Figure 16. Critical success factors.

JOHN PIERCE is vice president of technology at DuPont Applied BioSciences, with responsibility for DuPont's biotechnology R&D efforts in the production of fuels, chemicals and materials. He began his career at DuPont in 1982 as a research scientist in Central Research & Development (CR&D). He moved to agricultural products in 1988 and held research-management positions in agricultural biotechnology and in crop-protection chemical discovery. In 1994, he became director of chemical and biological sciences in CR&D, where DuPont's current focus on industrial biotechnology began to take shape.

From 1996 to 1998, Dr. Pierce was based in Paris as planning manager for agricultural products for Europe, the Middle East and Africa. Upon returning to Wilmington, he worked to integrate the agricultural biotechnology research efforts of DuPont and its subsidiary Pioneer Hi-Bred International. In 2001, he returned to CR&D as director of biochemical sciences and engineering and was named to his current position in June 2006.

He is a founding board member of the Society of Biological Engineering and serves as a member of the Department of Energy's Biological and Environmental Research Advisory Committee. He has a BS degree from Penn State and a PhD from Michigan State University.

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Megatrends Reshaping American Agriculture and Agricultural Universities

Steven G. Pueppke
Michigan State University
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A cluster of interlocking megatrends is converging to make twenty-first-century agriculture much different from its twentieth-century counterpart. These trends are not novel, twenty-first-century phenomena. We saw them begin to stir during the waning years of the last century, and now they are upon us, reshaping both US agriculture industries and the land-grant universities that have traditionally served them.

I left the farm exactly 40 years ago this fall to attend a land-grant university (the one that now employs me), and so let me use 1968 as the anchor point for how things used to be. Many of you in the over-50 category will identify with my story, which begins with an 800-acre farm in the Red River Valley along the Minnesota-North Dakota border. We grew wheat, barley, sunflowers and corn. Most of the crops were sold, but we chopped much of the corn into silage to overwinter the small herd of brown and white cattle that spent the short North Dakota summer on pasture out behind the barn.

There was no question about the identity of the customer. We hauled grain to the Arthur Farmers Elevator Company or to Amenia Seed and Grain, and when the cattle were fat and the prices good, we delivered them to the West Fargo stockyard. I still remember the names of the customers, because they were our neighbors. And while we had a vague sense of that great river of grain making its way from Dakota to the millers and other food processors in the east, my father and the other farmers did not much concern themselves with what we now call the food system.

I was part of the great twentieth-century outflow of talent from America's farms and rural areas—some of us more modestly endowed than others. We were the sons and occasionally the daughters who wanted to maintain a connection to "the land," but who chose not to farm it. So we migrated to land-grant universities, settled down into agricultural majors, and as professors of agriculture, became—as our academic parents and grandparents before us—the foundation of those institutions.

These were careers made simple by a natural transition from our own formative experiences early in life. We intuitively knew what agriculture was all about, and agriculture remembered where we had come from. It was a world of transactions within neighborhoods—geographical ones, philosophical ones, and those enriched by customer-client relationships.

Looking Back

This kind of agriculture, one that we now see receding through the rearview mirror, had several defining features. I think that the key megatrends relating to today's agricultural system all relate to the recasting of these features by a series of smaller trends that were not so much spawned from within as imposed from outside of agriculture. All of them relate to globalization. I want to focus on these trends, but first let's think about those twentieth-century features as cast through the lens of someone who has spent most of his career in land-grant universities.

- Each of the participants in the agricultural value chain, especially those producers on the front end, focused not on the ultimate consumer as customer, but rather on the next participant down the chain. My durum-wheat-producing father could not have even named more than one or two of the pasta products that he was helping to produce, and we had certainly never tasted them. It was inconceivable that the opinions of diners would ever have an impact on our dusty wheat fields.
- Land-grant universities stayed close to the farm. We understood and drew our talent from production agriculture, and we enjoyed easy relationships with grateful commodity groups and agricultural firms. The land grants were equally comfortable with their historical structure and its emphasis on disciplines—among them soil science, agronomy, entomology, plant pathology, agricultural economics, and animal science. Soil scientists solved fertility problems, entomologists took care of the insects, economists assisted with farm management, and so on.
- We all knew about Cooperative Extension, which was hard wired into the system and linked operationally and on a day-to-day basis with research. It enjoyed a near monopoly market share as provider of science-based information to our production-agriculture customers.
- Strategy at the land grants was ideological. There was no need for much discussion of the importance of what we were doing, the beneficiaries of our efforts, or how we could best meet their needs. Most of us just understood, thanks to the forces that had been shaping our world views since childhood. Because we all shared a common system of beliefs, we could be spontaneous and deliberate in our actions.
- We were interested in international activities, but engagement with the rest of the world meant helping those less fortunate than we. If you were curious about international agriculture, there was sure to be an office down the hall or around the corner that dealt with such matters and could help you "go on an international assignment."

In short, the agricultural world, including that of the land grants, was defined and seemed well understood. So what happened? What are those megatrends that upended our cozy twentieth-century existence? The rise of global agrifood systems is arguably the single most defining change. We have left the world in which it was sufficient for agricultural producers to simply deliver raw materials to the elevator or the local stockyards or some other buyer, and have entered one in which far-away people really matter. And it has not been easy.

Some of these far away people are global competitors who have learned to exploit their local resources and ever-cheaper global transportation networks to deliver agricultural products to our local customers, sometimes more cheaply than we can do so ourselves. Many such competitors have been able to construct and then exploit efficient twenty-first-century infrastructure, even as we attempt to refine and update our aging manufacturing, logistics, and transportation systems of the last century. Few of us can speak their language or bother to understand their political and social systems. But if you speak to them (almost certainly in English), you will quickly learn that they have taken the time to know all about us.

Globalization

Globalization has greatly changed the fabric of the land-grant universities, too. Cooperative Extension has rapidly lost market share as new, web-based forms of information exchange have become commonplace. And international agriculture is rapidly being assimilated into the fabric of our activities. It has been humbling—and to some of our faculty, inexplicable—to see our models of helping the less fortunate morph from the narrow one-way alleys of the past into modern thoroughfares in which knowledge moves rapidly in both directions. The asymmetry of the last century's "we give, they receive" model has been reformatted into a much more balanced equation in which our ability to listen is as important as our ability to speak.

Globalization has also dislodged the strategy that guided most land-grant universities during the past century. My generation's vision, one that rested on shared beliefs and collective experiences, is being replaced by that of younger talent that increasingly is drawn not from rural areas of the United States and our land-grant educational systems, but from other places. I recently assembled the numbers at my institution and learned that fully one-third of our new faculty hires were either born abroad or had received formal degrees in other countries.

The effects of globalization should not be viewed as bad. An understanding of the true customer creates value and opportunity; competition breeds innovation and entrepreneurship; strategy based on something other than ideology can make for flexible organizations willing to confront risk; and faculty members with early exposure to the globalized world offer color and perspective to the institutions that employ them. But there have been challenges.

With the advent of global food systems has come a new sense of empowerment on the part of consumers. Some of them are far away, and others are close, but they share a desire to know where their food is coming from, how it was produced, processed, and transported, and the impacts of food systems on the environment. Sometimes they ask politely, but more and more often they are demanding this information—and if the answer is not what they want to hear, they get fussy and tell us to change the way we do things. The CEO of a major meat-products firm summed up this situation a few months ago at a large agricultural forum, and I wrote down what he said: "Customers care a lot about the background of our products. Conversation is radically, and I mean radically, different than before. They ask about animal welfare, antibiotic usage, environmental stewardship, trace back, total food safety, community involvement, how you monitor your suppliers—and then, if there is time left, they ask about price, quality, and delivery." His tone was poignant as he described how his firm had moved beyond perplexity and begun to grapple with these issues.

Land-grant institutions are perplexed, too, as we scramble to align our expertise with new realities of the twenty-first century. I have experienced this myself. Shortly after the turn of the century, I represented my land-grant university at a meeting with the state's pork industry leaders. After our animal-science faculty had summarized their recent accomplishments, several of us found ourselves in informal conversation near the end of the day. I asked the industry leaders to identify the most important challenge that we could help them overcome. After a slightly too long pause that had begun to make me uncomfortable (just what had I said?), one leader—and then the others—agreed that their number-one problem was coping with environmental regulatory policies related to confined animal units. We had some of the world's best nutritionists, reproductive biologists, experts in genetics and lactation and physiology—but environmental regulation? Sorry, wrong department! And as I later thought more deeply about this issue, I concluded that "sorry, wrong university" might have been a more accurate assessment of the situation. We did in fact have someone in another department who was interested in animal wastes, but he wasn't into policy.

This experience was repeated just a few months ago, when someone asked a group of Michigan fruit growers about their top problems. We have a world-class cohort of horticultural faculty dealing with all aspects of fruit production, but the industry's questions were of another sort. "Can you help us secure a reliable supply of labor?" "How can we compete with China?" And "how can we cope with global retailing and the power it is exerting back through supply chains?" We can and are helping our fruit producers address these issues; but, as an institution, we are not adequately prepared for these sorts of questions—ones defined by the twenty-first century. And yes, we are a little bit perplexed.

Strategy Development

So what about our collective future in agriculture? How can we move beyond simple recognition that things have changed and get on with developing sound strategies for the future? Key to our land-grant future is strategy itself. Shared ideology was sufficient in the professional world that I entered 40 years ago. In today's much less predictable and much more complex global world, there is need to be adaptive.

Writing in 1998, Mintzberg, Ahlstrand, and Lampel (see *Further Reading* below) draw a distinction between strategy as position and strategy as perspective. The positioning part is easy, and indeed, most strategic planning at land-grant institutions focuses on where we are and where we want to be in the future (numbers of students, ranking of our programs, level of grants income, and so on). It is more difficult to optimize organizational perspectives on the future, especially when tomorrow will almost certainly be much different from today—perhaps chaotically so.

Here are four interrelated strategic perspectives that I offer to those of us with a stake in agrifood systems. I frame them through the lens of land-grant institutions, but each is equally valid when viewed through the lenses of others.

- We are part of a world that really is flattening, and so knowledge, goods, and—increasingly—talent, will be moving around more freely in the future than today. Maybe much more freely. We must learn as much as we can from those who are far away from us and position ourselves to compete with and address the needs of those who are not like us.
- We are competing in a flat world that is also developing spikes—places with qualities that attract and retain the best talent, create disproportionate amounts of knowledge and put it to use, and generate the technology that the future demands. We should aim to become these spikes, understanding that we may have to alter our structure, practices, timeframes, and metrics of success in order to do so.
- Each of us must position ourselves to address the needs of our unique piece of the greater agrifood system, recognizing both that there is no alternative to tomorrow's spiky, globalized world and that our piece may neither want to be part of it nor even view itself as unique. This will require synthesis across disciplines, new types of reward systems, much more involvement of "nonagriculture" expertise at our institutions, redefinition of our stakeholder communities, and deep, candid conversations with the members of these communities.
- We have to attune our programs to the needs of tomorrow's globally savvy consumers, some of whom live far away and some of whom are our geographical neighbors. They will impose a variety of different demands on us, some of which neither we nor our stakeholder groups will understand or agree with. Few of these consumers will be satisfied with conventional scientific explanations. Addressing these needs will require a lot of listening, new models for communication, and a bold commitment to involvement in policy arenas.

Further Reading

Florida R (2008) How's Your City? How the Creative Economy is Making Where to Live the Most Important Decision in Your Life. New York: Basic Books.

Friedman TL (2005) The World is Flat. A Brief History of the Twenty-First Century. New York: Farrar, Strauss, and Giroux.

Mintzberg H *et al.* (1998) Strategy Safari. A Guided Tour Through the Wilds of Strategic Management. New York: Free Press.

On January 1, 2006, STEVEN PUEPPKE became director of the Michigan Agricultural Experiment Station and assistant vice president for research and graduate study at Michigan State University (MSU). Shortly after his arrival, he was appointed to serve also as the director of the Office of Bio-Based Technologies. It was a homecoming of sorts. The Fargo, ND, native received his undergraduate degree in horticulture from MSU. He also has a doctorate in plant pathology from Cornell University.

Dr. Pueppke came to MSU from the University of Illinois, where he served as associate dean for research in the College of Agricultural, Consumer and Environmental Sciences (1998–2005), as a professor of crop sciences and as director of the University of Illinois National Soybean Research Laboratory and of *Global Connect*, an initiative focused on globalization of the college's academic, research and outreach programs.

Before moving to Illinois, he served as chairman of the Department of Plant Pathology at the University of Missouri and as plant sciences unit leader. He was also a faculty member in the Departments of Plant Pathology at the University of Florida and of Biology at the University of Missouri-St. Louis (1976–1979), and was a senior research associate at the Charles F. Kettering Laboratories (1975–1976). He served as the 2003–2004 chair of NABC.

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Energy Independence: On-Site Fuel Cell Systems Operating on Biofuels

Benson P. Lee
Technology Management, Inc.,
Cleveland, OH

Our fuel cell is a high-temperature ceramic device that chemically converts hydrogen into electricity, requiring a little oxygen. The byproducts are water and heat. In order to turn it into something useful, we have to make our own hydrogen, generally by conversion of hydrocarbon fuels. Some impurities flow through, with production of a little carbon dioxide. Efficiency is maximized by recovering the heat and water and recycling the latter internally. We also look at the exhaust heat as a way to provide cogeneration and handle heat loads, which can cool as well as heat. And depending on the electrical loads we condition the power.

There are many types of fuel-cell systems, categorized largely in terms of scale. In Ohio, some fuel-cell companies are replacing batteries and some are replacing utilities. We chose to create new markets and carved out a 1–20 kilowatt (kW) space largely because we felt we could compete against the largest companies in the world by taking the harder, rougher road. To put it in perspective: although fuel cells have been around for decades, opinion suggests that some types are a decade away. I want to stress that the fuel cell is a disruptive technology like the telephone, the automobile and the Internet. It took the telephone 70 years to achieve 50% market penetration, over 50 years for the automobile and close to a decade for the Internet. Like these technologies, fuel cells require a paradigm shift; they have the ability to drive a megatrend.

Megatrends

Oil supplies are dwindling, whereas demand is growing. National security concerns are rising. Greenhouse gases are a problem as are waste and pollution. In this context, entrepreneurs see many opportunities, with growing interest in renewable energy in the wind, solar and clean-tech areas. Although interest in biofuels is driven largely by transportation, we see it also as a source of fuel for stationary systems. And there is now emphasis on biofuels from non-edible derivatives.

We are seeing an emphasis on incentives to reduce fossil-fuel consumption and this has resulted in money and opportunities for development of high-efficiency devices. We all know what a carbon footprint is and there are opportunities to develop businesses moving toward zero carbon and, most recently, carbon sequestration. Biochar—just emerging—is a form of on-farm carbon sequestration that I'll discuss later. And there is now an awareness of business opportunities in eliminating waste before it occurs at the site, and if you can go one step further and convert it into energy, you are addressing some of the other issues.

Technology Management, Inc.

Technology Management, Inc. (TMI) was formed in 1990 as Ohio's first fuel-cell-systems developer. Our mission is commercialization of a fuel cell that was developed originally by Standard Oil of Ohio, which we obtained. Longer term, we see this as being the heart of a device to produce power anywhere, anytime and be operated by anyone. Because we are a small business entering a large market potentially, our goal was to develop a product, which was a platform, an original equipment manufacturer (OEM) platform that could involve other products. We didn't want to be limited by the fuel-supply infrastructure or by the availability of a trained workforce or even by the logistics necessary to maintain a parts inventory. We didn't want to be limited to any specific type of fuel, so we developed flex fuel for a variety of markets, including military, commercial, residential, rural and remote. Finally, we knew we had to have a proprietary technology manufacturable at low cost and we are now pretty close. TMI is one of fewer than a dozen companies in the world that have actually put together a complete kilowatt-scale system, operated in public on ordinary fuel, *i.e.* fuel that you and I can buy in most places.

Our laboratory system is small and can be shipped overnight by common carrier (Fig. 1). It's easy to operate by one person without special tools or equipment. If you need more power you just put several together in parallel. And if it needs maintenance you ship it back, so you never have to deal with a parts inventory.

Several types of gas and liquid fuels have been tested in the lab:

- Natural gas
- Propane
- Kerosene
- JP-8 (jet fuel)
- Diesel

- Ethanol
- Biodiesel
- Digestor biogas (simulated)
- Ammonia
- Vegetable oils (soy and corn oil)
- Used cooking oil

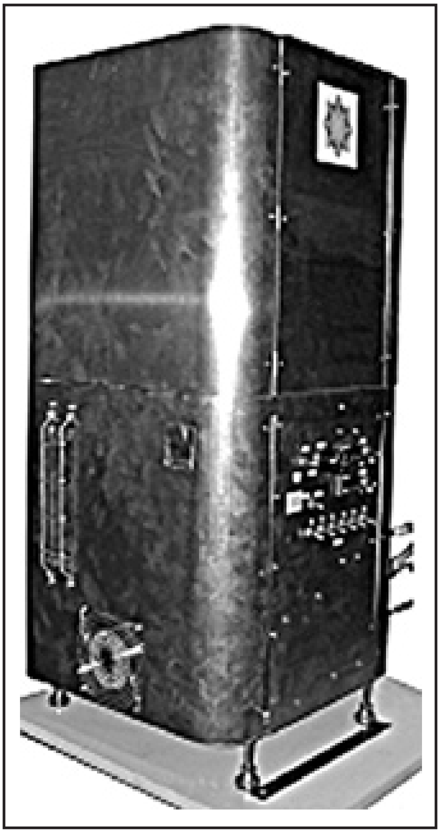

Figure 1. The 1-kW unit.

The upper group is fossil-based and the lower ones are renewable biofuels. You can switch between liquid and gas fuels on the fly, which starts to distinguish what our device can do from others. Its simplicity of design means that it can be manufactured like an appliance. Our target is to reduce the 1-kW unit from its current size of 16”×16”×32” (Fig. 1) to 13”×13”×28”.

Because it is a generic product and technology, it has multiple product-embodiment opportunities. Three have emerged over the last decade:

- an anti-idling device for trucks; we are pursuing this market
- remote rural use, as part of sustainable agriculture
- military

In September 2007 at the Farm Science Review, thanks to funding from the Ohio Soybean Council and USDA and some help from the Ohio Agricultural Research and Development Center (OARDC), we demonstrated the 1-kW solid-oxide fuel cell system operating on soybean oil. To our knowledge, this was the first demonstration of direct electricity generation from soybean oil. It also has been proven on corn oil, and we have done it on used cooking oil. We are looking to get our hands on jatropha and some of the other non-edible oils. Basically, the fuel cell is not fussy about what it converts.

What a Kilowatt Can Do

Most people don’t know what 1 kW can do. It’s larger than the base load of the average US home. We can scale it up by putting more together and it can augment solar and wind installations that charge battery banks.

It doesn’t produce carbon monoxide which allows its safe use as a heat source indoors. In addition to producing electricity at about a 35% efficiency, if you can use the heat an efficiency of 90% is achievable. It’s quiet and it’s clean and may be located in the barn, in the chicken coop or in the home. Distributed power generation is an exciting megatrend that will change the way we think about personal energy generation in the next few decades.

The fuel cell is very different from engines and turbines. To achieve the fuel cell's high efficiency, engines and turbines have to be much larger, which is one of the reasons we came in at the kilowatt scale. With the same hardware you can operate with liquid or gas, which is not the case with many other devices, and you can even switch between fuels on the fly. This opens up the whole idea of independent energy generation, whether it's fitted into the grid or independent of it. And it opens up serving markets and regions where power is unreliable or faulty or doesn't exist. With multiple 1-kW modules combined, mission-critical applications are feasible: cell-phone tower, law-enforcement, fire-protection, airport, *etc.*, support.

Figure 2 shows the fuel cell that we acquired from SOHIO/BP. It uses no precious materials and is featureless and symmetric, which means it's easy to manufacture in high volumes. The 2-inch diameter cell is full commercial scale and can be nested in various groupings for a range of power products.

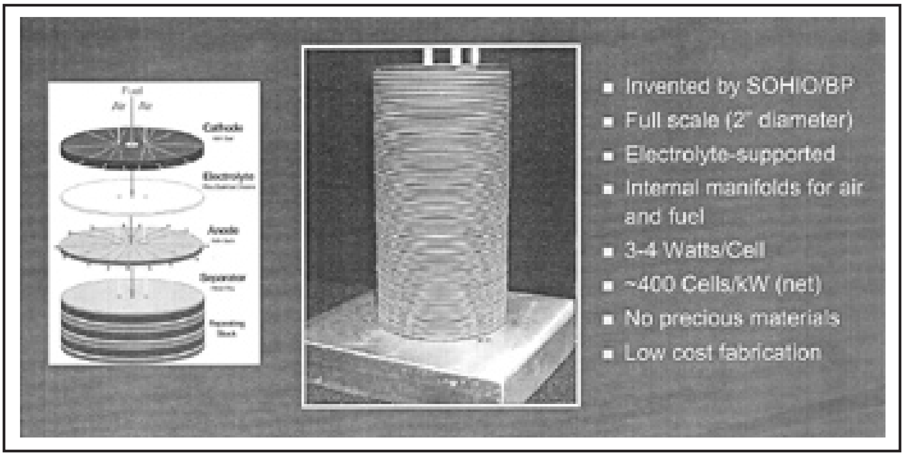

Figure 2. Simple, low-cost cell and stack design.

Integration with Biofuels

Fuel cells can be added to the biofuels discussion to open new areas that, for the moment, I'm going to call energy-independence. I'll describe four provocative scenarios.

Farm Waste to Bioenergy

The first scenario deals with conversion of farm waste to bioenergy. In the center of Fig. 3 is a small digestor ("biogas plant") of which millions are in existence. They take organic material in the forms of agricultural residues and animal, plant, human and food waste, producing methane and ammonia if urine is involved. The fuel cell converts the methane and ammonia into heat and electricity and the solids can be used as fertilizer.

Figure 4 is illustrative of the potential for energy independence. With integration of a fuel cell, the manure produced by a herd of 400 to 500 cows would allow a dairy farm to be energy-sufficient. Methane from the digestor goes to the fuel cell (not ours in this illustration) with the heat being fed to the various buildings. Electricity from the fuel cell provides power to the main house and to the farm. Solids from the digestor can be composted and/or used for dry bedding for the cattle and the nutrient-rich stream has various uses, including as liquid fertilizer. The carbon dioxide from the fuel cell can be can be captured and utilized.

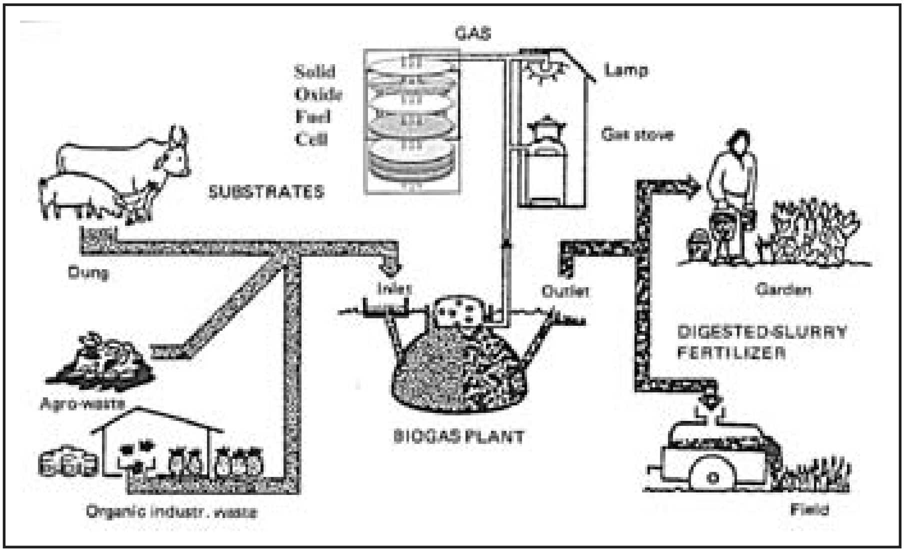

Figure 3. Organic waste conversion to electric power via a fuel cell.

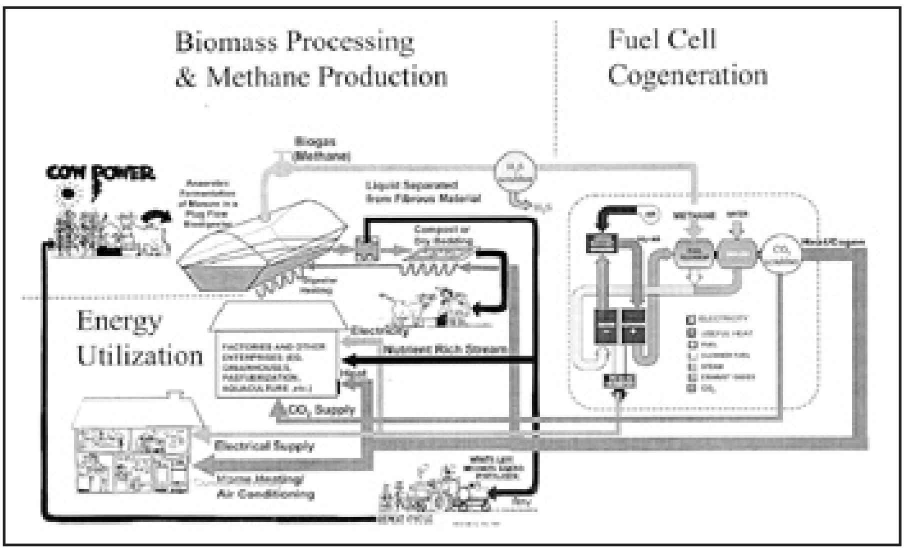

Figure 4. Energy independence from cow manure
(http://www.cowpower.cornell.edu)

Biomass to Energy

For the second scenario—biomass to energy—Fig. 5a provides a blueprint for what will emerge from the OARDC. The second column from the left shows various types of conversion. At the top are fermentation and anaerobic digestion and the middle shows mechanical extraction, *i.e.* screw presses to squeeze oils out. In the lower section are thermochemical gasification and pyrolysis; slow pyrolysis is now being explored at a number of institutions, including Cornell and Ohio State. Biochar is a form of carbon sequestration; up to 30% of the carbon that goes into a slow pyrolysis process can thus be sequestered. It has physical properties that enhance soil—helping retention of moisture and certain nutrients—and is considered to have commercial value. We come in at the third column. Each of the biofuels can be converted by the solid-oxide fuel cell into renewable energy and heat.

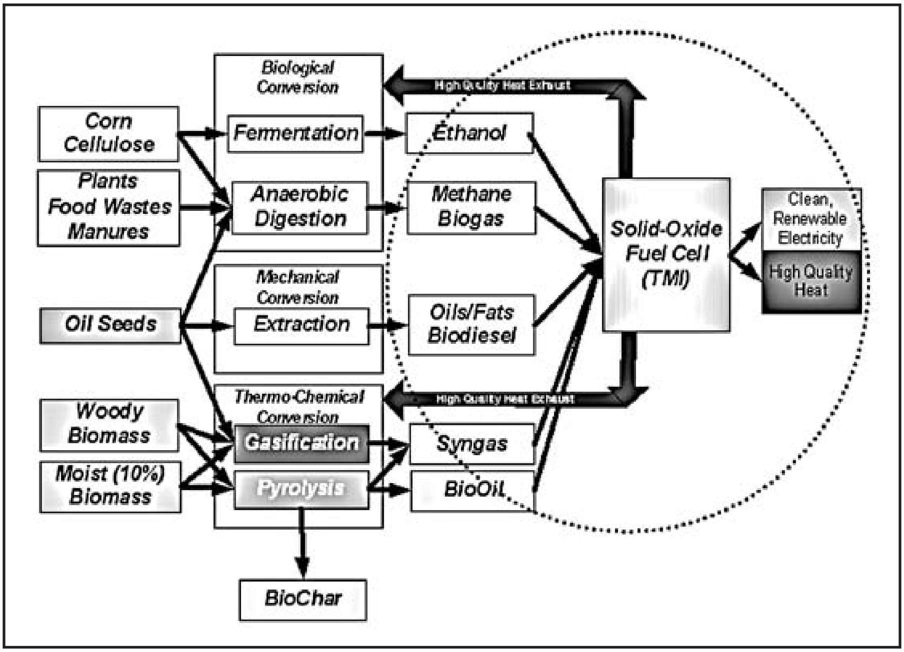

Figure 5a. The Ohio State Biomass to Energy Program
(courtesy of Floyd Schanbacher).

Figure 5b illustrates the near-term vision at OARDC. Wet biomass at the top is converted in two 800-gallon anaerobic digestors and at the bottom dry biomass is converted in a small gasifier, developed at the University of North Dakota. Both are small so that they can be matched with our 1-kW fuel cell; this system is applicable to many small-scale operations and is also scalable.

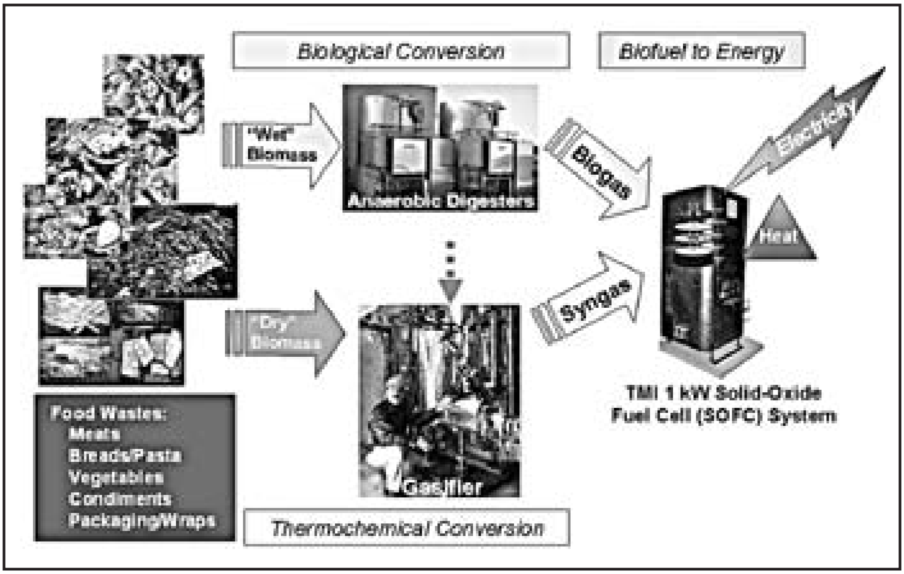

Figure 5b. The Ohio State Biomass to Energy Program (courtesy of Floyd Schanbacher).

Several other possible applications exist for combined heat and power (CHP). We can take wastes from dairy-, hog-, chicken-farm and food-processing operations put them through a digestor or gasifier and feed the electricity and heat to onsite buildings, greenhouses, fish farms or water-treatment plants (from which, sewage gas can be utilized). Again, mission-critical operations needing mobile power—disaster relief for example—can be served by this small-scale fuel cell in conjunction with biofuels and other fuels.

Biomass to Energy—Global Markets

Consumption of electricity in the United States is expected to increase by over 40% by 2030. However, this increase is relatively small when compared with the projected increase for the world as a whole (Fig. 6).

As described above, there is potential to develop agricultural and rural applications here in the United States, and with care we may put ourselves on a trajectory to move into the largest market for power generation. Interviewing people in developing countries revealed lack of enthusiasm for electricity generation *per se*. On the other hand, they do care about clean water and refrigeration. Fuel cells produce electricity and heat, from which production of clean water and refrigeration isn't rocket science. It simply involves thinking smaller about technologies that already exist. We need to start thinking outside of the box beyond just biofuels and beyond just bioenergy to solve problems meaningful to society as a whole.

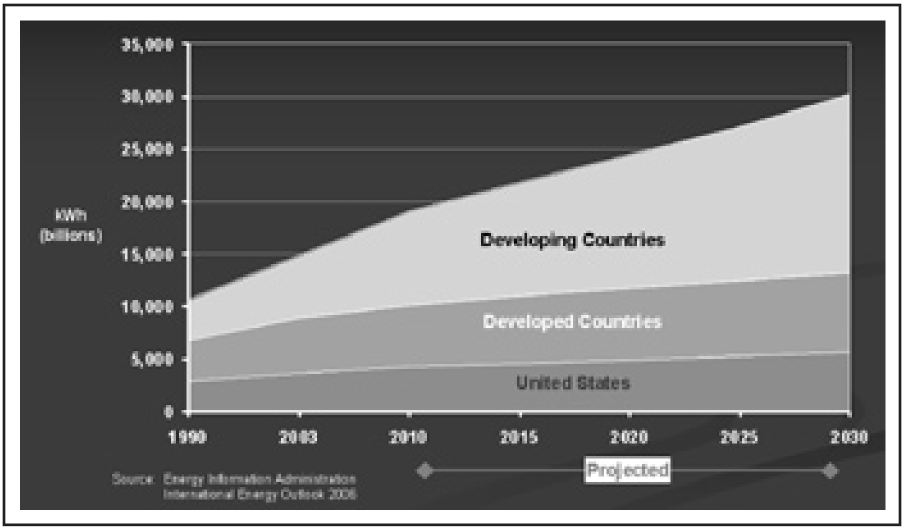

Figure 6. Global electricity consumption.

Beyond Bioenergy

The World Health Report of 2005 (WHO, 2005) provided these statistics:

- 1.1 billion people do not have access to improved water supply sources
- 2.4 billion people do not have access to any type of improved sanitation facility
- 2 million people die every year due to diarrhea diseases; 90% are less than 5 years of age
- 88% of diarrhea disease is attributed to unsafe water supply, inadequate sanitation and hygiene

The third and fourth bullets are particularly alarming, when you compute how many children under 5 die every hour from diarrhea, resulting from dirty water. The following quote highlights the non-obvious potential impact of modern technology.

> *We shall not finally defeat AIDS, tuberculosis, malaria, or any of the other infectious diseases that plague the developing world until we have also won the battle for safe drinking water, sanitation and basic health care.*
>
> —Kofi Annan, United Nations Secretary-General (2001)

We read about teams of doctors working across the developing world, but there is little they can do to prevent deaths from poor sanitation. This is an engineering problem. It's a problem that biofuels, bioenergy and engineers can solve. One kilowatt, which is what our system produces, can pump water from rivers or wells into sand filters; we don't need high-tech purification systems. We can add ultraviolet light, with just 10 or 15 watts of power, and provide heat to treat water to complement the work of doctors being sent overseas by the World Bank, USAID, Gates Foundation, church groups, *etc*.

Reference

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BENSON LEE is the founding CEO of Technology Management, Inc. (TMI), a Cleveland-based developer of modular, solid-oxide fuel-cell (SOFC) systems for kilowatt-scale, "on-the-farm," rural and mobile applications. Developed originally by SOHIO/British Petroleum, the system operates on a range of liquid and gas fuels and is designed for operation and maintenance by end-users without special tools, equipment or access to a trained service workforce. To identify cost-effective biomass-waste-to-energy applications in agriculture, TMI has formed collaborations with the Colleges of Agriculture at Cornell University and the Ohio State University. The current system prototype—using biomass-derived fuels such as ethanol and transitional fuels such as natural gas—is being engineered to begin field-testing.

Mr. Lee received his BEE and master's certificate in engineering from Cornell University. He has specialized in product development and commercialization throughout his career, starting with IBM and Westinghouse, and continuing as a fulltime entrepreneur. He is a trustee (emeritus) of Cornell and is on the board of Cornell's Center for Sustainable Global Enterprise at the Johnson School of Management. In Cleveland, he serves on the boards of the Cleveland Foundation, the Ohio Fuel Cell Coalition and the Nance School of Business at Cleveland State University.

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What Future Role for Biofuels?

Peter Ashcroft
Environmental Defense Fund
New York, NY

As I prepared for this meeting, I asked myself where I could most constructively contribute to an agenda that includes many accomplished scientists well versed in the scientific and technical aspects of renewable fuels. I concluded that I should focus on the political context for biofuel policy and the environmental perspective.

Where Are We?

The 2007 Energy Independence and Security Act (EISA) that was signed into law in December of last year put the nation on a course that included a greatly expanded national renewable fuel standard (RFS). This RFS created several escalating volumetric mandates, including 15 billion gallons of corn ethanol each year by 2015, and a total of 21 billion gallons each year of advanced biofuels, cellulosic ethanol and biodiesel by 2022. For corn ethanol, the 15-billion-gallon target represents a doubling of what had been considered just 2 years earlier in the 2005 Energy Bill to be an ambitious mandate (Fig. 1). For advanced biofuels and cellulosic ethanol, the 2007 Energy Bill mandates a flourishing market 15 years from now for fuels and processes that exist only in the laboratory today (Fig. 2)

Transportation is responsible for approximately 70% of the oil used in this country. For perspective, the 15- and 21-billion gallon mandates of EISA should be compared to the much larger overall transportation sector oil demand. In 2005, the United States used 230 billion gallons (gasoline equivalent) of liquid transportation fuels (DOE, 2007). Even at the greatly expanded renewable fuel volumes of the 2007 EISA, renewable fuels will still meet only 10% of our overall transportation fuel demand by 2022.

California has adopted a low carbon fuel standard that is now being implemented by the California Air Resources Board (part of the California Environmental Protection Agency). At least eight other states have established volumetric requirements for renewable fuels, and more than thirty have adopted some combination of producer or retailer incentives for renewable fuels. The Renewable Fuels Association claims that, as of January 2008, annual corn ethanol capacity will exceed 13 billion gallons of ethanol. (This is capacity, rather than actual production.)

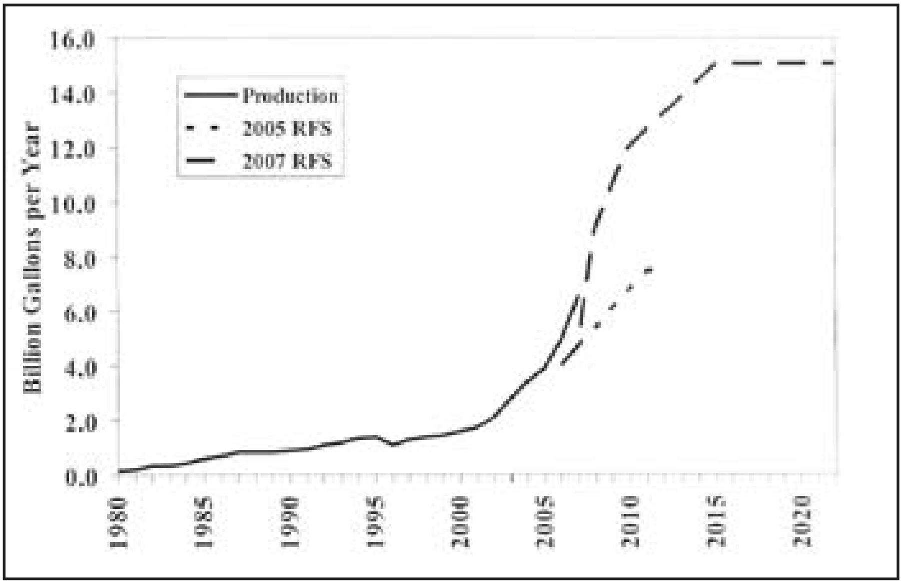

Figure 1. US corn-ethanol production and targets. The volumetric corn-ethanol mandates of the 2005 and 2007 RFS far surpassed the actual production at the time that each law was passed. The 2007 RFS mandate for 2015 is approximately twice current production.

Domestic biofuels currently enjoy direct financial supports at the federal level, including a 51-cent per gallon tax credit for blenders of corn ethanol and a 54-cent tariff on ethanol imports. Biodiesel and renewable diesel enjoy similar incentives and supports. These supports have occasionally been challenged, but their base of political support remains strong and, currently, do not appear to be seriously threatened.

Despite the generic terminology, "biofuel" in the United States is currently synonymous with corn ethanol, and corn is a major American crop. From nearly 94 million acres of corn planted in 2007, US agriculture harvested almost 13 billion bushels of corn, with a value of over $50 billion. The US corn production constitutes 43% of the global total, and approximately 25% of this was used to produce fuel ethanol (NCGA, 2008) and (USDA ERS, 2007) (Fig. 3). The Renewable Fuels Association estimates that the United States produced 6.5 billion gallons of corn ethanol in 2007. Biodiesel and renewable diesel volumes are much smaller than those of ethanol, on the order of 100 million gallons in 2007.

How Did We Get Here?

For decades, biofuels in the United States have been proffered as a tool for energy security, inspiring slogans about relying on the Midwest rather than on the Middle East. While analyses of the lifecycle performance of biofuels have varied somewhat, there has been general agreement that use of corn ethanol slightly reduces the need for oil. The net overall

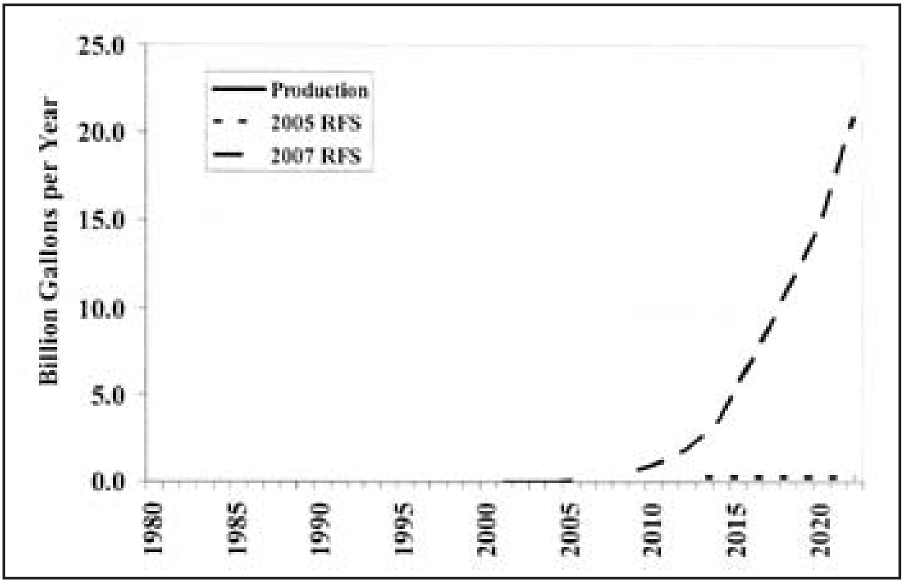

Figure 2. US advanced biofuel production and targets. The 2005 RFS volumetric mandate for advanced biofuels was modest, but the 2007 mandate for 2022 is dramatic. Current production of advanced biofuels is almost invisible in comparison with these mandates.

energy impact of corn ethanol has been more debatable. The ethanol production process (*e.g.*, planting, fertilizing, harvesting, distillation) entails fossil-energy inputs, but much of which is provided by forms other than oil, (*i.e.*, natural gas or coal). In this way, these other fossil-energy sources were effectively being used to produce liquid ethanol fuel, and thereby reduce the need for oil.

More recently, biofuels have been proposed not just for energy security, but also for climate policy. Like the debate over the net energy required to produce ethanol, the greenhouse-gas (GHG) analysis has been contentious. Some researchers, as exemplified by Michael Wang with the

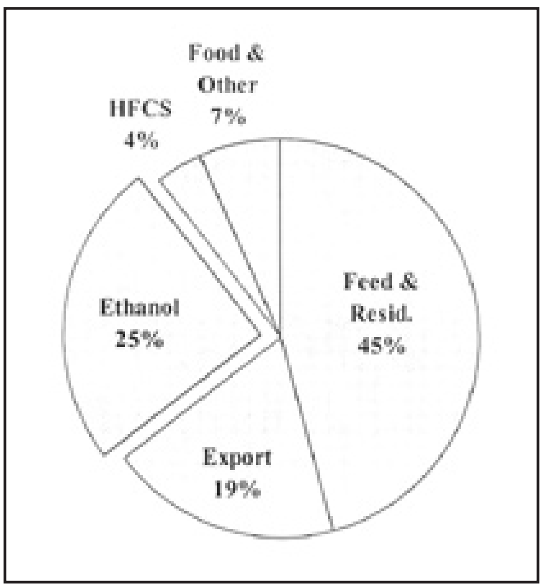

Figure 3. US corn use, 2007–2008. One quarter was used to produce corn ethanol. The largest portion was used for animal feed.

GREET model, concluded that when evaluated on the basis of its greenhouse impact, corn ethanol is modestly (~20%) superior to conventional gasoline. Others, such as David Pimentel, persistently claim that corn ethanol is inferior from a GHG perspective. Until recently, the balance of scientific opinion seemed to fall on the side of corn ethanol being slightly superior to fossil fuel when judged on its complete lifecycle emissions. One often-cited summary is that of Farrell *et al.* (2007).

This was the scientific understanding in place last year when Congress passed the 2007 EISA. As recently as December, 2007, the president, farmers, and some environmental organizations were celebrating the renewable fuel provisions of the bill as a step forward on climate policy.

The Indirect Land-Use Debate

That celebratory euphoria came crashing down earlier this year with publication of two papers in *Science* (Fargione *et al.* 2008) and (Searchinger *et al.,* 2008). These papers, particularly the one by Princeton researcher Tim Searchinger *et al.*, catalyzed a harsh reaction to biofuels, the reverberations of which are being felt throughout the popular press. See, for example, the April 7, 2008, *Time* magazine cover story or the recent *Washington Post* series on food scarcity that examined the impact of biofuel production.

The logic of the Searchinger paper is simply the following. Cultivation of crops for fuel production makes that land unavailable for production of other crops. Therefore, commodity prices will be somewhat higher, and somewhere else in the world, new land will be placed under cultivation to compensate. A complete analysis of the GHG impacts of cultivated biofuels should account for the fact that agricultural land was converted from something else to be placed in cultivation. Of course, exactly how much land, what kind of land, and the greenhouse impacts of that land are subject to debate, but Searchinger concluded that a true accounting of the costs of corn cultivation for ethanol would give it twice the GHG emissions of gasoline.

When examined closely, the implication of the Searchinger paper is not solely that biofuel demand leads to deforestation. The paper argues that agricultural demand collectively leads to deforestation, and biofuels are one part of the demand. The conclusion that biofuel demand leads to deforestation follows only because that was the question that was asked, but exactly the same logic could have been used to assess the land-conversion implications of any aspect of agricultural demand. Some biofuel advocates have cited this broad logical applicability as evidence of flawed reasoning, but in doing so they may fail to appreciate the strength of Searchinger's argument. Indeed, the current spotlight on biofuel production may presage a much broader future debate about the collective global impacts of domestic agricultural demand more generally.

I believe that assessing the indirect land-use impact of biofuel production will be a stubborn challenge. The objective scientific and economic questions are formidable, but the challenge goes beyond that. Indirect land-use impact is not a question that can be completely resolved through science, or even through economics, because it is not just a question of *what* happens but of *why*; it entails attributing responsibility. Suppose, for example, that there is no uncertainty in the science and economics. Suppose we could calculate exactly how global agriculture would change as demand for biofuels increases and all other demands are held constant, and we could calculate exactly what that implies for GHG emissions. (I emphasize that this is only a thought-exercise because we don't actually know these things.) One might then associate that marginal change in GHG emissions with the indirect land-use impacts of increased biofuel production.

Note, however, that even this seemingly straightforward approach contains embedded assumptions about what will happen in the future for the land that is converted to agriculture as well as for the land that is not converted. How well can we predict the future use of forest land, and to the extent that we can do so, how should that affect our assessment of biofuels? Should the impacts of deforestation be ascribed narrowly to the biofuel portion of agriculture, or more generally across all agriculture? These are the kinds of questions that will need to be resolved in order to assess the indirect land-use impacts of biofuel production.

The indirect land-use debate will not be resolved quickly. Academic disputes often play out over many years, even when the economic stakes are not as high as they are in this case. Assessing the lifecycle GHG implications of renewable fuels is an accounting question, with all the attendant subtleties, nuances and ambiguities. Given that we know that GHG emissions from both fossil-fuel use and land-use change are ongoing and collectively must be greatly reduced to protect the climate, a key question is, "How do we pursue constructive and effective policies in the face of these uncertainties?"

What to Expect for the Future?

Predicting the future in such a turbulent atmosphere is probably foolish, but I offer the following general observations.

- Oil prices may fluctuate, but driven by increasing global demand, oil will generally remain more expensive in the future than in the past. While fossil energy prices do increase the cost of renewable-fuel production, the net effect is to make the alternatives more competitive with fossil fuel.
- The problem of world hunger, even if not created by biofuel production, will continue to focus public debate on the morality of using land or anything that compromises food production for fuel production.
- Some form of climate legislation will probably be signed into law in the near future. The Lieberman-Warner climate bill has passed the Senate Environment and Public Works Committee and is awaiting debate on the floor. Similar bills have been introduced previously in the Senate and in the House, and there is nothing to suggest that climate change will diminish as a political issue.
- Oil is becoming more greenhouse-intensive as unconventional sources such as Canadian tar sands are exploited.
- In practice, virtually all biofuel in the United States is corn ethanol at the present time, and the political power of those established agricultural interests will continue to shape policy. Corn ethanol represents billions of dollars in direct federal support that will not be relinquished easily.

These general observations give rise to a number of important and, at this point, unresolved questions.

Unresolved Questions

- How can we exploit the differences in existing fuel- and feedstock-production practices to motivate established and emerging biofuel industries to evolve in ways that minimize GHG emissions and other adverse impacts?
- How effectively can cellulosic and advanced-biofuel technologies be commercialized? This is the multi-billion dollar question. The 2007 EISA mandates 21 billion gallons of advanced biofuels by 2022, but can this actually be accomplished?
- When the United States produces 21 billion gallons of advanced biofuels, what form will they take? Ethanol? Butanol? Biodiesel? Fuel that is fungible with gasoline or diesel? Any fuel must be integrated with our existing transportation infrastructure, and that includes pipelines and distribution networks as well as more than a hundred million vehicles.
- If the fuel is to be ethanol, where can we put it all? Most ethanol today is blended with gasoline at concentrations of 5% to 10%. The 36 billion gallons of ethanol to be produced in 2022 will represent more than 25% of expected gasoline demand. Can we use it?
- Have we thoroughly explored the universe of potential renewable fuels—including those that may not take the form of ethanol or biodiesel—for the options that most robustly, cost-effectively, and sustainably reduce both oil demand and GHG emissions?
- Will a well-established corn-ethanol industry (bolstered by the RFS and various federal supports), facilitate or impede development of second-generation biofuels?

Renewable fuel policy is generally tumultuous, and this is a particularly dynamic time for it. How well we, as a society, respond to our energy and climate challenges will be dictated in part by how we answer the questions above. The policy questions will play out in Washington, but the scientific and technical questions can be answered only by researchers such as those represented through the National Agricultural Biotechnology Council. I look forward to a fruitful conversation as we address these questions together.

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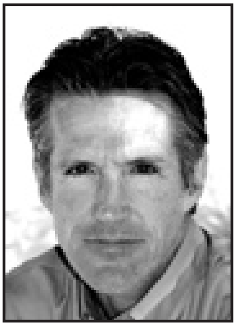

PETER ASHCROFT earned an undergraduate degree in applied physics from the California Institute of Technology before obtaining a PhD in engineering and public policy from Carnegie Mellon University. His graduate research addressed the use of ground-, air-, and space-based observations to characterize atmospheric methane fluxes. He worked for nearly a decade in satellite microwave remote sensing before receiving the Roger Revelle Global Stewardship Fellowship through the American Association for the Advancement of Science. With that fellowship he moved to Washington, DC, where he concentrated primarily on energy issues while working in the office of Senator Joseph Lieberman.

Subsequently, Dr. Ashcroft accepted a position with the National Climate Campaign of Environmental Defense, where his focus has been fuel and transportation policy. He has taken a leading role in coordinating a council of industrial and non-governmental organizations to develop policies to promote low-carbon fuels and otherwise reduce the greenhouse impact of vehicle fuels as part of a comprehensive climate policy.

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Megatrends Reshaping American Agriculture

Q&A

Moderator: Stephen Myers
The Ohio State University
Columbus, OH

Irwin Goldman (University of Wisconsin): For Peter Ashcroft: I'm unschooled in the policy scenarios, but I read that the cap-and-trade system, the carbon-cap system, has the potential to create a vast capital market. How will the creation of a capital market figure into the equation and the support for that? Is that true for the other types of policy approaches? And if it isn't, does that give it any more push?

Peter Ashcroft: Maybe one of the things I should have been clear about is that those various policy tools aren't necessarily incompatible with each other. It's not necessarily an either/or situation. So, for instance, the renewable-fuel standard included some performance requirements and it's entirely possible and desirable that a cap-and-trade system would have some complementary policies. For instance, maybe a low-carbon fuel standard that would apply some additional influences to transportation and to fuels. So, they're not meant to be mutually exclusive.

Tom Richard (The Pennsylvania State University): Peter asked if we can make that much corn ethanol in a short period of time and I think that there are people here who might be able to respond to that in terms of the yield increases to expect over the next 7 years from that particular crop. John Pierce actually can comment on that as well, but a few percent a year is not going to get us to doubling. I did notice on that slide that you had 17% exports for corn last year—not too far away from 25%. When you think about the fact that feed is the largest part of the use of corn in this country and the potential to recycle some of the byproducts, as you mentioned, I think there are some issues there. Fundamentally though, the point we all need to look at is that, over the last couple of years, we've gone from many decades where we could overproduce from our agricultural system. We were exporting because we could produce more than we needed and markets didn't always exist for all that material. When we put energy into the equation, the markets are huge. They are insatiable. At least in this country they seem to be that way. And that changes the game. This means that land is now a fundamentally precious resource and we have to increase its productivity for all of the things we need, whether it's food or fiber or flowers or whatever. And fuel is just part of that equation.

John Pierce (DuPont): I'm not sure there's a question left to answer, but I think there were two challenges. One is how do you double production in the near-term? How do you get to 21, or so, billion gallons of so-called advanced biofuels (which many people think means cellulose when there's a broader definition than that)? I agree with Tom. Agricultural productivity is going up at a faster rate now than it has in the past number of years without corresponding increases in alternative demands, which could go straight to fuels. There's a bigger challenge in obtaining the technology for advanced biofuels. For 21 billion gallons, somewhere between $40 billion and $100 billion of investment will be needed. However, in the fuels industry that's chump change. So people ought to be able to find that. The technologies are emerging. We're going to see some this year and next year. I think it's going to be a challenge to get production facilities sighted appropriately and to deal with feedstock supplies, but I do think that the fundamental processing technologies will be there. The capital will be there, but whether you can build it fast enough and whether you can find enough stainless steel all at once, I'm not entirely sure.

Uko Zylstra (Calvin College): A question for Steve Pueppke primarily: I appreciated your analysis as far as a shift in understanding with regard to farmers, is concerned, and how they relate to the food system. Although farmers in the twentieth century did not concern themselves much with the consumer or the food system, there were some major players in that food system that did determine policy and still determine policy. And even though consumers are now more concerned about where food is coming from, to what extent do you see food policymaking being put into the hands of different people? In other words, whether ADM or whether it be the meat packing CEOs that you referred to—they often are the ones who shape food policy because they control the system. Will the food system become more decentralized so that more people will have input?

Steven Pueppke: The players in the food system are responsive to the consumers, and my little quote from the CEO at a meat packing company was an example of that. We can be pretty sure that they will respond to what consumers request. We shouldn't view consumers as being monolithic and all wanting the same thing. We'll see more and more consumers segmenting or differentiating and wanting different things. You and I both live in a state where fresh and local is a big issue right now. That will create opportunities for some that will be irrelevant for others. So, we are in for an interesting time where a lot of different things are going to happen, but I would not discount the power of the consumer because, at the end of the day, the players have to meet the consumers' needs.

Charlie Carr (The Andersons): Peter, you mentioned a dollar per gallon cellulosic fuel credit. Is that something in the Farm Bill? Or what is that? And who gets the credit?

Ashcroft: It's in the Farm Bill. It was recently passed, so it hasn't historically been true. It's new, but if it operates the same as other tax credits, it doesn't go to the person who produces the cellulosic ethanol, it goes to the blender. The implication is that the blender will pass it along to the producer. People can argue about whether or not that's what happens, but that's the way it works.

Allan Eaglesham (NABC): Dr. Lee, how much does your 1-kilowatt fuel cell cost to the buyer, what are its maintenance needs and what is its longevity?

Benson Lee: Installed fuel cells are largely demonstration and test systems. So, nobody can give you an answer as to actual cost and maintenance. Those that are out there were engineered by people who put them into space, and while they have pioneered a wonderful market opportunity, the rest of us are not going to have the luxury of getting paid what they got paid for theirs. Now I can try to give you an answer, but it's theoretical. The life of a high-temperature fuel cell should be in the 4-to-5-year timeframe, 40 to 50 thousand hours continuous service. In terms of the maintenance, there are no moving parts in a fuel cell; it's a chemical process. Maintenance of pumps and compressors will be required, and engineering of more durable units will be required for the fuel-cell industry. In terms of target price, all of us recognize that at low volumes we are going to have to pick off the early adopters and go into markets that are less price sensitive. Most of us are looking at what solar is getting today, which is on the order of $10 a watt and I would think that you are going to see entry points up the kilowatt scale at that point. The first fuel cells that you are going to see will be battery replacements and those are coming to the market now. But those are different types of fuel cells. They are not intended to run for years and they are nowhere near the kilowatt scale.

David Koetje (Calvin College): Microalgae have been getting some press lately. There was a study several years ago funded by the Department of Energy, I think, that suggested that microalgae have potential as a biofuel source from algae farms in places like the Sonoran Desert. Nobody has said anything about that yet today. Is anything in the works regarding that?

Pueppke: There's immense interest in algae for oil production that could be converted to diesel. The theoretical yields per acre are absolutely unbelievable, but a number of issues need to be solved. For example, if they are grown in open ponds, think of the issues of trying to keep the culture clean—essentially a 640-acre petri plate. If one would use closed containers, plastic bags or things of that sort, which have been suggested in the desert, then the cost issue must be deal with. But, in theory, the combination of the high yields plus the relatively simple extraction of the biomass to yield the oil makes it very, very attractive. In Michigan, we have certainly seen people coming out of the woodwork with great interest in moving the technology a little faster than perhaps we are really prepared to do, given what we know today.

Pierce: There's got to be a dozen or more companies in the United States alone working on various aspects of that—trying to balance the capital costs of enclosures vs. open ponds—all that kind of stuff. Most often they are finding a need to make early competitive bids to have co-culturing of the algae with some other, let's call it higher value, product like fish, and then you get biofuels and seafood out of the same pond. Or, if you supplement the atmosphere with carbon dioxide the algae grow faster. So there are schemes to site algae ponds close to ethanol facilities, for example, that make lots of carbon dioxide, or next to coal-firing plants. Some outfits in New Zealand are doing that too. We still have got a long way to go. The National Renewable Energy Lab ran a program for some 10 or 15 years, quit, and is now starting up again. I happen to agree that oil prices are not going to go down as far as they've been, and $100 to $130 oil makes a lot of things possible.

Lee: We would love to get our hands on some algae oil to see if that can be added to our portfolio. And if it can, we can take our fuel cell to the algae pond, run it directly off the oil and hand back, to those that are covered, heat and carbon dioxide and electricity, which might kick up the efficiency and the economics of the overall algae production. That's a wonderful combined opportunity for distributed power and heat generation.

Michael Long (Resource 100): In one of your slides, you had a small-scale biomass-to-energy system. One thing that was missing there is the fact that, since you are running that system on waste material, you have an additional revenue stream that may make this project work where it wouldn't in other cases. You get more income than just the production of power and heat. Please comment on how the economics works with the avoided costs and the additional income.

Lee: That was a soft ball. Mike Long is the well known director of the Solid Waste Authority of Central Ohio here in Columbus, and he's absolutely correct. As we look at waste as a feedstock for many of the conversion devices, one of the compelling arguments is accompanying cost offsets. Mike, why don't you speak to it, because you have taught me everything I know.

Long: If you recall Benson's slide—he didn't describe it in detail—along the left side were listed waste materials from restaurants, grocery stores, hospitals and other institutions. If you think about the chain of custody, starting at the farm and moving to the food processor, to the grocery, the restaurant and the home, at every step along the line waste is created. So the question is, how can we gather that waste in a cost effective way and direct it to some sort of a facility where we do not have any negative environmental impacts? I'm not looking for direct combustion, but I'm looking for conversion of waste biomass into fuels that can then go into small-scale systems such as Benson's, avoiding transportation costs. In the waste business, moving stuff around is 75% of the cost. When you pay your garbage bill, you can bet that 75% of it is for moving it from the curb to the landfill. So, if you can take transportation out of the equation by putting in a small-scale system, you make projects like this cost-effective and produce a lot of energy at the local level.

Lee: In my talk I mentioned that a number of megatrends would be emerging and what you just heard from Mike is one of them. The notion of converting waste to energy is well known. The thing that Mike has taught me is the best way to deal with solid waste is to not let it occur in the first place. This is an exciting area that is starting to emerge and its got to take off.

Larry Curtis (Oregon State University): John, is DuPont or any other large chemical company investing in liquid-fuel molecules other than butanol or ethanol—any other ideas out there for energy-rich small molecules?

Pierce: I don't know what other companies are doing. I don't want to oversimplify it, but a fuel molecule is something that burns in the presence of oxygen. It's not real fancy. If you put gasoline or diesel through a gas chromatograph, you get lots of peaks and they all work just fine. One of the issues in using renewable resources is that you start off in a highly oxygenated state, whereas most of our existing fuel molecules are entirely reduced. So you need to find a way to get rid of those oxygens if you want to make it just like diesel or just like gasoline, and, in fact, some small companies are doing that. Half a dozen small companies are looking at making more gasoline-like and more diesel-like molecules. DuPont has a hydrogenation technology that makes triglycerides more like diesel, but conversion volumes remain small. I think that the world is open to that, but there are some fundamental thermodynamics that you need to deal with when you go from highly oxygenated to highly reduced molecules, which is why we landed in the middle, as a kind of optimum. There's no reason you couldn't land in another place in the future, but I can tell you that DuPont isn't doing it. DuPont is doing butanol.

Bruce McPheron (The Pennsylvania State University): I want to take off from Steve's presentation where he implied that our paradigm has shifted. Whether it was a complete transformation or something more gradual, we need to think about different things and I want to turn to the other three panelists, who spoke about various aspects of bioenergy and moving into a biobased economy. The other product beyond the research that we do at our universities is obviously our educational portfolio. In your disciplines, what attributes should our students have to be successful in this new world? Steve set the question, so he gets off the hook here.

Lee: They should challenge the very effective silos that have made America's great research universities and challenge whether that is the way to go forward. The point that Steve made is that where universities have done a great job is they understand that their mission is to teach critical thinking. The problem is that most of the time it is restricted to a narrow field and thinking laterally. Crossing into what we will call the "softer" sciences is what I heard. You start not by looking around the university, but by going out and listening and observing more than teaching. So that would be it from my side. It's very difficult in our business to teach top engineering minds to look at the softer areas because they are so adept at dealing with hard numbers and metrics. And it's even more difficult to take them into a field like fuel cells. That's called disruptive technology. There's no paradigm or blue print on how you move it into a market. This is where the entrepreneurs' comfort level in leaping into ambiguity puts them well ahead of scientists who absolutely wouldn't think about leaping into ambiguity. We'll just plunge in and we will figure out a solution when we get there, but don't ask me beforehand what the solution is going to be. I think a blend of the two is what we can put together in this country.

Pierce: I'll add to what Benson was talking about—the softer side. I was thinking of folks that really can do integrated science and technology and that requires a little bit of the "softness" that Benson was talking about. The group I run is called "biochemical sciences and engineers" and we have all of those types of people in there. Initially, their inability to talk was profound for some of the reasons that Benson cited. Scientists are fine with ambiguity. Engineers can't stand it. And you have to work on that together because, when you have an engineering mindset it's reality based and its not going to be head-in-the-clouds forever. When you let them roll around in that multidisciplinary ambiguity for a while, major things can happen. Maybe we're saying the same thing in different words, but integrated science and technology is what's going to have to work, especially when you look at something that goes all the way from a farmer planting a seed to some polymer or some fuel cell working away or some diesel molecule. An enormous number of hands have to touch it. It's a fascinating time.

Ashcroft: At the risk of just echoing the insights that the other speakers have offered, I would also say that intellectual agility or diversity or breaking out of the silos is the most desirable aspect in education. If you can't be excellent in all fields, at least be conversant enough that you can talk to those people. So, you're not an economist but you understand the language enough to talk to people who are. That's a recipe for personal satisfaction and personal success in your career; but, also, its necessary because, frankly, the challenges that we see are almost overwhelming if you think about them deeply enough. The only hope we have to rise to the occasion of addressing these huge social challenges is by revolutionary approaches and breaking out of the silos.

Steve Howell (Iowa State University): Regarding the goal of 21 billion gallons of cellulosic ethanol by 2022, I'd like to get an industry perspective on this in terms of where we are with respect to being able to technically produce that volume of ethanol using cellulosic feedstocks. As I see it, there are innumerable hurdles in the biochemical approach and the fermentation involved in getting there. What's the industry perspective on either the biochemical route or the thermochemical route of being able to reach these kinds of goals by 2022?

Pierce: We should see legitimate working facilities of both thermochemical and biochemical persuasions in the next 18 months or so. Now, which of those will turn out to have an advantage with respect to feedstock that allows them to work, and which of them can be generic enough that you can place them in a random location in Iowa and allow them to work, I don't know. At DuPont we have a long history with, for instance, syngas production and synthesis with molecules from syngas and all that catalytic thermochemical stuff. We've done an analysis and our conclusion was that the biochemical route is the near-term way to go despite the specificity of some of the steps of that route that cause headaches. Although we like the lack of specificity of the thermochemical route, we've picked, right or wrong, the biochemical route. I think the good news for society is that every route you can think of, and some you have not thought of, are being studied even as we speak. I hear rumors of big plants firing up later this summer that no one has heard about, with some wonderful new technology. Okay, that's good. As I said, we just recently doubled up a bet by doing a joint venture with a company called Genencor which provides some of the enzymes needed to do the saccharification. We're absolutely convinced we now have the pieces to do that. And every other kind of technological dodad you can imagine that can be applied to this is being applied by someone. Who's going to win? I don't know. Twenty-one billion is a lot of gallons and a lot of capital dollars. Over the next 2 or 3 years some legitimate-sized facilities will be out there and we'll be able to see. The first one is not the trick. It's the second, one right? Because when you build the second one that's like the clue. Right now, everyone is building their first one. The second one is a few years away.

Ashcroft: It's been suggested that part of the reason that corn ethanol grew so fast recently was the 2005 renewable-fuel standard; because, even though the number wasn't huge by our new definition of huge, it guaranteed that there would be a market for the product. It's possible that the advanced biofuel mandate will prove to be very useful in the sense that they guarantee a market for the product in the year 2022 independently of whether the number is 21 billion gallons or 15 billion gallons.

Pierce: 2022 is a little bit away in terms of the rate at which technology is improving. If you had asked at the start of this ethanol boom whether we'd be able to make as many gallons as we are today there would have been all kinds of reasons to say absolutely not, there's no way to do it. I wouldn't discount the ingenuity of the American farmer or the American entrepreneur or the American engineer, with these types of mandates in front of them.

John Glaser (US Environmental Protection Agency): I have two questions. First of all, linking to the question previously asked, and also some of the predictions, or at least perspectives, offered in Peter's talk, it strikes me that we are talking around an invisible elephant in our midst and that is dependable agricultural production. We are positing, at least in part, that we can rely on corn or some other carbonaceous material as feedstocks for these biofuels. I suspect and suggest to you that, in that perspective, we are really technologically focused, that is production-technologically focused for the biofuel and not agriculturally focused. There are many ways we can lose crop yields on the agricultural side. We have not worked into the agricultural yields the expectations of meeting these fuel goals as influenced by weather, insect pressure, *etc*. We are going now, in many cases, to corn on corn exclusively throughout the corn belt, which is going to have deleterious effects on the soil. We'll have to apply more fertilizer and other treatments to maintain yields. Right now we are getting some spectacular yields in the central part of the cornbelt but, the fact is, we are projecting an enormous amount of expectation that that will be a static basis that we can build on. And I suggest to you that it's a fool's paradise to expect that situation to stay in place. So that's question one. Question two, which is to John: in your biobutanol technology, do you have a US production facility? I have read that your work with BP is centered in the United Kingdom.

Pierce: I think your assertion was that agricultural productivity goes up and down over the years.

Glaser: It doesn't just go up and down. It is highly reliant on uncontrolled components.

Pierce: One of the main parameters driving our Pioneer seed business is yield stability. We couldn't agree more that this is a profound difficulty, not only for biofuel producers but also for farmers. I would say that the way you could deal with the swing, mathematically, would be based on how much variation you expect. So, if you need fifty units of something you should arrange to have access to seventy-five and then you could depend on never having less than fifty. And then the question would be can you afford to do that? And that applies whenever you have an innovation in agriculture. If you come out with a new corn plant or high-oleic soybean, you want to be sure you have enough oleic oil. You better ask for more because you never know if that's going to be a year when production is low. Therefore, innovation has to pay for that early overhead until it fills up enough of the infrastructure that you start dampening out those effects. I understand your general point. I don't know specifically where people are assuming something at odds with expected reality. There may be some, but I don't see that 21 billion gallons in and of itself is at odds with an expected ability of US agriculture to produce the raw materials. Were you asserting that you thought it did?

Glaser: No, I was reflecting on our current dependence on corn. Corn certainly is a good starting point, but to suggest that we can double the production in the timeframe that has been identified—I just don't see it. But I can be proven wrong too.

Pierce: I understand. Well, I will tell you that, at DuPont, we have big expectations built on trying to make those targets come true. In fact, we do have a lot of interesting things in the pipeline—as do other seed companies—that have rather dramatic yield-enhancing capabilities like drought-tolerance and improved nitrogen-use efficiency that have been the bugga-bears of traditional agriculture.

We are working with BP, but butanol is not some kind of European fuel although it is important for Europe. The United States and Brazil have all these nice ethanol-blending facilities all over the place. Europe doesn't have those, and so the ability to interact with the pipeline infrastructure in Europe is particularly advantageous. But, we also have a blending wall today in the United States. When I go to the gas pump in Wilmington, Delaware, it says, "May contain up to 10% ethanol" or may not. But the point is that ethanol can't get from Iowa to Wilmington with any surety. And part of the reason is because of lack of infrastructure even in this country. So, it will help out here also. We're piloting abroad but we are planning on producing in the United States, absolutely.

Michael Kahn (Washington State University): The way I interpreted the question just asked is a little bit different, and I'd like a comment on it. Because we are having a problem with global warming, which is caused by a very large scale emission of carbon dioxide from fossil-fuel burning and other things, what would have been a minor perturbation on a small scale becomes a major thing when we scale it to the consumption that we have in the United States. I think the estimate is that if the entire world burned gasoline at the rate that we are burning it, it would be something like two and half earth's capacity. Where is conservation? Peter basically said commuting is not something we can deal with in the short term. Solid waste—clearly if you don't generate problems they are not there to solve. Where might be the next problem? Because if we move to large-scale cultivation of switchgrass or, if we move a large fraction of our corn into ethanol, where do you see other problems coming and how do we deal with them? Peter pointed out that the new Farm Bill has a fuel standard that is much higher than the current fuel standard. In fact that's sort of a trick. It turns out that the way gasoline mileage is calculated is on the basis of miles per gallon of gasoline that's burned and if you have a flex fuel vehicle then the mileage is assumed to be 50% on 85% ethanol, which effectively doubles your gas mileage for the cost of putting in about $200 worth of piping. It looks good, but it's a trick. How are we going to come to grips with these sorts of things?

Ashcroft: Working backwards, you are absolutely right in that when fuel performance is calculated for a manufacturer's vehicles, an assumption is made about flex-fuel vehicles that's a very arguable assumption. That's a detail that we'll work out one way or another, and I hope it works out in a way that leads to the most efficient vehicles. But no matter how that's worked out, it's pretty clear to me that simply improving the efficiency of our vehicles isn't going to be enough to single handedly reduce greenhouse gas emissions by 60% to 80% if we are ignoring those other terms in the equation, the vehicle miles traveled and the fuel characteristics. So, I don't want to minimize the importance of the accounting that's used when EPA decides whether or not vehicle manufacturers have met their legal requirement, but I'm saying that, regardless of how that works out, we've still got a big problem. You mentioned conservation and I guess that corresponds to the vehicle-miles-traveled factor in the equation. I think that is something that can change over time, but it doesn't change quickly. And, as I mentioned, it's difficult to reduce the total number of vehicle miles traveled when the population is growing. The vehicle miles traveled are affected by things like the layout of our cities. Those are things that can change over time and, as public-transit systems go in, they can change over time, but they don't change quickly.

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Renewable Polymers and Advanced Materials

Stephen C. Myers[1]
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Agriculture's role in providing a secure food supply is widely recognized as a priority. However, emerging trends indicate an increasing role with respect to renewable energy and materials. Growth rates in the renewable-energy and biobased-materials industries could exceed 20% per year over the next decade. Along with significant industry activity in this emerging bioeconomy, numerous initiatives are underway, involving research institutions across the United States.

Ohio BioProducts Innovation Center

The Ohio BioProducts Innovation Center (OBIC), initiated in 2005 with an award from Ohio's Third Frontier Program, integrates academia and industry in the development of renewable specialty chemicals, polymers/plastics and advanced materials. The Center is a new research alliance that operates on a market-pull business model designed to link core-research capabilities in genetics, biotechnology, chemical conversion and product development towards the commercialization of bioproducts that represent value propositions to industry members. This enabling research alliance builds on the strength of two of Ohio's largest industries: agriculture and the chemicals, polymers, plastics and rubber materials sectors. A board of advisors, established with the award to provide advice and feedback on basic management structure and policy, includes representatives of the Archer Daniels Midland Company, Ashland, Battelle, Cargill, Cooper Tire, Hexion, Ohio Corn Growers Association, Ohio Farm Bureau Federation, Ohio Soybean Council, Ohio Polymer Strategy Council, Owens Corning, PolyOne Corporation, Proctor and Gamble, Scotts, Sherwin-Williams, The Andersons, The Ohio State University, PolymerOhio, and USDA's Agricultural Research Service.

OBIC's scientists are focused on development of research and commercialization projects that are designed to address specific needs of industry. Projects are not limited

[1]The author invites comments, questions and interest in potential collaboration (614.292.2922; myers.603@osu.edu). Additional information on bioproduct initiatives is available at http://bioproducts.osu.edu.

to those of the industry members on the advisory board. The Center leverages industry involvement with extensive core research capabilities at Battelle, the Ohio State University, and the University of Akron. Linkages have been established with the US Department of Energy (DOE), National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL) and US Department of Agriculture national labs.

Bioeconomy Drivers

As a major manufacturing state, Ohio is a significant user of energy and materials. These materials include chemicals and polymers that are typically combined to create advanced materials such as composites. In fact, it is estimated that chemicals, polymers, and advanced materials are integral components in 90% of all manufactured goods produced in Ohio. From 1999 to 2005, the production of chemicals, polymers, and advanced materials in Ohio increased over 15% (combined). Currently ranked #1, Ohio's polymer industry looms large in the state's economy both in dollar value of products exported and number of people employed. Leading business sectors within the polymer industry include paints and coatings, plastics, adhesives, detergents, and rubber.

Chemicals, polymers, and advanced materials are capital-intensive and rely heavily on petroleum in three significant ways: as a raw feedstock material, as energy for production, and as fuel to transport products to their destinations. Approximately 98% of all chemicals are derived from petroleum and natural gas (Frost, 2005). Relative to petroleum refining in the United States, economic viability is related to the value created by a portfolio of goods and services derived from petroleum. In fact, the petroleum-refining business is built on the basis of an integrated approach to allow flexibility and mitigate risk. Approximately 67% of petroleum goes to the transportation-fuel sector whereas only 7% is utilized in the chemical and polymer sector (Fig. 1). However, the latter sector has a 7-fold greater value.

Representatives from public- and private-sector groups supported by DOE and USDA established a target that the portion of plant/crop-based renewable resources addressing chemical and material needs will grow to 50% by 2050 (Fig. 2), the main drivers for which are volatility of fossil-based resources and potential impact of plant biotechnology. Global consumption of oil will increase in these and other emerging economies by 57% over the next 15 years. Fossil-based resources are finite, and many competitors are more strategically located than are major petroleum and natural gas reserves. New biotechnology is now enabling the development of oils, proteins, and carbohydrates with targeted functionality to produce value-added adhesives, coatings, polymers, composites, and other industrial products with differentiated properties and performances. In a 2000 McKinsey report, biotechnology is projected to make biopolymers cost-competitive with their petroleum-based counterparts by 2010 to 2015 (Bachman *et al.*, 2000). Furthermore, scientific and market research projects that biotechnology-based products will capture as much as 50% of the polymer market and 15% of the basic chemical market as a result of cost competitiveness as well as novel functionalities that have potential to revolutionize material applications.

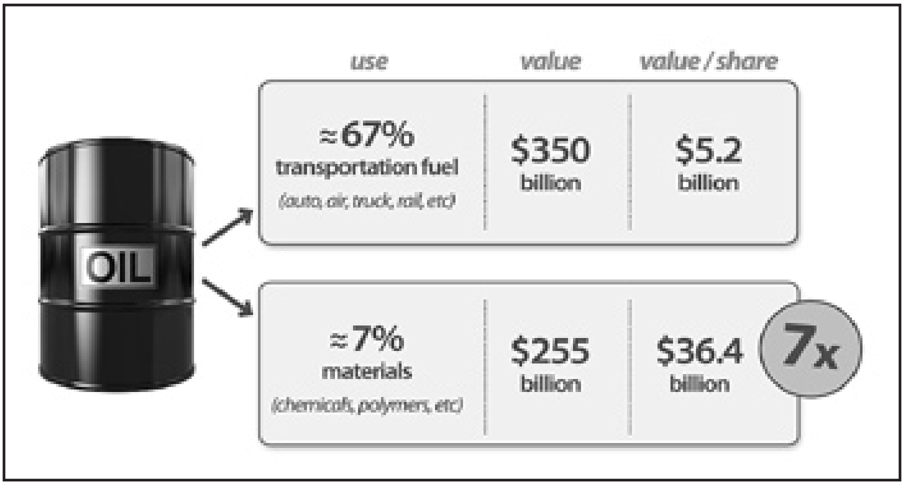

Figure 1. US petroleum market (Frost, 2005).

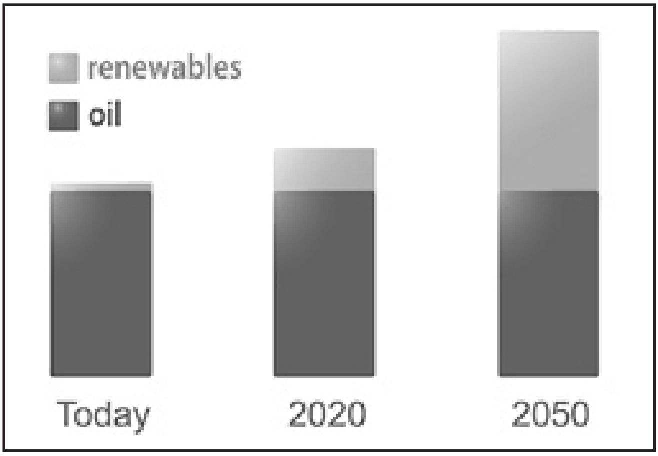

Figure 2. Targets to meet projected global material needs (ESG, 1999).

Ohio's Contributions

In an independent study, biopolymers were projected to be a major source of innovation for Ohio's polymer and advanced materials industry (Battelle, 2004). Based on a 2005 study, polymers and agriculture are two of the seven major industry sectors driving the economy in Ohio (CSU *et al.*, 2005) The convergence of new technologies (*i.e.* biotechnology, nanotechnology) at the intersection of these industry sectors is opening doors to innovations that could revolutionize nearly every aspect of our lives, from industrial manufacturing to production of chemicals and consumer goods and even environmental protection.

Ohio's agricultural bioscience industry is well positioned to take advantage of these emerging materials-based opportunities. In a recent study documenting Ohio's commercial bioscience industry, agricultural biotechnology was the largest economic sector (BioOhio, 2007). Recent analysis indicates that the state's food, agriculture and natural resource cluster generated approximately $93 billion in economic output, approximately 12% of the state's total output. This added 10% to Ohio's gross state product accounted for over a million Ohio jobs (15% of total state employment), and was responsible for 10% of total income. The state's employment concentration in agricultural processing is almost twice the national average, making agricultural processing in Ohio significantly specialized. While this industry is currently focused on food production, the presence of a bioprocessing infrastructure complements the potential development of additional valued-added uses of agricultural feedstocks for renewable energy and biomaterials. In fact, economic sustainability of biorefineries will likely be enhanced with an integrated approach with which biomass feedstocks are converted to a range of goods and services including food, materials and energy.

Ohio's agricultural industry has the potential to utilize substantial biomass resources, many of which are currently underutilized and offer significant value-added opportunities for conversion to biobased energy and materials. Ohio State University Professor Fred Hitzhusen (Jeanty *et al.*, 2004) recently completed a research assessment of Ohio's biomass resources in the following categories:

- crop residues,
- wood biomass,
- livestock manure,
- municipal solid waste, and
- food processing waste.

Ohio is nationally ranked as eleventh in total amount of biomass potential. However, this ranking is thought to be higher due to the fact that detailed data are currently not available on food processing waste, which is significant given that Ohio ranks fourth nationally in total food-processing production.

Strong linkages between industry and research are fostering a research and development portfolio that will form the foundation for the emergence of a biobased chemicals industry centered on key Ohio technical assets with the capacity to:

- enhance genetic design capability to create novel building blocks,
- develop fundamental processes and products related to materials, and
- demonstrate and commercialize technologies and products through the Ohio polymer and materials industry.

Gaining full advantage of emerging biobased materials and integrating them into useful products will require a wide breadth of high-level research and application development with close collaboration among engineers, chemists, physicists, and biologists. Multifaceted partnerships in research and commercialization of integrating biobased polymers and new applications involving academia, industries, government, and national laboratories can emerge optimally and most rapidly when there is a focal driver for the needed synergies and leveraging the respective capabilities.

Currently, OBIC alliance members are involved in a number of major initiatives. Soy-based industrial applications are being developed and commercialized by efforts of the Ohio Soybean Council through their support of research at Battelle and the Ohio State University. Ashland has established a leadership position with a new family of soy-based resins. The Program of Excellence in Natural Rubber Alternatives seeks to develop a domestic source of natural rubber and includes Ohio State, Oregon State, University of Akron, and USDA as well as leading rubber-industry leaders including Cooper Tire, Bridgestone and Goodyear. The Advanced Natural Fiber Composites initiative has established a consortium of academic and industry collaborators to commercialize breakthrough technology developed by the Natural Fiber Composites Corporation.

In Conclusion

Energy and materials are integral components of Ohio's economic future. While Ohio will continue to depend on fossil-based sources for energy and materials, developing alternatives may mitigate risk as well as provide sources of innovation and economic growth. Ohio is well-positioned to capitalize on emerging opportunities associated with the bioeconomy as related to biobased energy and materials. Ohio's strategic assets include strong polymer and agricultural industries, comprehensive supply chains and logistics, extensive research capabilities, abundant natural resources, and prime location.

As the bioeconomy develops to complement fossil-based sources of energy and materials, it will be imperative that efforts focus on areas where there is a strong value proposition for consumers. Likewise, an integrated refinery approach inherent to the petroleum industry is highly relevant to biobased energy and materials. Similarly, economic sustainability of biorefineries will likely be enhanced with an integrated approach where biomass feedstocks are converted to a range of goods and services including food, energy and materials (Fig. 3). With the appropriate balance of public/private effort, Ohio has the potential to achieve a leadership role in the emerging bioeconomy, particularly in respect to materials.

Throughout human history, agriculture has been a source of food, fuel and fiber. Opportunities have arisen unexpectedly and often through external events and trends that impacted patterns of production and utilization. While agriculture's role in providing a secure food supply remains the priority, emerging trends indicate increasing roles in terms of renewable energy and materials that will catalyze innovation as well as mitigate risks associated with over-dependence on imported fossil fuels. Growth rates in the renewable energy and biobased materials industries could exceed 20% per year over the next decade, creating significant economic opportunities. These opportunities will involve intersections of the agriculture, materials and energy sectors, as well as integration of emerging technologies, such as biotechnology, nanotechnology and bioinformatics. These advances will not be limited to technological innovation within the biological, physical and mechanical sciences. Societal values, government policy, environmental stewardship and economic drivers will, in great part, govern the extent of society's utilization of new technologies. Strong public/private collaborations involving multidisciplinary approaches

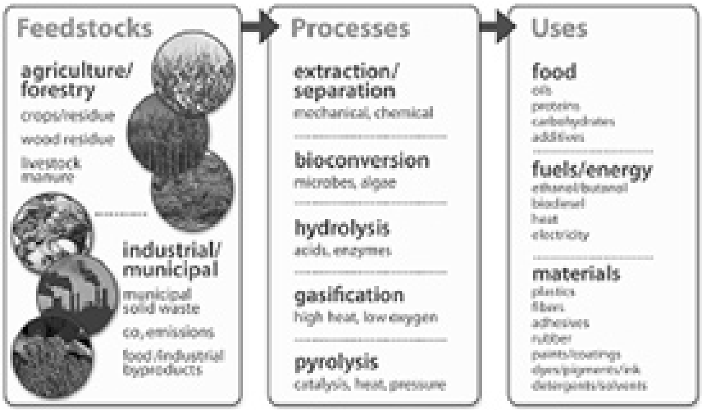

Figure 3: Integrated bioeconomy of feedstocks and products.

will be necessary to develop an integrated bioeconomy that addresses the food, fuel and fiber needs of society in a more sustainable manner. Given the complexity of this challenge, significant opportunities exist for institutions in research as well as in training the next generation of leaders for the bioeconomy.

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The Center leverages significant core-research capabilities at the Ohio State University, including the Ohio Agricultural Research and Development Center, the Molecular and Cellular Imaging Center, the Plant Biotechnology Center, the Center for Advanced Polymers and Composite Engineering, and the Center for Advanced Processing and Packaging Studies. With major leadership from the Battelle Memorial Institute, Center alliance members include the Archer Daniels Midland Company, Cargill, Cooper Tire, The Andersons, Hexion, Polymer Ohio, National Renewable Energy Lab, Oak Ridge National Lab, Ohio Corn Growers Association, Ohio Farm Bureau Federation, Ohio Soybean Council, Ohio Polymer Strategy Council, Owens Corning, Pacific Northwest National Lab, PolyOne Corporation, Proctor and Gamble, Scotts, Sherwin-Williams and USDA's Agricultural Research Service.

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ARS Research on Bioenergy and Co-Products

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The US Department of Agriculture (USDA) recently published[1] a strategic energy-science plan under the auspices of the Research Education and Economics mission (REE). Figure 1 summarizes the vision and goals.

Figure 1. USDA REE strategic energy-science plan.

[1]http://www.ree.usda.gov/news/bead/USDA_REE_strat_plan.pdf.

Sustainability will remain front and center in our work, with special emphasis on rural economies. Also, within the Agriculture Research Service, we have retooled bioenergy—one of twenty-two programs—for the next 5-year cycle. Before it was focused mostly on biorefining, whereas now it has been expanded to include feedstock development and feedstock production (Fig. 2).

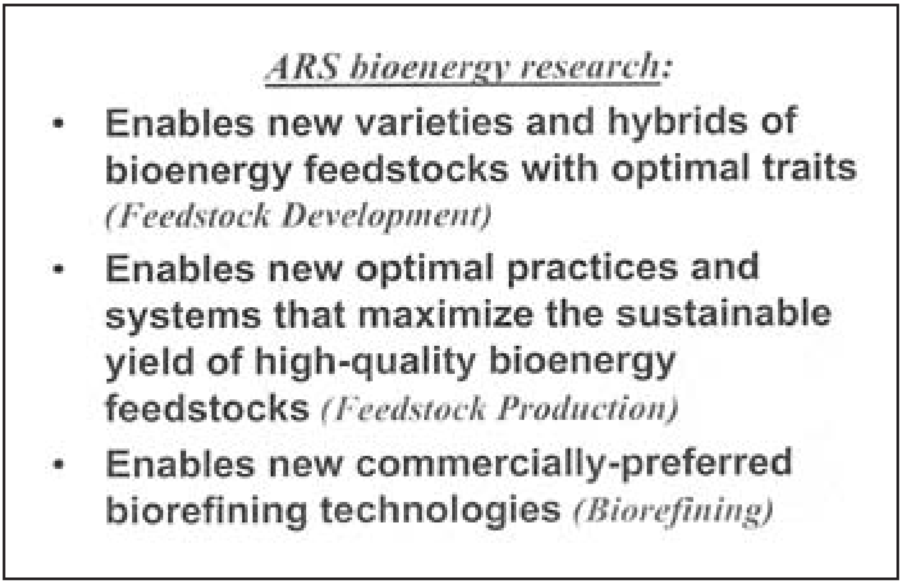

Figure 2. ARS bioenergy research: strategic vision.

Federal Coordination

Much effort is expended in coordinating the efforts of the USDA/ARS and other parts of the federal government. The Biomass R&D Initiative Board will soon publish a federal-wide biofuels action plan. Other interagency working groups include a temporary one examining feedstock availability, and others are examining feedstock-production sustainability and biomass conversion. We have a science-exchange program with the Office of Science and their bioenergy research centers. Inside the USDA there is the Energy Council at the undersecretary level and the Biobased Products and Bioenergy Coordination Council, which is composed of people at my level doing more hands-on coordination of programs and efforts.

Bioenergy Research

ARS research on bioenergy involves multiple programs. The most important is the Bioenergy Program, in addition to which a number of the other twenty-two programs include research that contributes to bioenergy. Again, there are three major components in the new Bioenergy Program: feedstock development, feedstock production and biorefining.

I share leadership roles with Kay Simmons, who leads our team on feedstock development, and Jeff Steiner on feedstock production. I head up biorefining as well as the overall integration. Feedstock development has two major components. One is looking at the molecular and genetic bases for plant traits that are important for bioenergy production, understanding the basics, and then using that knowledge, among other tools, for breeding new, superior germplasm.

For feedstock production we are focusing on three major areas. First is sustainable practices for feedstock production. We are also focused on developing decision tools that would help producers as well as biorefinery operators understand what kinds of feedstocks—and how much—might be produced sustainably on a particular farm in a particular region and the economic implications for the producer and the region. And we are working on on-farm utilization of byproducts from the char to gasification ash to distillers dry grains (DDGs).

With respect to biorefining, a number of efforts are ongoing, including biochemical conversion, not only of starches and sugars but also cellulosics and wastes. Emphasis on cellulosics constitutes the major part of the program. We are also investing in thermochemical approaches—gasification as well as pyrolysis—at the farm-scale or near it.

We have a strong biodiesel-research program, working closely with industry, particularly on fuel quality, which is still an issue. We also have a unit that helps us all in the biorefining area with process economics, to help us focus with respect to conversion technologies.

Co-Products

Co-products are a strong component of our program and require grantees to declare, up front, technology-transfer plans and partnerships. Much of the ARS work on co-products from biorefining occurs at four regional research centers:

- The Western Regional Research Center, Albany, CA
- The National Center for Utilization Research, Peoria, IL
- The Eastern Regional Research Center, Wyndmoor, PA
- The Southern Regional Research Center, New Orleans, LA

They were designed as utilization centers for developing new products and processes for utilization of excess materials from agriculture.

History of Achievement

These examples of contributions from the USDA give a sense of the activities in the regional research centers:

- 1943—Linoleic and linolenic acids were found to retard the process for producing synthetic rubber from butadiene and styrene; the problem was solved by partial hydrogenation.
- 1944—Epoxidation was discovered, enabling production of flexible vinyl
- 1950—Economical methods were developed for producing dextran, from cane or beet sugar, as an alternative to blood plasma for use in the Korean War.

- 1950—Xanthan gum was developed as an edible food ingredient fermented from glucose by a microorganism.
- 1976—SuperSlurper was invented—a combination of starch and a synthetic chemical that absorbs hundreds of times its own weight in water—initiating the superabsorbent industry.
- 1994—Fantesk was invented—an inseparable mixture of starch and oil that has numerous food and non-food applications.
- 2000—Nutrim was patented—a soluble oat fiber nutraceutical obtained from thermo-mechanical processing.

From Biodiesel Synthesis

The major co-product in biodiesel production is glycerol for which we have been working on a number of possible uses. One of them is the production of polyhydroxyalkanoates (PHAs), including polyhydroxybutyrate. We can actually obtain better yields of these materials if we make them from the biodiesel-based glycerol, probably because of small amounts of nutrients that would otherwise be considered as contaminants, but in this case are beneficial.

Other co-products from glycerol include microbial sophorolipids, which have several potential applications:

- Surfactants, detergents
- Cosmeceuticals (skin regeneration)
- Source of novel oleochemicals
- Source of bioactive disaccharides (inducer of fungal cellulases)
- Excellent antimicrobial agent

From Ethanol Synthesis

Co-products from ethanol refineries that we've been working on include corn fiber, which is typically a low-value material. We have developed corn-fiber oil, which has nutraceutical properties; it has been patented and licensed to Monsanto and a large corn refinery, among others. We have patented corn-fiber gum, which National Starch is using as an emulsifier and thickener agent in paints.

Some 95% of the oil in the corn kernel is in the germ, which is obtained by hexane extraction. We have developed a highly efficient enzymic extraction process that eliminates the use of solvents.

Another co-product is thin stillage from which we can extract and produce the carotinoid astaxanthin, which is used in feed on salmon farms to impart the characteristic red color, circumventing the need for expensive fish meal. Also, enzymic hydrolysis of corn fiber and distillers' grains provides novel oligosaccharides for use as probiotics, *i.e.* non-digestible carbohydrates that stimulate growth of beneficial bacteria in the colon.

Another application for distillers' grains again is in aquaculture. We developed a relatively inexpensive feed that is now used broadly for tilapia production.

There is a misconception that there are no co-products from cellulosic biorefineries. One that we've developed is xylitol, the five-carbon polyol, that's used as a food sweetener. It has anticariogenic properties and is used also in dental products, chewing gum, soft drinks, ice cream, *etc*. The traditional production route for xylitol, by catalytic reduction of hemicellulose hydrolyzate under alkaline conditions, is low-yielding and expensive. We have developed two alternative processes using recombinant microorganisms. In one it is made from xylose, and in the other from L-arabinose.

Land-Grant Collaboration

A number of our scientists work closely with university collaborators. In collaboration with B.J. Singh at the University of Illinois we developed a new milling method for corn-starch refining, which is being commercialized. That work involved scientists at our Eastern Regional Research Center outside of Philadelphia. We encourage people to look for required expertise within the ARS system as a whole, rather than for who is closest. On the other hand, many of our laboratories are co-located in land-grant universities and our scientists not only collaborate scientifically with faculty but also participate on graduate-student committees and teach as adjunct faculty. We are proud of these ties with the university community and look forward to continuing them under a new Farm Bill and new administration.

In November, 2004, **robert fireovid** joined the national program staff of the USDA-ARS to help lead research programs in quality and utilization (*i.e.* bioproducts). Previously, he was at the Department of Commerce's National Institute of Standards and Technology where he spent 10 years as a program manager in the Advanced Technology Program (ATP). While at ATP, he led nationwide programs in high-risk/high-payback R&D within the chemical, materials, agricultural and industrial biotechnology industries and worked with companies such as Cargill-Dow, Genencor, Metabolix, Seminis, Cognis, Metabolix, Maxygen/Verdia, Maxygen/Codexis and CropTech. Currently, he is the ARS national program leader for bioenergy research.

Dr. Fireovid has been involved in research on bioenergy and biobased products since his PhD work on ethanol fermentation of cellulosic feedstocks over 30 years ago, including bioproducts research on penicillin fermentation and enzymatic production of 6-aminopenicillic acid (Wyeth Laboratories), the conversion of lactic acid to acrylics (Corn Products), and fermentation-derived food additives (Hercules). In addition to a PhD in chemical engineering, he has an MBA from Northwestern University. He served as a business manager at Black & Decker and GE Plastics.

Biomass as a Source of Carbon: The Conversion of Renewable Feedstocks into Chemicals and Materials

Joseph J. Bozell
University of Tennessee
Knoxville, TN

The exceptional current interest in biorefinery development is intimately linked to the country's access to a large amount of renewable carbon in the form of biomass. Recent work has identified a sustainable biomass supply in the United States of 1.3×10^9 tons/year without upsetting normal supplies of food, feed and fiber, and without requiring extensive changes in infrastructure or agricultural practices (Perlack *et al.*, 2005). The corn industry produces $8–10\times10^9$ bushels/year, each containing about 33 pounds of carbohydrate as starch, and equivalent to almost 500×10^6 barrels of crude oil (Varadarajan and Miller, 1999; NCGA, 2008), and the current surge of production of corn-based ethanol will drive production even higher. The pulp and paper industry converts over 240×10^6 tons/year of wood for the production of paper products (Anon, 2002). Cellulose, the most abundant organic chemical in the biosphere, is produced at an annual level of about $10^{10}–10^{11}$ tons (Hutchens *et al.*, 2006). Second-generation facilities for ethanol production will rely on lignocellulose, and the renewable fuels standard has legislated cellulose as the source of 16 billion gallons of fuel ethanol by 2022 (RFA, 2008). The other primary component of lignocellulosic feedstocks, lignin, comprises up to 25% by weight of the biomass feedstock, and is a promising source of aromatic chemicals (Bozell *et al.*, 2007). When measured in energy terms, the amount of carbon synthesized by plants is equivalent to about ten times the world consumption (Indergaard *et al.*, 1989). Importantly, the cost of biomass raw material has been shown to be comparable to that of nonrenewable carbon sources on the basis of contained energy (Lynd *et al.*, 1999, 2008).

Biorefinery Operation

The biorefinery concept has developed to unify the processes and technology necessary to convert this vast resource into chemicals and fuels. The biorefinery is exactly analogous to a petrochemical refinery, and contains three primary process operations (Fig. 1). First, the biorefinery requires a raw-material supply. Nature provides diverse potential feedstocks, ranging from well-recognized agricultural materials (wood, corn, soybeans) to more exotic materials such as guayule or regional processing streams. The supply component of the biorefinery is possibly the most complex when viewed in the context of petrochemical processing, as nonrenewable carbon supplies can frequently be described by the single terms “crude oil” or “natural gas.” Nonetheless, this perceived complexity largely disappears when it is realized that almost all renewable raw materials are sources of a much smaller group of more structurally defined biopolymers.

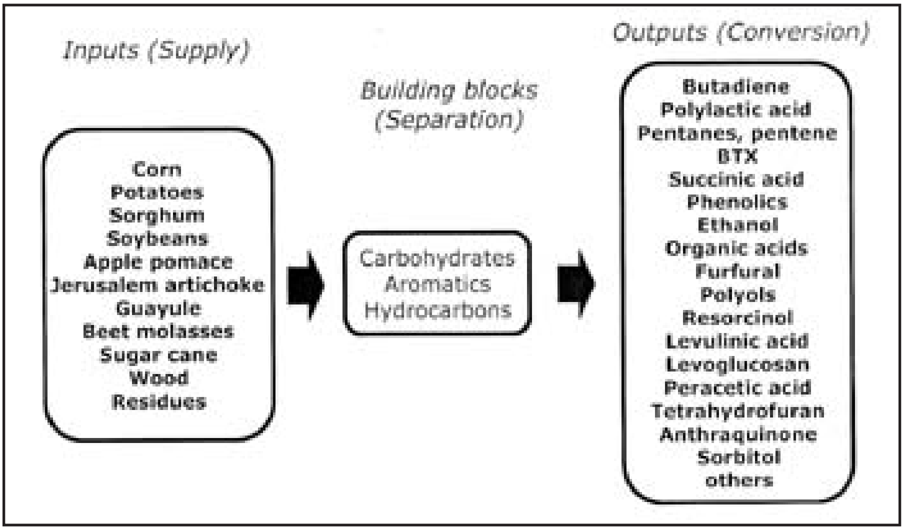

Figure 1. The three stages of biorefinery operation.

These biopolymers are isolated in the separation stage of biorefining, which generally provides three process streams: carbohydrates, in the form of starch, cellulose, hemicellulose and monomeric sugars, aromatics in the form of lignin, and hydrocarbons in the form of plant triglycerides. Separation processes in the biorefinery are closely related to pretreatment technologies normally associated with ethanol production (Sun and Cheng, 2002; Mosier *et al.*, 2005). As the concept of the modern, integrated biorefinery has evolved, pretreatment technology has also evolved from activation of a biomass feedstock for a monolithic biofuel operation into fractionation, where the various primary components of a given raw material might now be used in several different chemical or biochemical transformation processes.

The final operation in the biorefinery is conversion. In this stage, the intermediate building blocks from separation are subjected to a variety of conversion technologies, giving a family of biobased chemicals and fuels. Production of high-value products as part of the total output is important economically, as it allows the biorefinery to “afford” more costly—but perhaps more selective—upstream pretreatment/fractionation technologies.[1] However, it is also in conversion operations that the greatest difference between the petrochemical refinery and the biorefinery is found. For the most part, it is straightforward to collect either renewable or nonrenewable carbon (supply) and subsequently transform it into an initial set of primary building blocks (separation): ethylene, BTX (benzene, toluene and xylenes), *etc*., from nonrenewables, or glucose, xylose, *etc*., from renewables. However, the petrochemical industry has developed an impressive array of selective, high-yield structural transformations for the transit of crude oil to an initial set of simpler building blocks and eventually to the thousands of chemical products used by consumers. In comparison, a chemical industry hoping to use biomass as a raw material currently suffers from a much narrower range of discrete building blocks and fewer methods to convert those building blocks to other materials. *This technology gap is not the result of any inherently greater level of difficulty in processing of biomass.* Instead, it is the result of chemical-production research and technology to date being focused almost exclusively on highly reduced, oil-based hydrocarbons, rather than highly oxygenated carbohydrate-based materials. The increase in research interest in renewables in recent years is an effort to narrow this technology gap and develop methodology for renewable carbon as efficient as that available for nonrenewable carbon.

The Impact of Chemical Production Within the Biorefinery

Sustainable exploitation of the nation's domestic resources requires that the biorefinery address two strategic goals. First, the biorefinery's substitution of imported petroleum with domestic raw materials is primarily an *energy* goal. But realization of the energy goal requires a financial incentive to build facilities able to use renewables as feedstocks, to justify industrial use of new raw materials and to incorporate technology for their conversion. These incentives are the characteristics of an *economic* goal. The energy goal is addressed by biorefineries producing fuel, primarily fermentation ethanol. However, since fuel is a high-volume, low-value product, new, stand-alone fuel facilities are often burdened by a low return on investment, making their construction less desirable. For example, recent decreases in the profit margin for production of corn ethanol as a result of higher raw material costs in the United States has led to delay or cancellation of a number of ethanol-production projects. A biorefinery based on chemical products alone can realize a much higher return on investment, but lacks the potential for a large energy-displacement impact. This results in attempts to identify "blockbuster" products, the energy impact of which might be significant. However, few of these opportunities exist and chemical production accounts for only about 7–8% of our oil imports (Donaldson and Culberson, 1984). Various analyses (Dorsch and Miller, 2004; J. Bozell and A. Aden, unpublished results) reveal that producing both chemicals and fuels in an integrated biorefinery meets the energy and economic goals simultaneously. In an integrated operation, high-value products become an economic driver providing higher margins to support low-value fuel, leading to a profitable biorefinery operation that also exhibits an energy impact.

[1] The use of terms such as "high volume" or "high value" is extremely subjective, as a "high-value" product to a fine chemical producer might be well over several dollars per pound, but considerably under a dollar for a commodity producer.

Pre-identification of Biobased Products vs. Broad Technology Development

Despite the projected impact of chemical production on the economic viability of the integrated biorefinery, current research on chemicals lags that on fuels. For example, programmatic funding for biobased-product development by the US Department of Energy (DOE) ended in 2006 (DOE, 2007). The single biggest barrier to chemical production within an integrated biorefinery is a lack of broad-based processes tailored for renewable process streams that demonstrate scope comparable to that available for petrochemicals. A significant contributing factor to this situation is that chemicals are a much more complicated segment than fuels. The great complexity inherent in chemical products accurately reflects the nature of the chemical industry itself, which is anticipated to be the primary customer for any technology development. Many approaches to biorefinery chemical production begin with a search among the huge number of potential opportunities and an attempt to pre-identify the best single, specific structures for research and development. Because of the broad diversity of materials currently supplied by today's chemical industry, and the basic structural differences between renewable and nonrenewable building blocks, this identification process frequently becomes mired in a confusing array of possibilities, fragmenting chemical development in the biorefinery. An alternative approach to this question results upon recognition of the marked difference between the production of chemicals and the production of fuels. The fuel component of the biorefinery is *convergent*, whereas the chemicals component is *divergent* (Fig. 2).

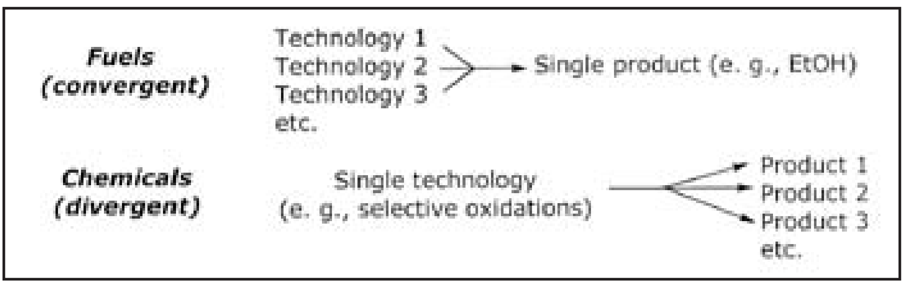

Figure 2. Fundamental differences between biorefinery fuel and chemical production.

The high-volume fuel outputs of the biorefinery are primarily single-product operations, such as fermentation ethanol or syngas from biomass gasification. As well defined single products, such materials can be assigned highly specific cost targets, and can have a wide range of technologies applied to their production. Whether a given technology is adopted for production of these materials depends almost exclusively on how well it meets the cost targets. If the targets are missed, the technology is discarded in favor of other approaches with a better chance of achieving cost goals, making single-product studies convergent.

In contrast, biobased products are much more diverse, as would be expected based on the experience of today's petrochemical industry and the tens of thousands of products it offers to the market. The chances of picking a winner are small, making a product-by-product approach less effective. Moreover, technology development for products is different from that for single materials such as ethanol or syngas. It tends to be divergent, in that technology found unsuitable for one structure may be useful for another because the cost-structure and economic drivers for the two-product candidates may be entirely different. Accordingly, success in biobased-product development will result more readily from identification of broad-based technology best suited for biomass, and applicable to producing a range of potential structures from biorefinery process streams. An investigation based on broad technologies will have a better chance of identifying those structures most easily available from biomass, simplifying evaluation of their properties and potential industrial/commercial viability. This approach would model the early days of the petrochemical industry as it evolved from thermal cracking (with kerosene as a primary product) to steam cracking (with olefins as key products).

Thus, while it may prove difficult (or even impossible) to unambiguously define a specific chemical structure that is the ideal target in the early stages of an R&D effort, broad technology development can be coupled with a straightforward definition of broader characteristics that a successful product candidate exhibits. For example, a biobased product should:

- Address large market segments of the chemical industry
- Exhibit or duplicate properties already identified by the chemical industry as marketable and valuable
- Provide attractive price and production volume opportunities
- Be easily made in high yield and a minimum number of steps from the biomass raw material

Biobased Platforms

A small but growing number (in comparison to those available from the petrochemical industry) of biobased products fit into these categories. Broad technology development has identified products such as sugar alcohols (catalytic reduction) and acids (catalytic oxidation), furfural, hydroxymethylfurfural (Zhao *et al.*, 2007), and levulinic acid (dehydration) (Bozell *et al.*, 2000; Fitzpatrick, 2006), acetone, butanol, ethanol (Ezeji *et al.*, 2004) and lactic acid (fermentation) (Danner and Braun, 1999), or fatty acid hydrocarbons and glycerol (transesterification). Further, if a candidate product is made in a single step from biomass, it has the potential for use as a primary platform chemical within the biorefinery, serving as a starting material for the production of a much larger family of derivatives. Currently, somewhat less is known about the types of markets biobased products will address, or the types of properties the products may exhibit, but by examining their structure, a categorization of potential uses can be made. Recent DOE "Top 10" reports on products from biorefinery carbohydrates or lignin (Werpy and Petersen, 2004; Bozell *et al.*, 2007) have examined the combination of broad technology needs with an initial list of potential biorefinery product structures. A conclusion from these reports is that success in technology development will provide methodology applicable to a much wider number of compounds than the initial "Top 10."

Characteristics closely linked to choice of biobased products are appropriate price and volume targets for new materials. Too high a price on a product relegates it to extremely low-volume niche materials (*e.g.*, pharmaceuticals), and lessens its potential to provide an economic incentive for biorefinery development. Price and volume predictions seem to suggest a need to identify specific structures for evaluation. But can realistic bounds be set on a product from a huge number of potential candidates? A high-level answer to this question can be obtained by examining the product choices historically made in the petrochemical industry and business models adopted. Sources such as the Chemical Economics Handbook (SRI, 2008) provide product-manufacturing information from dozens, if not hundreds, of chemical companies worldwide. Information on compounds and materials that are viewed as most important to the success of the chemical industry is available. Figure 3 provides a plot of about 125 different chemicals and polymers produced by the petrochemical industry. Several chemical and polymer products are labelled as reference points.

As expected, Fig. 3 shows a general correlation between reported prices and volumes. The highest-volume materials tend to be cheaper, with the prices exhibiting a floor of about \$0.20/lb, even at the highest volumes (2003–2005 data). However, 85% of these materials cluster between 30 million tonnes/year and less than \$2.00/lb. Of these materials, 65% cluster below 10 million tonnes and less than \$1.00/lb. Additional subsets of these materials can be pulled from the data to give more specific categories. Although not shown in Fig. 3 or 4, a cluster of materials used primarily as polymer precursors

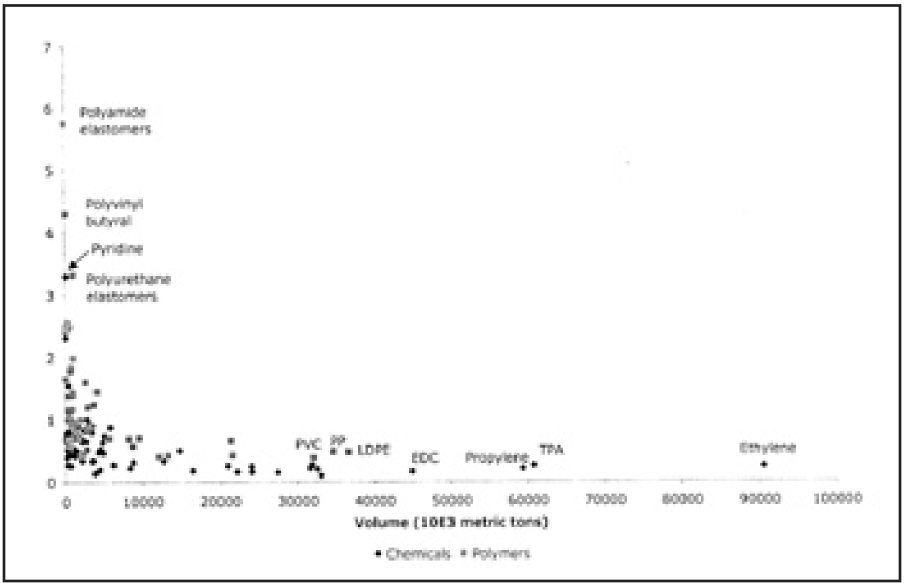

Figure 3. Correlation of chemical and polymer volumes with price (\$/lb) (2003–2005 data).

appears between \$0.35–0.75/lb, and less than 5 million tonnes/year. Despite this being a simplistic approach, industrial data provide some potential initial cost and volume targets for biorefinery chemicals. Figure 4 expands the area of Fig. 3 for chemicals with production volumes less than 30 million tonnes/year and costs less than \$2.50/lb. Most of the chemical industry's important products, as defined in the *Chemical Engineering Handbook*, are produced to meet costs of less than \$1.00/lb and production volumes less than 10 million tones, as shown within the circle in Fig. 4. Expanded, second-generation targets may be based on the needs of the biorefinery operator, such as materials inside the oval in Fig. 4.

Combining the technology needs identified in reports such as the DOE "Top 10" evaluations with first-approximation evaluations of price and volume for bioproduct development provides general characteristics of potentially successful biobased materials. As technology appropriate for bioproduct development improves, and the number of structures easily obtainable from biomass increases, the results of R&D activities can be subjected to high-level screens that suggest that if 1) a structure's production cost plus profit is less than \$1.00, 2) production can be scaled to around 5×10^6 tonnes/year, and 3) the product exhibits properties meeting or exceeding those already in the marketplace, an industrially viable compound may result. Improved technology will also result in improved economic evaluation and process analysis so that biorefinery operators will have the best combination of technology and economic information to make informed decisions regarding product choice.

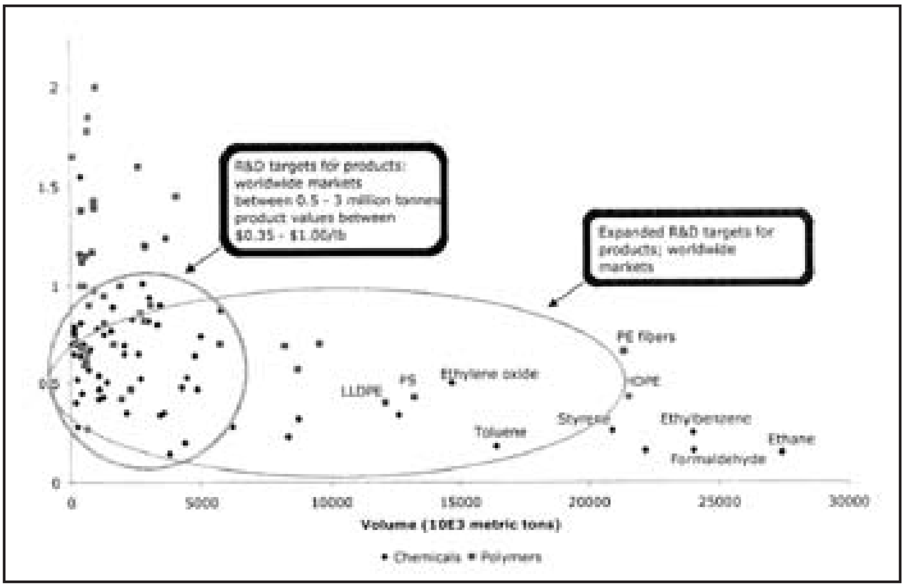

Figure 4. Potential cost (\$/lb) and volume targets for biobased products.

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JOSEPH BOZELL was appointed associate professor of biomass chemistry at the University of Tennessee's Forest Products Center in April, 2006. He has a BS in chemistry from South Dakota State University, and a PhD from Colorado State University in organic synthesis and organometallic chemistry. After a postdoctoral fellowship at Princeton University, he joined Monsanto's corporate research staff in St. Louis in 1982. In 1989, he joined the staff of the National Renewable Energy Laboratory in Golden, CO, where he rose to the rank of principal scientist in their National Bioenergy Center.

His primary research interest is in using the tools of organic chemistry to develop technologies for converting renewable materials (biomass, carbohydrates, lignin, lignocellulosics) into chemical products and polymers.

Dr. Bozell has served as editor of two ACS symposium series assessing chemicals from biomass opportunities, has organized two ACS symposia on the use of renewables for chemical production, and is an editor of the Wiley journal *CLEAN – Soil, Air, Water*. He has numerous peer-reviewed publications, meeting and symposium presentations, and has delivered a number of invited lectures on the topic of chemicals from renewables. In 1999, he was a co-recipient of the Environmental Protection Agency's Presidential Green Chemistry Award.


NABC

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Optimizing the Value of Co-Products and Byproducts

Panel Discussion and Q&A

Moderator: Richard P. Heggs
Battelle
Columbus, OH

Panelists:

David K. Jones	John Lumpe	Charlie Carr
Ashland, Inc.	*Ohio Soybean Council*	*The Andersons*
Dublin, OH	*Columbus, OH*	*Maumee, OH*

David Jones: I've worked with Stephen Myers on the board of the Ohio Bioproducts Innovation Center (OBIC), and the key thing from the industry side is that OBIC provides the connection that we need to be able to see where the value is. The big thing about a new industry is the return on investment, and by connecting the value chain, and understanding where that value is going to be, is a huge thing. The next thing is exposure to work typically outside of your sphere of experience. For Ashland it could be genetics. We're not going to be a biotech company. We'll continue to make chemical products, but to be able to understand what is coming in the genetics field is of great value to us. Also OBIC handles some of the social issues that typically affect businesses, and that is important.

Moving on to Dr. Fireovid's talk, I liked the farm-scale concept of having sustainable local production of energy and, even possibly, of chemicals. Our company is moving rapidly overseas into some developing countries, and we see the same issues. We've got to think about how we develop these locally because the supply chains don't exist. The concepts that apply for rural energy production we can take to developing countries. There is no reason to build entire petrochemical industries in these countries when we can achieve it with new technology as you are doing with biotechnology. That excited me. Some of the co-products are crucial to the total value obtained from a biorefinery. I've had some experience in this regard. Ashland and Cargill announced about 18 months ago that we were putting together a project to produce propylene glycol from glycerin and you wouldn't believe the effort required for that, which takes me to the next talk.

Again, Dr. Bozell's talk was excellent. The experience we had with Cargill—we went into it with the exact same mentality. Wow! We are going to make propylene glycol. We're going to have these byproducts, which we will distill and sell as a range of products. Well after almost a year of engineering work, the costs just didn't play out. The whole energy balance is so crucial. When you make propylene glycol, a byproduct is a mixture of alcohols and water. To get to the specific desired alcohol we would have to add two or three more boilers and another $2 million or $3 million worth of engineering costs. So, we've changed our minds on this now and are thinking that we have to find a use for the co-product as is. This happens also in the petrochemical industry. For example, when you make nylon you generate a solvent that's sold as dibasic ester, DBE—a blend of various things—which has become a crucial raw material for a lot of our products. The bioindustry is going to have to do the same thing and develop new uses for co-products instead of trying to distill them down to individual chemical components because it's just going to be too expensive.

John Lumpe: Our focus at the Ohio Soybean Council, on behalf of soybean farmers in the state of Ohio, who also grow corn, is finding those bioproducts. What can you make with the glycerin from a biodiesel facility? What can you make with byproducts from an ethanol facility? Our focus obviously is on soybean, but our farmers raise both crops and we are seeing a lot of investment in the new-use product categories that were highlighted in the USDA listing, including adhesives and coatings. We have a great powder coating that is based on soy. Much new technology has been created here in Ohio and through the United Soybean Board. Tens of millions of dollars of soybean farmers' money has been invested in developing new markets and new opportunities, for example soy-based foam in the seats of the new Ford Mustang. Ford is talking about expanding green technology. And when such a company starts talking about utilizing soy-based products not only at one level of their vehicles, but across the board, it's real. It's happening and it's coming to fruition. And what's exciting is that the industry is recognizing that agricultural-based products are a part of the future. It's not a silver bullet. It's like energy. Biodiesel isn't the key and neither is ethanol. But put them together with wind, solar, and other new sources of energy and they can help meet the needs of the future. The speakers all hit on some very good components, not only on corn and soybeans but also biomass. What will farmers grow in the future? They will grow what the market demands. And they are excited about these opportunities.

Charlie Carr: I've been with the Andersons for 36 years of the company's 61-year history. About 7 years ago, President Mike Anderson approached a couple of us and said that we had some facilities that were busy for only 5 or 6 months of the year—grain and agricultural fertilizer facilities. We needed to find what else we could do with those locations and the sky was the limit. We were free to go after anything and everything. These locations are now busy 11 or 12 months of the year; employees who previously worked part time now have full-time jobs and benefits. Diversifying our business was a key to growing our business. And diversification is what we are talking about today—the number of items that we can produce with ingredients that we work with. We handle liquid and dry products. We mix them. We bag them. We blend, package and bottle them. And it's amazing what opportunities we have in Ohio, Michigan and Indiana where we are located. And we just purchased a business in Florida. My point is, there is much opportunity for everyone in this room to work with these various products and technologies. It's a nice problem to have when you can't sort out what you should go after and what you shouldn't go after. Every week, we get calls from people asking us to work with them, asking us to support them. It's hard to sort through who has the technology that will work and what is best for us; groups like OBIC put us in touch with the right people in the right businesses to help us decide. The Third Frontier Project[1] has brought many dollars to the state of Ohio and my hat is off to the governors who have supported it. And along with OBIC we've got the Regional Growth Partnership and its subsidiary Rocket Ventures, the Edison Institute and USDA has jumped in with some things, and the polymer industry has large potential for us. It's hard for us to get our arms around all of the groups that are approaching us and wanting us to work with them. It's a nice problem to have, but somehow we've got to all work together and prioritize who should be working on what. At times the biggest entities are coming at us with similar offers and thoughts and that is a challenge for us.

There's been some talk about how ethanol has affected food prices and how it's a bad thing. Well, ethanol was a natural for our company to get into and we have three facilities. I don't know how the public is going to get educated, but it has been clearly shown that ethanol does not affect food prices as suggested by the news media and politicians. Informa Economics put a statement out that there's only a 0.3% increase in food prices for every dollar rise in corn. So, since 2005 until now, there's been a $4 increase in corn and that equals 1.2% in food inflation. Now there are many other sources, but that nails it. With $4 corn, the price of a box of corn flakes in the store is increased by $.09 or $.10 cents. We need to educate our world on how much ethanol really does affect food prices. Transportation costs do affect food prices; according to Informa Economics, $.20 out of every dollar in food is for transportation. So, we need to be looking at some of that. When we talk about waste products from ethanol production, right now we are able to market 100% of distillers dry grains (DDGs) with the majority going to animal feed. At some point there are going to be more DDGs than we can sell to feed producers, so many companies are working on alternative uses. That's an opportunity for many people in this room and an opportunity for us.

When we talk about the polymer and other industries needing corn or soybeans to develop new enzymes, everyone says that it's in place. We can identity-preserve those crops and store them separately. The only caution I have about that is to start planning now, because to identity-preserve and store small quantities is a challenge for a larger company, and then as the business grows and you need to do it in larger quantities, that's another challenge. So we keep saying that we are prepared, that we are ready, and we do know how to do it. We've done it in soybeans for years but each industry is different and each

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[1]http://www.thirdfrontier.com/

volume requirement is different. So we need to be talking about that now if it's going to happen 5 years from now, 10 years from now, whatever the plan is.

Our company cooperates with the coal-fired power industry to produce electricity. We supply the reagent that is sprayed into the stacks to bring the "bad guys" down. One compound thus captured—ammonium sulfate—comes out in a liquid stream for reuse as fertilizer for agriculture and turf production. We can't haul water very far so we employ a technology that granulates the stream into fertilizer. That's a prime example of what we can do with a waste product to everyone's benefit

Richard Heggs: Now is the audience-participation portion of the session.

Tom Richard (The Pennsylvania State University): When we talk about co-products and making materials and polymers from them, we need a feedstock to start with. And that feedstock could be a co-product from an energy facility, but also could be the primary feedstock of the energy facility, sugar for example. First-generation biomaterials companies, NatureWorks and now DuPont, for example, are using sugar as a feedstock for polymers. The question I can't work through is, if you're making sugar from a feedstock and you have different pathways—given the diseconomies of scale in a biorefinery because of feedstock aggregation—why would you employ two processes that produce small quantities of energy and small quantities of materials or biochemicals versus choosing one and focusing on that?

Joseph Bozell: I guess the issue is what would a biorefinery look like with regards to scale. In our evaluations we are not looking at small operations making small amounts of fuel and small amounts of chemicals. We would be looking at something that we would hope would begin to approach the scale that would give you economies similar to a petrochemical operation where you make a large amount of fuel and a sufficient amount of chemicals to economically support that large amount of fuel. If a process makes 50 million pounds a year of something, that is probably not going to pay off. Certainly, it isn't going to pay off for a fuel operation. It might pay off for a chemical operation and there may be chemical facilities, chemical producers, that would like to take sugar, make sugar, buy sugar, and use it as one portion of a larger chemical operation because it's profitable. One of the things we are trying to look at, though, is how one can incorporate the nation's energy needs into this and that takes you to a different level of operation. It scales up the biorefinery where we would hope we wouldn't run into those diseconomies of scale you are talking about.

Richard: That's one model. We are going to have these very large biorefineries, but I think there is another paradigm out there and maybe Bob could speak to that—the decentralized strategy and whether it makes sense to have the two.

Robert Fireovid: This is an interesting question because we just went through a lengthy dialogue internally in ARS, the national program staff, about how we are going to organize the bioproducts and bioenergy programs, because they are separate programs, specifically in relation to co-products. And the final decision that we came up with is that co-products that are very much associated with a biorefinery—like DDGs or DDG-derived products or glycerol or glycerol-derived products—will be managed under the bioenergy program. Other co-products, not necessarily from a biorefinery for fuel production, but from a corn wet-milling operation or something like that, will still be managed under the bioproducts program. And you've got examples today of the economies-of-scale kind of situation; for instance in Blaire, Nebraska, Cargill is putting its PLA plant right next to its huge corn wet-milling plant. Wet milling, of course, is a large-scale operation and in such situations you are going to have multiple products based on sugars. For dry-grind and particularly small-scale dry-grind operations, they won't have enough byproducts in many cases to justify the capital investment required to make value-added products. It's going to be economics driven on a case-by-case basis by the investors in the facilities. We are interested in developing, to the extent that we can, co-products that can be economically made at a smaller scale for the reasons that have been elucidated before. We want to help the rural economies. We think that this is the best way to do it, to help rural communities capture the lion's share, or as much as possible of the economic returns that are going to be generated in this new industry. We can do research that will push it in that direction, but ultimately it's simply an economics-based business decision.

Heggs: Let's say a forward-thinking and progressive state government was going to put a pot of money out there, lets say $50 million, to foster innovation and grow this industry. How would each of you prioritize the spending of that $50 million to get the best return?

Stephen Myers: Well, in this particular case, I think that hypothetical $50 million has some caveats in it. They are expecting a pretty quick return on the investment in terms of job creation, so that begins to set some guidelines about what projects it should support. The other thing is there are going to be caveats that there needs to be strong leverage in private sector with that funding. So, since you have a short time frame you would want to use some existing groups, already in place, that focus around that area and put together an evaluation of particular projects that fit the criteria, for implementation as fast as you can and try to do it faster than other groups.

Fireovid: At the Advanced Technology Program at National Institute of Standards and Technology, we had pots of money like this. It was higher risk and a bit longer term, and was made available to for-profit companies for research. They could involve university or federal labs, *etc.*, as well as their own. That worked well for us because market pull was involved in whatever they were doing.

Bozell: We had a similar hypothetical in Tennessee. Just last year the state government authorized $40 million for construction of an ethanol-from-switchgrass biorefinery and eventually co-products, and also a fairly large pile of money for operating expenses and a component for research. The prioritization process was to make sure that we had allocations to all parts of the value chain, and one of the key components was getting it through the Tennessee legislature in 18 months, which was presented to me as unbelievably fast. And one of the components was making sure that the people on the producing end, the farmers, were intimately involved from the start. The producers were already on board with a guaranteed income for 3 years to allow us to have the feedstock that we could then feed into our biorefinery development along with an allocation for research funds to develop the technology that is the gap that I pointed out, in order to try to fill that gap all across the value chain. And we are hopeful that that is a model that will also work. It certainly has received a lot of favorable play in Tennessee and we are hoping it will be a model that others will want to consider.

Carr: If anyone in the audience gets the $50 million, remember The Andersons—we want to work with you. We are Ohio. We've been here since 1947 and we are here to stay. We want to work with Ohio people and when we start hearing that these dollars are available, we want to make sure we stay on top of what is going on in Ohio and we stay in touch with the companies that have the ideas for co-products and byproducts in this great industry in this great state. If we are the ones who receive the $50 million, we've got to organize our thoughts, determine what the best products are for us to market but it will take other companies and other associations in Ohio to make it happen. Each of us should assume that that money is going to hit somewhere and we've got to work together to bring the most dollars and the most new jobs to Ohio. That would be our game plan—to see what we can do to contribute the most.

Lumpe: The money is available. The $50 million is going to be there, but it's the value chain, it's working together. It's groups like OBIC, who have been out in the forefront of this. We were one of its founding members. It's very important to us and to the farmers that we represent that this industry now is in—many of you have heard the term—the "valley of death." This is where capital from government is necessary to catapult this industry forward and make it happen. But, it needs all sectors of the value chain working together to make it happen. And it's going to be an investment portfolio. I believe they are looking at a 3-year payback out of this, so you are going to have to look at short term, medium and long term, but it has to be job related. And we can't sit around and do a bunch of studies and that type of thing. We have to look at what is here and what is the future of this and make sure that it happens, because this is our time for Ohio to shine. It's very exciting. The first bioproduct project that we invested in was back in 1994, so now that we can see this happening we have products being commercialized. We are selling licenses. It's an exciting time to be an Ohioan. Now is the time to make it happen. We have to work together.

Jones: As the others mentioned, this money is about job growth and we need to focus on things that are going to create jobs. For me it's not a long-term research program but maybe taking some of these projects that were mentioned earlier and even yesterday, some of these things that are coming from soy or coming from the grains that The Andersons deals with and expanding those to make Ohio a leader in those types of products. One that was mentioned yesterday was a soy toner for print cartridges. Where is that manufacturer? Is it in Ohio? Well, why not? Lets get somebody making that. A paint plant, can employ twenty to thirty people. That's where I think the money should be spent, because it's for job growth.

Steve Pueppke (Michigan State University): My question relates to the interface between industries and the universities or the Agricultural Research Service. I'd like your thoughts on what makes it tough. To some extent, I exist in this space and am involved in discussions of this sort. They are tough in the sense of structures and how we work, getting from the universities what needs to move out into the private sector.

Jones: I spend a lot of time with universities, trying to license technology, and it can be frustrating. Every state has its own rules about what companies can have and not have. We want to make money on this technology, but the university also wants to make money so you have this back and forth. I am encouraged that, across the nation, universities are investing a tremendous amount in this space. Michigan State is an example of a leader in making investments here. And I like the fact that start-up companies are spinning off from these universities and then the university licenses that start-up company, and then we as a bigger company can move technology faster with those small companies than we can with a state university. So I like what's coming. The trends are there. I keep hearing about the new kids coming up with biochemistry majors and all the great things universities are doing. You guys are the ones who are really developing the infrastructure and the new work force. Somebody used the phrase "the green collar work force." I see the young kids today becoming that, but the ease with which the state government makes it possible for industry to license technology is still the hang up.

Fireovid: The university and corporate relationships that work best are those that are true partnerships. Situations where a technology is developed and then is given to the Office of Technology Transfer to find a potential customer or licensee don't work as well as partnering with a company up front, early on. You have champions on both sides. You have a champion on the commercial side and one on the academic, research side, and they work together throughout the process to develop something that can be used by the companies successfully, and everybody, of course, wins. For government-university collaborations, we are pushing our scientists to work with the best and the brightest, wherever they are, in terms of alliances and research collaboration. That may be inside ARS. It may be outside ARS. Finding the right partners and then working with them is the key.

Myers: We have interacted with many different cultures; even within academia—colleges and departments—every situation is a little different as it is with different companies. If you are working on a huge grant proposal, it's advantageous, as Bob mentioned, to get everybody together in the very beginning. We've found that independent facilitation can be advantageous, maybe a private group to coordinate a grant, or some other kind of neutral body to facilitate discussions, but get everybody in the room in the very beginning to lay out expectations very clearly. Lay out the milestones very clearly. Everybody moves at a different speed. Sometimes a researcher is moving at 20 mph and if you bring that person into 70-mph traffic that doesn't work. Expectations have to be established quickly so that people know what's going on and can choose whether to be involved or not. The interface between cultures is a challenge, but it's also an opportunity to figure out how to deal with it.

Carr: I agree with everything said, but I think the important thing is not to wait until you have a project and contact a university. It's better to build relationships, as we have, over the years. We have a great working relationship with Ohio State and a wonderful working relationship with Michigan State.

Module III: Enhancing Productivity of Biofeedstocks

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Opportunities for Enhancing the Productivity of Biofeedstocks and Minimizing Inputs: Theory and Practice

Stephen P. Long
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Although I am the deputy director of a recently formed joint effort—the Energy Biosciences Institute (EBI)[1] involving the University of California at Berkeley and the University of Illinois at Urbana-Champaign, funded by British Petroleum (BP)—I've worked in this area for many years. Much of this presentation comes from that background, rather than from current research[2]. A lot of my work has been on the impacts of global change. When I moved to Illinois in 2000, I set up a unique facility for looking at the impacts of global change on corn and soybean[3]; my interest in bioenergy comes from seeing biofuels as part of the solution.

Food Crops as Feedstocks

At the present time, our main bioenergy crops are sources also of food and feed. The motivation is that we have a huge knowledge base for these species. We have agronomy, genetics and genomics information, and huge germplasm resources. And the infrastructure is in place to make use of extension-service know-how and commercial advisors who are used to dealing with these crops.

Why, then, is there interest in nonfood/nonfeed crops as feedstocks for bioenergy? First of all, generally, they require few inputs. They are perennial and you plant them only once. Optimal nutrition is not important, since you only want the carbon; you are not interested in the protein, which can get in the way of a successful system. So, these

[1]http://www.energybiosciencesinstitute.org/.
[2]Many people have helped in this work, most notably graduate students Clyde Beale, Emily Heaton and Frank Dohlman
[3]http://soyface.uiuc.edu

plants have these options plus the fact that, if your main requirement is lignocellulose, it opens up virtually every plant there is as a possible feedstock; there's a huge range of germplasm to be explored. An advantage is that they can grow on non-prime land. We have a wide range of germplasm that can grow in saline soils or on land irrigated with sea water. For example, spartina (cordgrass) will produce about 60 tons of dry matter per hectare per year—about 26 tons per acre—growing in sea water. Perennials, in general, are well suited to sloping, erodible land because they bind the substrate and they can be grown on low-fertility soils. This is one way of avoiding food-versus-fuel issues.

The Ideal Biomass Crop

The concept of an ideal biomass crop comes from an EU bioenergy network that I was involved in 25 years ago. We said, "If we could start from scratch, what would our ideal crop look like?" I should say that we were thinking about crops that could be put on set-aside or Conservation Reserve Program (CRP) land, or possibly on nonagricultural land that would probably be managed by farmers. This is the shopping list we came up with:

- C4 photosynthesis
- Long canopy duration
- Recycles nutrients to roots
- Low input
- High water-use efficiency
- Sterile, non-invasive
- Can store harvest in field
- Easily removed
- No known pests/diseases
- Uses existing farm equipment

At the top of the list is C4 photosynthesis, because it's the most efficient form of photosynthesis that we know of. Long canopy duration is important; to be efficient, a plant has to capture energy for as much of the year as possible. Within 1 day, the solar energy the earth receives is equal to all the energy that we consume in a whole year. Recycling nutrients to the roots is important, otherwise when you harvest the above-ground material you remove nitrogen and other expensive inputs. Low input is also important, from the environmental aspect and even more so from the economic aspect. Pressure on water resources is ever greater; it's unlikely that biofuel-feedstock crops will be grown with irrigation. Sterility and/or noninvasiveness are necessary to avoid the possibility of new crops becoming aggressive weeds. Huge volumes of feedstocks will be needed to service biofuel-production plants. If biomass can be stored at the farm, just-in-time delivery systems become feasible, circumventing problems of long-term biomass storage. Being easily removed is important because if prices or pressures on food increase, farmers may need the flexibility to quickly change crops. If you grow anything on a large scale, you are not going to escape pests and diseases but, initial lack of such problems is desirable.

And ability to use existing farm equipment again makes a crop a more viable option, potentially part of a more diverse operation.

Corn, the major US crop, is a C4 species. However, it doesn't have long canopy duration. As we approach the summer solstice, most of the Midwest corn is nowhere near covering the soil surface. Neither does it recycle nutrients. On the other hand, it's not invasive and is easily removed.

Another option, which is quite widely used, is short-rotation coppice. Fast-growing trees, such as willows, poplars, eucalypts and bamboos, can be productively harvested on a 3- to 5-year cycle. Although there are no C4 trees, they do have long canopy duration and are good at intercepting radiation. Some trees store nutrients in the roots over winter and others store them in the trunk; nutrient recycling does not occur in the latter. They require moderately low inputs, are generally considered noninvasive, and harvested feedstock can be stored in the field. On the other hand, they are not easily removed, which is a major encumbrance for many growers.

A third option is C4 perennial grasses. This system works well if harvested after it has senesced in the fall. Possible crops include switchgrass, miscanthus, big and small bluestem, Indian grass, and many US-prairie, pampas and steppe species. Considering the "ideal" list above, attributes vary from species to species, but they come closest to the ideal biomass crop.

Biomass Yield

Biomass yield depends on the solar energy available and the efficiency with which the crop intercepts and converts that energy:

$$W_h = S\varepsilon_i\varepsilon_c$$

where W_h = harvested yield,
S = total solar energy,
ε_i = energy interception efficiency, and
ε_c = energy conversion efficiency.

Issues include how much of the year the ground is covered with green leaves and the efficiency with which intercepted radiation is converted into biomass as determined by photosynthesis and respiration. Of course, the interception efficiency is often a factor of resistance to pests and diseases, and of nutrient availability and use efficiency. The maximum theoretical conversion efficiency is about 6% for C4 plants and about 4.6% for C3 plants. However, no C4 plant reaches that 6% limit. Some reach about 4% in the short term, maybe 3% in the long term. We could gain a great deal of energy by getting closer to the maximum theoretical efficiency.

Perennial Grasses

Perennials do a better job of absorbing solar radiation than do annuals. As soon as it is warm enough, the former have the reserves to form an active leaf system that intercepts that radiation. Perennial grasses also recycle nutrients efficiently; in the spring they move them from the root system into the shoot, allowing it to be photosynthetically active. In the fall, those nutrients move back, thus autumn harvesting leaves the nutrients in the root for growth needs the following spring. It has been shown, in Denmark for example, that these crops can maintain a high level of productivity over as much as 20 years without application of nitrogen.

Two frontrunners in this arena are switchgrass, which has been heavily trialed by the USDA with much progress made, and miscanthus, which has been trialed quite extensively in Europe. The plant we work with[4] is a hybrid (*Miscanthus* x *giganteus*) of *M. sinensis* and *M. sacchariflorus*. They have different ploidy levels, so the hybrid is a sterile triploid, eliminating the risk of it becoming invasive. The triploid is very productive. It is closely related to sugar cane and to sorghum. In our genomics work we are using sorghum as a scaffold for addressing the sequence of miscanthus. In 2002 we ran three trials in Illinois, planting rhizomes—rather like planting potatoes—of miscanthus and seeds of 'Cave-in-Rock' switchgrass, the recommended cultivar from Illinois. In 2004, the trial number was increased to seven. With BP's help, we are now setting up trials around the country and in Canada.

Miscanthus

We say that by the fourth of July, corn should be knee high. Figure 1 shows that by that date in 2006, miscanthus was already high enough to hide me, demonstrating how much more efficient it is than corn in intercepting radiation early in the growing season. Even with poor conditions in the spring of 2008, miscanthus is already covering the ground (June 4), whereas some of our corn is only at the fourth leaf stage. By early August the crop is usually over 11 feet in height (Fig. 2) and by late October it is flowering (Fig. 3). The crop in Fig. 3 produced 26 tons of dry matter per acre, one of the highest yields we have seen. That was in 2004. January, when it has died back (Fig. 4), is a good time to harvest because the atmosphere is dry—you can get its moisture content down to 6 or 7%—and farm equipment is idle. We often harvest in February using the Animal Science Department's cutting and baling equipment. Bales left in the field for as much as 2 years lost remarkably little biomass. Miscanthus is a traditional thatching material in Japan, which shows that it's not easily broken down when exposed to the elements.

In plot trials around the state, we found that miscanthus consistently out-yielded switchgrass. It has been suggested that if we had included the cultivar 'Alamo,' we would have seen higher switchgrass yields and that may well be the case. However, published records show that miscanthus has been consistently more productive than switchgrass. The trials we are now setting up across the country should give us a better idea. But, in 2004, our best plots in south and central Illinois gave over 20 tons per acre. One of the reasons for this yield level is that miscanthus intercepts solar radiation for a longer period of the year than does corn (Fig. 5). It invests a considerable amount of biomass in the roots. Over 5 years, we have accumulated, on average, about 15 tons of dry matter—about 7 tons of carbon—below ground. The idea that planting something like this means you forego any opportunity to sequester carbon is certainly incorrect.

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[4]http://miscanthus.uiuc.edu/

Figure 1. Miscanthus in Illinois: July 4.

Figure 2. Miscanthus in Illinois: early August.

Figure 3. Miscanthus in Illinois: late October.

Figure 4. Miscanthus in Illinois: January.

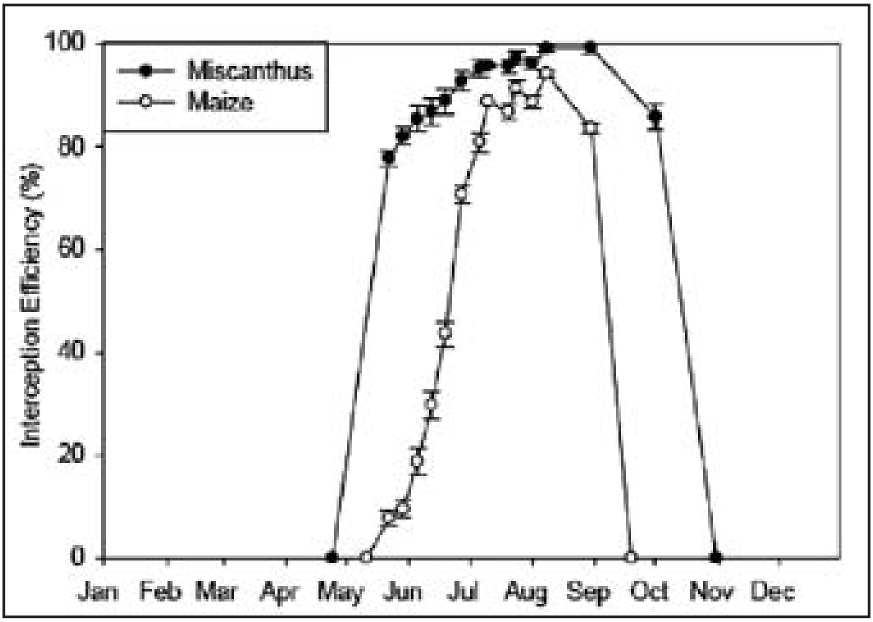

Figure 5. Light-interception efficiency, miscanthus and corn, 2007.

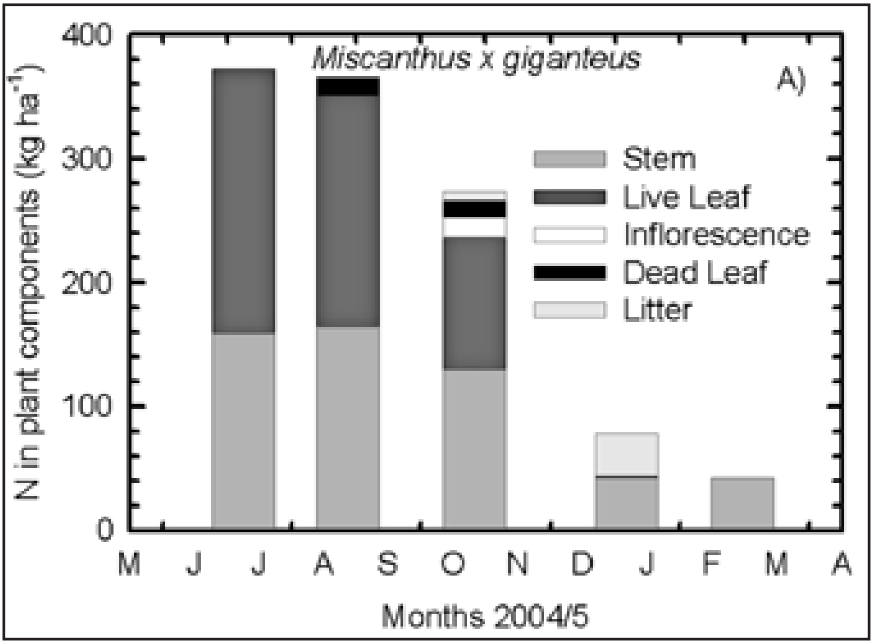

Figure 6. Miscanthus: shoot nitrogen distribution.

Miscanthus does require nitrogen; in one experiment the shoot accumulated almost 400 kg of nitrogen per hectare or 200 pounds per acre during the summer months (Fig. 6), but with the onset of autumn that material was translocated below ground and relatively little nitrogen was removed when the shoots were harvested in February.

Implications for Fuel Production

What does this mean in terms of fuel? To achieve the "20 in 10" target of 35 billion gallons of ethanol, how much land would be needed? At current corn yields, it computes at 25% of row-crop land in the United States (Table 1). A yield of miscanthus of 15 tons per acre computes at about 8% of crop land. It was suggested at this meeting that 1,000 gallons of ethanol per acre from corn will be possible with improvements in seed yield and inclusion of the stover as a feedstock. But even with current yields of unimproved miscanthus and little knowledge of its optimum agronomy, we should be able to average 1,500 gallons per acre.

Another way of looking at this question is in terms of a need for about 23 million acres (Table 1), which is about the area now planted to corn for ethanol. If we planted miscanthus on that land we could achieve the long-term target without taking any further land out of food/feed production. Furthermore, we know from Europe that miscanthus can be grown on marginal land; in the west of Ireland, on shallow acid soils, low in fertility and never previously used for row crops, 10 tons of dry matter per acre were obtained.

Table 1. Land area required for various crop options (Heaton et al., 2008).

Feedstock	Harvestable biomass (t/acre)	Ethanol (gal/acre)	Acres needed for 35 billion gals of ethanol (millions)	Fraction of 2006 harvested US crop land (%)
Corn grain	4.5	454	70	24
Corn stover	3.0	330	106	37
Corn total	7.5	784	42	15
Prairie	1.7	169	207	73
Switchgrass	5.6	557	63	22
Miscanthus	15	1,500	23	8.0

Water-Use Efficiency

How water-use efficient is miscanthus? You can't get large amounts of biomass without water, but its water-use efficiency is equivalent to that of sorghum—for a kilogram of water it gives about 10 grams of biomass, with a vapor pressure deficit of 1 kilopascal (Illinois average)—so it's pretty good. A rainfall of 1,000 millimeters in Illinois allows a theoretical production, if the plant is capable of it, of 100 tons per hectare or about 40 tons per acre. In Nebraska, with about 500 millimeters and 4 kilopascals, the yield potential drops to about 12.5 tons per hectare or 5 tons per acre. Almost anywhere east of the Mississippi River will have enough precipitation to produce 40-ton crops with the appropriate germplasm. In fact, the further east and south you go, the better are the conditions for miscanthus productivity.

Miscanthus Improvement?

Switchgrass and miscanthus cover the ground for similar periods of time, so why does the latter produce more biomass? The reason is that miscanthus's photosynthetic rate is higher. This tells us that improved photosynthesis may be achieved in other crops. In the past 30 years, we've learned a lot about photosynthesis, little of which has been applied to crop plants because the information has not being viewed as particularly important. If anything, too much productivity has been seen as a problem, rather than too little. Furthermore, a huge range of other opportunities has been identified in recent decades that could be applied to agriculture. High yields are clearly important if biofuel crops are to be successful.

Our work to date has been with just one genotype of miscanthus. It is likely that superior alternatives exist. We need to look for higher leaf photosynthetic rates, better early-season growth, and ecotypes for various climate zones. The potassium level is relatively high which is an advantage if it can be translocated to the roots. Lower lignin content would be advantageous, as would ability to retranslocate labile lignocellulose.

EBI

Although we hear a lot about greenhouse-gas balance, it's actually never been measured for important crops. At EBI, we are comparing miscanthus, switchgrass, no-till continuous corn and mixed-grass prairie, looking at their exact greenhouse balances and nitrogen drainage patterns, side by side. One of the themes of the Institute is that all of the people who are funded—the postdocs and graduate students—work together. Environmentalists, genomicists, microbiologists and plant breeders are located in a building adjacent to the Morrow plots, which is probably the longest running experiment on sustainability in the United States.

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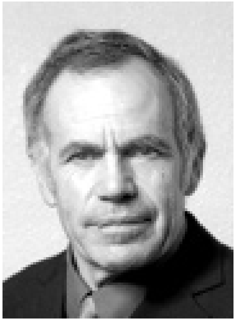

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Dr. Long is founding and chief editor of *Global Change Biology* and is listed by the Institute of Scientific Information as one of the 250 most highly cited authors in plant and animal biology, and one of the twenty most cited authors on global change. He has been a contributing author and referee for *Assessment Reports* on the scientific basis for climate change for the UN Intergovernmental Panel on Climate Change, and has served on several national and international committees for research on renewable energy and global change.

He is deputy director of the University of California-Berkeley and University of Illinois Energy Bioscience Institute—which was recently awarded $500 million over 10 years by BP. He is a fellow of the American Academy for the Advancement of Science.

High-Tonnage Dedicated Energy Crops: The Potential of Sorghum and Energy Cane

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The development of viable lignocellulosic-biofuel industries in the United States will require dependable delivery of supplies of feedstocks logistically available to conversion facilities. The selection of feedstocks ultimately will vary with geographical region across the United States. Dedicated bioenergy crops as sources of lignocellulose are likely to be most productive in the southern regions of the United States due to more abundant sunlight and longer growing seasons. Of course, dedicated bioenergy crops in the southwest must tolerate heat and drought, whereas species grown along the Gulf Coast must tolerate heat as well as variable soil moisture and variable soil-oxygen environments associated with different soil types. Dedicated energy crops for the panhandle of Texas and the Midwest will have shorter growing seasons and will need to be more cold tolerant.

Crop Selection

Economically viable bioenergy-production facilities will require the appropriate selection of crops to ensure year-round availability of feedstock tailored to local climatic, biotic, and soil stresses. From a facility manager's perspective, a complement of crops that allows year-round delivery of feedstock is paramount and, in this regard, is a contrast to regional monoculture systems that are predominant across much of the nation. Furthermore, biomass-crop production and management systems must be developed and tailored to each crop and each climatic region to ensure optimal biomass yields. These actions will require a coordinated effort focused on the development of multiple crop-production systems.

The primary limiting factors for sustainable lignocellulosic- and biodiesel-fuel industries in the United States are the reliable supply of economically priced feedstocks and the logistics of the harvesting, transport, storage, and overall supply chain. The current model for ethanol production from feed grains can be significantly augmented by the production technologies associated with high-yielding biomass crops, specifically sorghum, switchgrass, and energy cane. A key to sustaining and enhancing growth of the biofuels industry (combined with environmentally sustainable production systems) is the development of adequate acreage of dedicated feedstocks that produce high tonnage at prices that give producers and biorefineries acceptable profit margins.

Sorghum

Sorghum offers considerable potential as a dedicated lignocellulosic biomass crop. The broad genetic diversity within the genus provides plant breeders the opportunity to develop biomass sorghum adapted to diverse climates with low, and possibly high, water availability, to include many different biotic and abiotic stresses. The development and production of photoperiod-sensitive sorghum will facilitate full-season production of biomass, to maximize yield for significant tonnage. Yields in the range of 15 dry tons per acre have been achieved on the Texas A&M Farm at College Station. Even greater yields are anticipated under optimum conditions. Sorghum is of particular interest because it is the only annual, high-tonnage dedicated energy crop with the potential for being produced on large acreages, and it already has an existing agronomic (*e.g.* seed) infrastructure.

Energy Cane

Sugarcane, particularly the high-tonnage varieties (*i.e.* energy cane), offers the greatest potential as a bioenergy crop for production in much of East Texas and the US Gulf Coast. Sugarcane has a proven track record of producing exceptionally high yields on heavy clay soils in which many other crops are unable to grow well. For the past century, sugarcane varieties have been developed primarily for accumulation of high levels of sucrose. Commercially grown varieties can produce up to 40 dry tons per acre under optimal conditions. Biomass productivity probably could be increased even more if sucrose accumulation were no longer a constraint on breeding programs.

Several other grass species have the potential to produce exceptional biomass yields, including *Arundo, Miscanthus*, and *Miscanthus* crossed with sugarcane hybrids, known as Miscane and developed at Texas A&M AgriLife. The seasonal diversity of biomass production that these species afford may play an important role in ensuring year-round production of feedstock supplies.

Land-Use Changes

The development of sorghum, energy cane, and other biomass crops may require changes in land-use management but should include rotational cropping systems. Research is requisite for identifying which of these species will perform best in each climatic region of the United States. This will include detailed studies on a number of agronomic characteristics necessary to identify optimal performing inbred and hybrid varieties, as well as the identification of best management practices. Each region will require a management package tailored to its unique climatic and soils environments and its slate of biotic stresses. Unlike most conventional production systems, biomass cropping systems must be developed that incorporate appropriate combinations of high-tonnage crops that provide year-round delivery of feedstock at a price and volume that meet the production and financial needs of both the producers and the owners of bioenergy production facilities.

Biomass Priorities

The US Department of Energy has suggested that the delivered cost of biomass to conversion facilities should be in the range of \$30 to \$40 per dry ton, to hold down the cost of biofuels. However, the production costs for dedicated energy crops range from \$50 to \$100+ per dry ton. The keys to reducing delivered cost will be high-tonnage crops and highly efficient production systems, but delivering large amounts of biomass (hundreds of millions of tons per year) at rates lower than \$50 per dry ton will be difficult; farmers simply will not produce biomass feedstock for returns below what they can receive for current crops. For agriculture to deliver significant, sustainable supplies of lignocellulose from crop sources, a thorough evaluation must be conducted to assure producer buy-in. Table 1 shows a comparison of various delivered biomass costs.

Table 1. Productivity and cost of delivered biomass.

	Residue	Woody biomass	Switch-grass	Forage sorghum	Bioenergy sorghum
Biomass per acre per year (dry tons)	2	5–10	8	10	15–20
Estimated cost delivered to converter (per dry ton)	\$60+	\$50–75	\$60–90+	\$65	\$50–60

A successful, sustainable biofuels economy must be based on diverse biomass resources available consistently throughout the year that will include appropriate storage measures. Forest resources, municipal solid waste, urban construction residue, energy cane, switchgrass, energy sorghums, and algae will be important in a diversified portfolio. To develop this bioenergy portfolio several guiding principles should apply:

- protect the environment,
- assure economic viability,
- minimize water demand,
- minimize competition for food and feed production, and
- minimize disruptions in the marketplace.

Texas AgriLife Research

Texas AgriLife Research has funding exceeding $26 million for more than thirty projects supported by the Texas legislature, the federal government, and corporate partners to develop sustainable bioenergy production that addresses diverse feedstock development, agronomic practices, logistics, production modeling, and conversion technologies, as well as economic, policy and environmental assessments. Key faculty members with international experience in plant science, agronomy, agricultural engineering, biochemistry, biophysics, and economics are leading these research initiatives.

Since April 2006, **Bill McCutchen** has served as associate director of Texas AgriLife Research, within the Texas A&M University System. His mission includes developing and implementing strategic research initiatives across the biological sciences, with facilitation of university-industry relationships. He also assists in developing intellectual property from R&D.

He earned BS and MS degrees in entomology from Texas A&M, where he was recipient of the Distinguished Graduate Student Research Award in 1989. He received his PhD from the University of California Davis in 1993, having won the Young Scientist Award from the American Chemical Society in 1992.

Dr. McCutchen joined Texas AgriLife Research from DuPont Agriculture & Nutrition, where his responsibilities included crop-protection R&D across agricultural biotechnology and chemistry programs. He was named a DuPont Research Fellow in 2002. In 2007, he was presented with the Henry Wallace Agricultural Revolution Impact Award, DuPont's and Pioneer's most prestigious research award for agriculture. He has more than thirty patents and pending-patent applications. McCutchen provided the vision, innovation, and leadership that propelled a new generation of dual-herbicide-tolerant transgenic crops—corn, soybean, and cotton—and a new-generation weed-management solution, trademarked as Optimum GAT™.

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Synchronization of Biofeedstocks and Conversion Technologies: Current Status and Future Prospects

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As the biobased industry emerges, synchronization of biofeedstocks and conversion technologies is necessary to maximize economic competitiveness. The objectives of this paper are to

- address this issue primarily with respect to conversion technologies for production of bioenergy,
- highlight important logistical issues,
- address some needs of cellulosic energy systems, and
- speculate on future prospects for the industry.

Conversion Technologies

Cellulose and hemicellulose comprise more than 50% of fibrous plant biomass such as that contained in grasses, legumes, crop residues and wood. In the context of cellulosic biomass discussed in this paper, conversion technologies are methods for converting this material to energy in the form of heat, electricity or liquid fuels. These conversion technologies vary with respect to the ideal composition of the biomass raw material or feedstock to be processed. Therefore, in order to develop useful cellulosic energy crops, it is important to have a basic understanding of available conversion technologies and their needs in relation to feedstocks. However, certain desirable characteristics are common to almost all conversion technologies, including:

- high energy efficiency (useful energy produced as a percent of the energy contained in the feedstock),
- flexibility with respect to feedstock composition,
- low capital cost,
- low production cost,

- flexibility with respect to size of processing plant,
- ability to control undesirable emissions,
- market-ready products,
- high-value co-products,
- low volume of residue that requires disposal,
- low consumption of fossil fuels,
- low water requirement, and
- small environmental footprint.

Heat and Electricity

Production of heat is one of the most efficient processes for generating useful energy from biomass: typically it is possible to recover 80% or more of the energy contained in the feedstock. Both small and large systems are available for producing heat from cellulosic biomass. Pellet stoves are used for home-heating systems, and small furnaces or gasifiers are used for applications such as heating industrial buildings or broiler houses. Combustion occurs with limited or no restriction of air (or, therefore, of oxygen) to the furnace, and relatively high temperatures (> 2,500°F) are involved. If combustion is complete, the products are mainly water vapor, CO_2 and ash. However, depending on feedstock composition, combustion may also result in release of gases such as oxides of N and S, which are harmful to the environment.

Electricity can also be generated from biomass in both small and large systems. An example of a small biomass power system would be use of a gasifier to produce synthesis gas, or syngas (mainly CO and H, but also small amounts of CH_4 and CO_2), which then powers an internal combustion engine to drive an electric generator. However, syngas typically contains no more than 400 Btu/ft^3 compared to about 1,000 Btu/ft^3 for natural gas. On a larger scale, biomass can be used in a furnace or gasifier to generate steam, which then drives a turbine. This fundamental process is used in most pulp mills to generate power from mill residues and is also the basic method used to generate about half the electrical power in the United States from burning coal.

In typical coal-fired power plants, co-injecting the coal and biomass (a process known as co-firing) offers immediate opportunities to use biomass for production of electricity, with very little capital investment. Trials for co-firing up to 10% switchgrass with coal in existing power plants have been conducted in Alabama and Iowa. Co-firing higher proportions of switchgrass with coal is difficult because of its relatively low bulk density: 10% switchgrass by weight amounts to about 50% by volume. Low bulk density also necessitates separate handling of the two feedstocks. Coal is fed by gravity feeding systems to a pulverizer, and the resultant powder is delivered pneumatically to boilers. However, chopped biomass tends to "bridge" in gravity-feeding systems, causing blockages, and thus needs to be injected into the boiler separately from the coal. Co-firing biomass with coal typically results in a reduction in undesirable emissions but is more expensive than burning only coal on an energy-equivalent basis.

From the perspective of converting biomass to heat and electricity, ash and moisture are two important feedstock constituents. Moisture should be as low as possible to minimize the energy required to eliminate it in the conversion process. Ash is the inorganic material that remains after combustion or gasification. It has little or no value, and may be a liability if it has to be disposed of in a landfill. Therefore, ash concentration in cellulosic feedstocks intended for conversion to heat and electricity should also be as low as possible. Corrosion and slagging (solid deposits developing on the inside of reactors) can be a problem when biomass is processed in a furnace or gasifier. This depends largely on the ash-fusion temperature for the feedstock, which, preferably, should be as high as possible. Since ash-fusion temperature generally decreases with increased concentrations of Cl, K and, especially, Si in the feedstock, concentration of these elements should be as low as possible. In general, grasses typically have a lower ash-fusion temperature and are more prone to slagging than legumes or wood, mainly due to higher concentrations of Si. Finally, when feedstocks are processed by combustion or gasification it is desirable to minimize production of undesirable emissions, especially oxides of S and N. It is, therefore, desirable for the concentration of these elements in feedstocks to be low.

Liquid Fuels

At present, ethanol from corn starch or sucrose from sugar cane, and biodiesel from vegetable oils such as those derived from soybean, canola and oil palm, are the primary or "first generation" biofuels that are being produced commercially. Ethanol production from sugar cane is the cheapest process, because it simply involves fermentation of the sucrose in the juice of the cane to ethanol, and subsequent separation of the ethanol from the resultant "beer" by distillation. The residual solid material (bagasse) is used to generate heat and power needed to run the plant. Consequently, the fossil-energy ratio (FER: energy contained in the final product as a ratio of the fossil-energy input) for ethanol produced from sugarcane is well over 10.

A number of liquid fuels can be produced from cellulosic biomass. Even though ethanol is perhaps the most widely recognized and promoted, it has a considerable number of limitations. First, it contains only two thirds of the energy content of gasoline, thus providing only two thirds of the mileage in currently available engines. Although it can be blended with gasoline as an octane enhancer at a concentration of 10%, if used as a primary fuel it is typically made available in a blend of 85% ethanol and 15% gasoline, or E85. Use of this fuel requires flex-fuel vehicles and separate E85 storage tanks and pumps at filling stations. Furthermore, ethanol cannot be transmitted by existing pipelines, thus necessitating transport by road or rail. Even though it is possible to produce liquid fuels from biomass that are similar to those produced from oil, ethanol has accumulated considerable momentum as a transportation fuel due to the corn-to-ethanol industry.

Cellulosic biofuels can be produced by either of two primary pathways: biochemical or thermochemical (Pu *et al.*, 2008). The biochemical pathway for producing cellulosic ethanol (as well as other alcohols such as methanol and butanol) has received more research attention than the thermochemical pathway, possibly because it strongly resembles the corn-ethanol process. It involves enzymatic or acid hydrolysis of the cellulose and hemicellulose into component sugars, fermentation of the sugars into ethanol, and separation of the ethanol from the resulting beer by distillation. Typically, a pretreatment step is required to reduce feedstock recalcitrance (masking or binding of the cellulose and hemicellulose by lignin) to conversion. Most current pretreatment processes involve steam explosion or application of ammonia to break apart the feedstock fibers. Cellulose is more difficult to hydrolyze than hemicellulose, but the five-C sugars derived from hemicellulose are more difficult to ferment. Expected yields from biochemical processes are 60 to 80 gal ethanol/dry ton of biomass. Due to lower lignin and higher cellulose and hemicellulose contents in grasses and herbaceous legumes, ethanol yields from this process are expected to be higher than for wood. Lignin is a residue that remains after fermentation and can be used to generate heat and/or power to run the plant.

Thermochemical conversion involves gasification of the biomass into syngas and conversion of the syngas to liquid fuel by catalysts under high pressure and high temperature in catalytic reactors (Pu *et al.*, 2008). These fuels can be ethanol, methanol, and/or diesel, depending on the catalyst used. Thermochemical technology is more flexible with respect to feedstock, and expected yields are above 100 gal/ton of biomass.

A hybrid thermochemical-biochemical system can also be used in which the syngas from the gasifier is converted to ethanol by microorganisms, or biocatalysts, instead of chemical catalysts. Another version of the thermochemical process involves catalytic degradation or depolymerization of polymers, followed by catalytic synthesis into renewable alkanes or hydrocarbons that resemble the diesel, gasoline, and aviation fuel that are currently generated from oil.

While no economically successful commercial plants that produce transportation fuels from cellulosic feedstocks are in production yet, the US Department of Energy (DOE) is in the process of assisting with funding for six projects that involve building commercial-scale cellulosic-ethanol plants. In addition, private companies are proceeding with similar efforts without government assistance. Therefore, it is likely that the first plants of this kind will be in operation within the next 3 to 5 years, and substantial expansion of the industry can be expected in 5 to 10 years.

Biomass Crops

Although the ideal traits needed in a biomass-energy crop depend partly on the conversion technology that will be used, many desirable traits are not strongly dependent on the nature of the conversion technology. In this regard, desirable traits for biomass crops include:

- high yield,
- low input requirements,
- cheap, easy and quick to establish, preferably from seed instead of vegetative material,
- perennial, with good longevity,
- native and not invasive,

- good wildlife habitat,
- easy and cheap to harvest, dry, process and store,
- low in Cl, K and Si, and
- low in ash.

In a study that led to publication of a document by the US DOE and Department of Agriculture, commonly known as the "billion-ton report" (Perlack *et al.*, 2005), the aim was to determine if a billion tons of biomass could be produced annually in the United States. The report concluded that 1.36 billion tons of biomass could be produced per year, including 368 million tons of forest materials, and 998 million tons of agricultural materials. The agricultural materials included 428 million tons of annual crop residues (mainly corn stover, but also wheat straw and soybean residue), 377 million tons from perennial crops such as switchgrass, 87 million tons of grain, and 106 million tons of animal manure and other materials. Surprisingly, the report did not consider the potential contribution of cover crops. While corn and wheat are clearly grasses that could contribute substantially to the biomass resources needed to produce energy through use of their residues following harvest of grain, the main focus of this chapter is on crops that can be grown specifically for biomass production.

Because switchgrass has most of the desirable traits listed above, in 1992 it was chosen by the DOE as the model herbaceous energy crop for further development in the United States, and much of the ensuing discussion in this chapter focuses on this species. However, other important perennial candidates are *Miscanthus* × *giganteus*, which has been extensively developed for energy production in Europe and more recently evaluated in the United States, and sugar cane or a related hybrid known as energy cane. Finally, there is also considerable opportunity to use annuals in rotation with traditional crops: in particular, high-yielding sorghums can be grown in rotation with winter wheat, and winter annuals like rye and triticale can be grown in rotation with crops like corn, soybean and cotton. Not surprisingly, high-yielding C4 grasses are likely to play the biggest role in this developing industry. On the other hand, legumes have received relatively little research attention, probably due mainly to their failure to provide yields above the generally recognized break-even levels of 3.5 to 4.5 tons per acre. Use of polycultures, or species mixtures that resemble rangelands, have also been suggested for energy production (Tilman *et al.*, 2006). However, research so far has failed to demonstrate that this approach can achieve the yields required for growers to make a profit.

As is the case for forage that will be fed to livestock, the composition of biomass feedstocks for production of energy is important, and needs to be optimized for the conversion technology in question. Major constituents in herbaceous biomass include ash, cellulose, hemicellulose, lignin, and moisture. Herbaceous biomass typically contains 3 to 6% ash, 30 to 34% cellulose, 24 to 27% hemicellulose, 16 to 19% Klasson lignin, and about 8,000 Btu of energy per pound on a dry basis. Variation in these major components is remarkably low among species. In contrast, woody biomass such as that from hybrid poplar, is generally lower in ash (1–2%) and hemicellulose (16–19%) but higher in cellulose (40–43%), lignin (22–25%), energy (~8,400 Btu/lb), and moisture

(40–45%) than herbaceous crops. Both herbaceous crops and wood generally contain low levels of N and S, resulting in low emission of oxides of N and S, which can have negative impacts on human and environmental health.

Switchgrass

Switchgrass has been widely evaluated for biomass production in the United States, and several comprehensive reviews on this work have been published (McLaughlin and Kszos, 2005; Parrish and Fike, 2005; Parrish *et al.*, 2008). The species can be divided into two basic morphologic forms: tall, lowland types like 'Alamo' and 'Kanlow,' that are adapted mainly to southern regions, and shorter upland types like 'Cave-in-Rock,' 'Blackwell' and others, that are adapted to colder northern regions. Lowland types typically provide slightly higher yields (6–8 tons/acre/yr) than upland types (4–6 tons/acre/yr). Switchgrass is established from seed that is small, but varies considerably in size among cultivars. Recommended seeding rates are usually 5 to 10 lb seed/acre. When seeding switchgrass, great care is needed to avoid deep placement, to ensure good compaction of soil following sowing, and to implement effective weed control. It takes 2 to 3 years to reach full yield.

Following establishment, switchgrass is typically harvested once per year for production of biomass to produce energy. Harvesting after the aboveground biomass has senesced can improve persistence, facilitate harvest operations, conserve N, and improve feedstock quality for certain conversion technologies. However, anecdotal information from Alabama suggests that harvesting in late August or early September in the southeast results in the highest yields, and a small amount of regrowth before winter reduces establishment of winter weeds with less damage from spring frosts and provision of an attractive habitat for wildlife over winter. Fertilizer requirements should be no more than 50 lb N/acre/yr, with P and K applied according to soil-test results. Switchgrass has an enormous root system, and if established on land that was previously in annual row crops it will usually sequester a considerable amount of carbon in the soil. The crop can be harvested with conventional forage-harvesting equipment. General procedures for harvesting are outlined in the next section.

Miscanthus

Miscanthus × *giganteus* is a rhizomatous perennial that has provided biomass yields approximately double those recorded for switchgrass (Heaton *et al.*, 2004). This suggests considerably higher potential profitability for miscanthus than for switchgrass. However, miscanthus is a sterile hybrid that needs to be planted with vegetative material, such as rhizomes or plantlets, generated from tissue culture. Consequently, establishment costs will likely be higher, and ramp-up of acreage slower than for switchgrass. The crop is more cold tolerant than is switchgrass, also requiring only low levels of fertilization while providing similar soil and environmental benefits. It is already in commercial production as a feedstock for electric power plants in Europe, and is presently under evaluation and commercial development in the United States. Miscanthus is typically harvested once per year in late winter with currently available equipment.

Sugar Cane and Energy Cane

Sugar cane (*Saccharum officinarum*) is the feedstock of the renowned ethanol industry in Brazil. Although it is typically recognized as a tropical and subtropical crop, and is grown in only very small portions of south Texas, Louisiana and Florida, cold-tolerant varieties could be grown across a large region of the southeast. In addition, *Saccharum* hybrids known as energy cane are being developed with greater dry-matter yields and lower sucrose contents. Both sugar cane and energy cane offer opportunities to produce ethanol from the sucrose contained in the stems, as well as heat, electrical power or cellulosic biofuels from the bagasse that remains following extraction of the juice. As for miscanthus, dry-matter yields are typically about double those provided by switchgrass. Due to sterility, vegetative propagation is necessary, by means of stem material. Not a true perennial, it requires replanting approximately every 5 years. Sugar cane planting and harvesting equipment is available commercially, but will involve a major capital outlay if crop acreage is expanded substantially for production of energy.

Sorghum

Sweet sorghum offers opportunities similar to those provided by sugar cane: to produce ethanol from the juice, as well as other forms of energy from the bagasse. Other high-yielding sorghums can be used simply as cellulosic biomass crops. Because sorghum is an annual, it can be grown a lot further north than is sugarcane. The greatest potential for sorghum may lie in crop rotations with winter wheat, which was planted on 44 million acres in the United States in 2007. Yields of the best sorghum varieties are also double those recorded for switchgrass. However, due to thicker stems, it may be more difficult to dry before baling or field-chopping prior to storage.

Others

Winter cover crops, such as triticale and rye, offer considerable opportunity for biomass production in rotation with traditional summer row crops. Although yields of these crops on their own may be insufficient to be profitable, integration into crop rotations could facilitate economic viability. Legumes such as alfalfa may also offer potential as sources of energy, particularly in light of sharply increasing prices of N fertilizer. For example, alfalfa leaves and stems might be separated and the leaves used for animal feed while the stems are processed for energy. Legumes are typically better than grasses for combustion because they have lower levels of Si and an associated higher ash-fusion temperature, which indicates that they are less prone to slagging in boilers and gasifiers.

Logistics: Harvesting, Handling, Storage and Transport

Logistical procedures outlined in this section apply directly to switchgrass, but have similar implications for other crops such as miscanthus and sorghum. Green switchgrass is best cut with a mower-conditioner to ensure rapid drying. Once mown, raking switchgrass into windrows can accelerate drying, but in fields with high yields, this can create difficulty for subsequent chopping or baling operations: windrows may be too large for proper handling with existing hay-making equipment that is designed for lower yields, and in such cases it might be best to simply let the material dry in the mown swath instead of raking, even if drying takes longer. The biomass may be baled with a big-round or big-square baler. As an alternative to baling, mown switchgrass can be directly chopped in the field with either pull-behind or self-propelled silage choppers with pick-up heads attached. Ideally, the objective is to achieve a particle size of about half an inch. Chopping might be slower than round baling in the field, but chopped material can be loaded and unloaded in less time than it takes to load round bales, and in-field chopping eliminates the need for tub grinding prior to feeding the material into a processing plant.

Principles related to storing bales of biomass for production of energy are the same as for storing bales of hay: moisture causes damage and loss of dry matter. Uniformly dry material needs to be put into storage to reduce these risks and the likelihood of fire. It is best to store material under a roof or with a perforated tarp that limits condensation of moisture on the underside of the cover, particularly for large square bales. If this is not possible, bales can be stored outside, preferably on well-drained gravel to prevent contact with soil, and well spaced to allow adequate air movement among bales for drying following rain. Chopped switchgrass is also best preserved if under cover, but the material will stay remarkably well preserved if stored in a pile that is exposed to the weather. If such piles are compressed (by riding on them with a tractor) and care is taken to ensure the sides of the pile are smooth and relatively steep, the surface particles can form a thatch that sheds moisture. Cotton-module builders represent another handling option currently being considered for chopped feedstock. Chopped biomass can also be pelletized or cubed, but the spongy nature of grasses compared to material like alfalfa can make them more difficult to process, depending on equipment. In such cases, adding a "binder" might be effective.

The efficient transportation of biomass will depend on the hauling distance and the local road regulations. For longer-distance hauling, high-density 3×4×8 bales will provide the greatest load. For example using a 53-ft single-drop deck trailer, fifty bales can be transported. Using normal-density switchgrass bales, this results in a 22- to 24-ton load. Bulk density of switchgrass chopped to a particle size of half an inch is 8 to 9 lb/ft^3. This results in a load of 12 to 13.5 tons on a 42-ft walking floor trailer. Some newer forage harvesters are successfully achieving finer chops from the field, resulting in loads of up to 20 tons.

Cellulosic Bioenergy Systems

Wide adoption of biomass to produce energy will depend largely on developing economically competitive supply and conversion systems. Cellulosic energy crops will need to compete with traditional crops for land on farms and with other forms of biomass that can be used for the desired conversion process, such as woody biomass and crop residues like corn stover and wheat straw. Another economic hurdle for some perennial energy crops can be relatively low biomass yields in the seeding and second years. On the product end, cellulosic biofuel systems need to be competitive with other biofuels, such as ethanol from corn, and with competing fossil-fuel products including gasoline, diesel, heating oil, propane, natural gas and coal.

Because many traditional crops enjoy government price-support programs, it may be difficult for energy crops to compete for farmland without such incentives. One way to mitigate this disadvantage would be to provide bridging payments in the first two years following seeding. Alternatively, Conservation Reserve Program (CRP) land could be used to grow and harvest biomass crops for energy without growers forfeiting CRP payments, but this latter option will require cultural-management strategies that are compatible with concerns from the environmental and wildlife advocacy communities. Recently approved legislation that should facilitate use of biomass for energy in the United States is the Energy Independence and Security Act of 2007, which mandates at least 44% of alternative fuels be produced from cellulosic feedstocks by 2022. In addition, carbon credit markets are developing, and because perennial energy crops are effective in sequestering carbon, these should also facilitate commercial production.

At current input costs, the delivered price of switchgrass is between \$50 and \$60 per dry ton over a fairly wide range of conditions. If a \$10/ton profit for the grower is added, this would amount to an average delivered price to the processing plant of \$60–70/ton. Areas with low land rents will likely be in the lower end of this range and areas with higher land rents could be well above it. Successful projects will need to evolve in areas where energy crops can compete with alternative feedstocks. In some areas, woody biomass and crop residues are currently available at considerably lower prices than this.

Assuming an energy content of 16 million Btu/dry ton of switchgrass, a delivered price of \$65/ton amounts to a cost of \$4.06/million Btu. In comparison, oil (which contains 5.8 million Btu/barrel) at a price of \$90/barrel amounts to an energy cost of \$15.5/million Btu. Therefore, on a cost/million Btu basis, switchgrass is extremely competitive with oil as a raw material, and this could partially explain the rapidly increasing interest in cellulosic biofuels among oil companies. However, technology that can convert biomass to liquid fuel as efficiently as for oil has still not been developed. The current cost of natural gas is between \$5 and \$6/million Btu with higher prices in the peak winter heating period of January through March, and that of coal is mostly between \$2 and \$3/million Btu. The low price of coal explains why utilities are reluctant to co-fire switchgrass with it without significant government incentives or premium prices for the "green power" produced.

As energy cropping matures as an agricultural enterprise, new machinery for harvesting and processing biomass will likely be developed; but in the near term, it is likely that there would be an advantage to using existing forage-handling equipment. Bransby *et al.* (2005) developed an interactive budget model to evaluate four systems that could be used immediately in the southeastern United States:

- traditional mowing and round baling, then hauling bales to the plant where they are ground prior to processing,
- field chopping following mowing, and transporting chopped material to the processing plant in a walking floor trailer,
- field chopping and creating a compacted module with a cotton module builder, thereafter transporting the modules to the processing plant in a cotton module truck, and
- field chopping followed by pelletizing and transporting pellets to the plant.

The model was then used to examine the effect of switchgrass yield, transport distance, truck capacity, and stand life on delivered cost of biomass to the plant using each of the four systems.

The results indicated that field chopping and hauling chopped material in a walking-floor trailer or after it had been compacted with a cotton-module builder resulted in lower delivered cost to a large bioenergy conversion facility than round baling or pelletizing. The high cost of baling was related to more individual operations needed in the baling option, whereas the high cost of the pelletizing system resulted from producing the pellets. As suggested above, chopped switchgrass can be stored in piles that tend to thatch and shed water, resulting in relatively low losses. Switchgrass yield and hauling distance to the plant had greater impacts on delivered cost than stand life and truck capacity. Delivered cost decreased as yield increased, but this effect was not linear, and the response was relatively small above 8 tons/acre. In contrast, delivered cost increased linearly with distance from the processing plant. Delivered cost decreased as truck capacity and stand life increased, but effects were relatively small above a truck capacity of 20 tons and a stand life of 10 years. Breakeven yield was about 4.5 tons/acre.

Development of a viable commercial enterprise that uses biomass as a feedstock to produce energy requires consideration of a wide range of issues. These include the amount of biomass and land area needed, average hauling distance and business structure. The challenges related to developing a feedstock supply system are often underestimated, so a specific example of how these issues might be addressed should be useful. The capacity of most corn-ethanol plants ranges from 50 to 100 million gal/yr. If a 50-million-gal/yr capacity and an efficiency of 80 gal/ton are assumed for a cellulosic processing facility, the plant would need 625,000 tons of biomass per year. For 350 days of operation each year, this would amount to 1,786 tons (or eighty-nine truck loads of 20 tons each) per day. At a crop yield of 5 tons/acre, 125,000 acres would be needed, and if a 10-day supply of biomass is needed on site at the conversion plant, storage space is required for 17,860 tons. Assuming the plant is in the center of a circular production area, and assuming the average hauling distance is 20% farther than a direct line from the grower to the plant (to account for curvature of roads) average hauling distance would be 29.9, 21.2, and 15.0 miles if 5, 10, or 20% of the land surrounding the plant was established to the biomass crop.

Finally, the issue of energy balance (energy output as a proportion of energy inputs) is often raised in relation to production of biofuels. For corn to ethanol, this statistic is about 1.3 and, surprisingly, for gasoline produced from oil it is negative: 0.81. In contrast, a recent study from the Great Plains (Schmer *et al.*, 2008) indicated that, for ethanol produced from switchgrass, this figure is 5.4, or alternatively, that 440% more energy was contained in the ethanol produced, than was used in growing the switchgrass and converting it to liquid fuel. Because the emerging bioenergy industry is at a very early stage, it is likely that this figure can be improved substantially by improving crop yields and conversion technology.

The Future

Development of the bioenergy industry offers multiple benefits, including reduced risk of global climate change through reduced production of greenhouse gases, increased national security, and improved national and local economies. Grasses in particular, but possibly legumes as well, will play a vital role as feedstocks for this emerging industry. Production of heat and electricity from biomass is already commercial on a relatively small scale. Commercial cellulosic biofuel plants can be expected to be in production within the next 3 to 5 years, and initial expansion of the industry will begin in 5 to 10 years. On a per-unit-energy basis, the cost of biomass from cellulosic energy crops is higher than for wood and coal, but only 26% of that for crude oil at $90/barrel. Therefore, wood is likely to be the most favored feedstocks for the first plants. Commercialization of cellulosic energy crops for production of energy will require development and optimization of not only agronomic practices, but also harvesting, storage, transport and conversion systems. Procedures and equipment used for these purposes in commercial forage production can be adapted for this purpose, including baling, field-chopping and pelletizing. Due to economic growth in countries like China and India, the price of oil will probably continue to rise and this will ultimately lead to competition between food and energy crops for limited land resources: an issue that will need to be anticipated well in advance, and properly managed to avoid a crisis.

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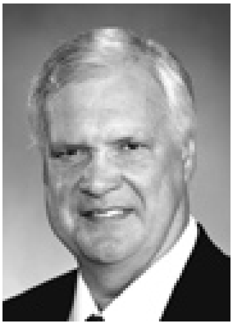

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With over 30 years of experience in agronomic research, he has spent 20 years specializing in the production and processing of energy crops, a subject in which he has established an international reputation. With over 300 technical publications to his credit, he serves on the editorial boards of two international bioenergy journals and consults for several private bioenergy companies.

In September of 2006, Dr. Bransby briefed Governor Riley of Alabama and President Bush on the status of the emerging biofuels industry. In February 2007, he was invited to the White House to advise President Bush, Secretary of Energy Samuel Bodman and senior White House officials on the feasibility of large-scale cellulosic biofuel production in the United States over the next 10 years.

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Enhancing Productivity of Biofeedstocks

Panel Discussion and Q&A

Moderator: F. William Ravlin
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Columbus, OH

Panelists:

Frederick C. Michel, Jr.
The Ohio State University
Columbus, OH

Dwayne Siekman
Ohio Corn Growers Association
Columbus, OH

Tom L. Richard
The Pennsylvania State University
University Park, PA

Frederick Michel: With regard to development of an ideal conversion technology, we need to keep in mind that cellulose, hemicellulose and lignin are the three primary feedstocks we are working with and there are multiple processes we can apply to them and products we could make from them, whether it's gasoline, butanol, ethanol or methanol, each with particular strengths and weaknesses. Lignin fractions have potential uses as feedstocks for energy and chemicals and as sources of carbon for reintroduction to the soil.

We also heard about the importance of the logistics of harvesting and storage, and soil management and optimizing nutrient use in the production of feedstock crops.

The ideal feedstock crop is likely to be region-specific.

One thing that I didn't hear much about, but may be important, is modification of corn and soybean to improve their suitability as energy crops, by increasing yields of ligno-cellulose in stover and straw, for example, in addition to increasing seed yield. And the best thing I heard is that biomass is now cheaper than oil.

Dwayne Siekman: I applaud the speakers for their coverage of diversified feedstocks. It may shock you, but the Ohio Corn Growers Association does support cellulosic ethanol. We supported the Farm Bill in terms of the cellulosic ethanol industry receiving a higher blender's credit. We see the need and we look forward to working together with the cellulosic industry. With that, I do want to caution everyone not to overstate corn ethanol. When I hear "every kernel of corn converted to ethanol will supply 20% of the fuel" or " to make 35 billion gallons we need 69 million acres," we need to keep it within the context of the Energy Bill. David Bransby pointed out a 15-billion-gallon cap and I think that's where we need to focus on the corn side. The media's treatment of food versus fuel has led to much uncertainty in Washington, DC. Governor Perry of Texas is already calling for waiver of the renewable fuel standard, whereas the renewable fuel standard is very important to the cellulosic industry. A couple of weeks ago a farmer told me that he is not obligated to plant corn or soybean or wheat. Farmers are going to plant the most profitable crop. So, land use really needs to be taken into consideration; food versus fuel will be there regardless, whether it's corn or a dedicated energy crop.

Tom Richard: We've heard a lot about win-win solutions to this energy challenge. We also need to think about who the losers are in the different systems and be proactive about prepositioning what can happen for them. There are issues in this regards in certain regions in the country and the comments on the Texas-livestock industry are right on the money. It's something for this industry to be proactive for and for the university community to be thoughtful about as well to be focusing on. There is a huge opportunity in terms of co-production of food from energy-crop systems and the conversion processes. That's a lead in to the main thing I want to comment on. We heard a lot about dedicated energy crops, whether they be perennial grasses or sorghum and other grains. We need to think about the multifunctionality of agriculture, which is what we've had in this country for a long time. To some extent, we've strayed from that in the last few decades, but, at least in my view and many of the folks I talk with, biofuels provide an opportunity to regain some of that multifunctionality. That means not just food *and* fuel—although that's got to be a starting point—but also other benefits that we expect from agriculture, including the ecosystem services that have been discussed. Along those lines, I want to elaborate on some of the comments that David Bransby made about aspects that we don't often focus on. If you look at the landscape of this country, particularly the rain-fed regions, the dominant species of the natural ecosystem is generally forest. The prairies are there in the Midwest, but much of the east, where there's a lot of the rain, is forested land. We don't often focus on that, but it represents a huge opportunity. That's one of the low-hanging fruit in this industry. We are doing work on that at Penn State. We happen to be in the hard-wood-rich region, but there is a lot of that material in many parts of the country. The numbers are impressive. The billion-ton study provided a very conservative analysis of the wood resource. The potential losers there are the timber industry and the pulp and paper industry, which are nervous about someone else going after their resources and potentially driving up their feedstock costs. They have allies in the US Forest Service, which is very conservative about making estimates about what the forest can provide, and basically have focused on byproduct wood residues and waste. There's an opportunity to get proactive about that and to think more carefully about what can happen there.

Municipal waste is another large piece. On average, each of us produces about a ton of solid waste per year, mostly organic matter. We recycle some of it but not all. We need to think carefully about the best use for that material. It has the advantage of being already collected. It actually has a negative value because somebody is paying to dispose of it, oftentimes in an environmentally suspect fashion; significant opportunities are worthy of exploration.

Possibly least appreciated is the opportunity to actually intensify our existing agricultural systems to provide energy crops along with food crops on the same area of land. We see hints of that, such as the discussion of co-production of corn grain and stover for energy. We've heard a little about cover crops, which represent another opportunity. If you look at the 400 million acres of crop land that we have in this country and consider a modest ton per acre of cover crops growing in winter when you don't have anything else there, helping to conserve nutrients and soil, that's almost halfway to a billion tons. You know you can run the numbers lots of different ways, but there are some big opportunities out there that we need to recognize.

I'll finish with a follow-up to David Bransby's comment about wet storage and dry storage. This happens to be my technical area, and I often have to defend wet storage, although less often than 5 or 10 years ago. Wet storage is a bit more expensive. If you look at the numbers it might be $5 to $10 a ton. We think there are some positives in terms of reduced downstream processing, at least for some conversion processes. But when you look at $250 in a ton of biomass as its energy value, we are really talking about the margins here. I worked with a company in Iowa that went bankrupt because they lost 100,000 tons of corn stover that they were trying to store dry. When you store stuff dry, it can burn. So, there are safety issues and, equally important, some security and risk-aversion opportunities that we should think about, not just in storage, but in the entire value chain because farmers are risk-adverse. Although the playing field is leveled in some ways with the cellulosic subsidies in the new Farm Bill, there are other risks that aren't protected in perennial-grass and energy-crop production. We need to be thoughtful about those and make sure that we have the right safety nets in place.

Siekman: That is one point I wanted to highlight. Traditional farm programs in the new age of bioenergy or biomass are going to have to adjust—whether it's the sugar policy, corn policy, soybean policy, *etc*.—to provide that safety net too. Absolutely.

William Ravlin: Very good. Thank you very much. Very thoughtful comments in a short period of time. We will open it up to some general questions.

Audience Member: Has there been much response to those articles in *Science*? David, you didn't talk about that.

David Bransby: There have been some responses. I don't want to get too personal, but there were responses right out of the University of Minnesota, the origin of a couple of those papers. The colleagues responded negatively to the articles. And there have been letters to newspapers and so on, but that has very little impact because, once an article is out there, the damage is done. The key response to this is "lets just get to it—get busy and do it—make it cheaper than oil and sustainable," and then we will prove them wrong."

Nancy Hodur (North Dakota State University): I have a question about a chicken-and-egg problem in converting to cellulosic and dedicated energy crops. A farmer will say, "If you buy this, I'll grow it." The conversion people will say, "If you grow this, I'll buy it." I think that such non-technical issues will be barriers to next-generation cellulosic ethanol production. Any comments on that chicken-and-egg problem?

Bill McCutchen: When I got to Texas A&M about 2 years ago, the first thing we did was an analysis, looking at the strengths, weaknesses, opportunities and threats to developing our program, and the one thing that we may have overlooked to this point is the logistics, the circle of economic feasibility. Unless technology changes—for example, rendering to a more-flowable form—we have a 50- to 60-mile radius for harvesting and transporting biomass to the conversion facility. We are working with a couple of co-op groups, one of them being the sugar-cane industry who work directly with producers. They know where they are planting the sugar cane and they have two different harvest fronts. They also grow cotton, soybean, corn in rotation. Sugar cane will grow for 5 to 8 years in the same ground and then they move it. But your point is exactly right. The logistics of moving all that biomass from point A to point B is a significant problem that we have to address, and we are working on it.

Bransby: I've had the privilege of working with a company that is going commercial now, and so I am close to the way they are thinking, which influenced a lot of what I said today. It's a reason why I push hard that this technology needs to be flexible with respect to feedstock. If it is flexible, it will use feedstocks that are already available—such as residues and municipal solid waste, because they are cheap. In line with the chicken-and-egg problem you raise, industry people are going to say, "Where are the feedstocks now?" The industry is chaotic right now. So much is going on, it's impossible to keep track of everything because you don't know what you don't know. We think we are ahead of the game. We are ahead of the conversion technologies. But I'm not certain about that. Somebody might pop out with a commercial technology within 3 months and then we're behind. I work a lot with Vinod Khosla these days and one of his favorite sayings is, "All predictions are wrong." We all are going to be wrong. If you want to predict the future, invent it.

Stephen Long: I've been surprised over the years how often farmers actually are ahead of us. When we started working with miscanthus in Illinois, where it was very out of the ordinary, a farmer wanted some to grow and we said, "Fine, but there's absolutely no market for it." And he said, "Well, anyway, I want to grow some." So he grew about 2 acres. He sold it last year for about a $250,000 dollar to a company that is setting up miscanthus propagation. We saw similar models in Europe of farmers who were willing to take those risks. Actually, if you can produce a significant amount of biomass per acre there are smaller markets out there. For example, the horse bedding industry: fall-harvested switchgrass and miscanthus are apparently valuable to them. They fetch a premium price, much higher than straw, for example. I agree with David that the big opportunities will come as these cellulosic plants are placed.

Richard: We do need to look carefully at the arrangements of the refineries with the producers because biomass is not as easy to move long distances as grains are. It's a captured relationship that needs to be explicitly worked out to mutual benefit. Our grain-marketing structure is very flexible. We can move those materials around the globe. They are annual crops so farmers can adjust to the markets, not immediately but at least in a feasible time frame. And when you are asking a producer or landowner to make a multi-year, perhaps decade-long commitment to a single facility that is within a commercial hauling distance, there's got to be a strong level of trust there, reinforced by different kinds of contractual arrangements from what we have right now in most of agriculture. There are exceptions. The sugar-cane industry is one area to look at, also the pulp and paper and wood industries, where those kinds of long-term relationships have been developed.

Mitch Minarick (University of Illinois): David, you alluded to some of the properties of an ideal conversion technique and made it seem like it's a thermochemical process. Could you elaborate on whether that is gasification or pyrolysis and also some of the techniques to produce gasoline. Secondly, do any panelists disagree that a thermochemical process would be the ideal way to convert a cellulosic feedstock? In other words, does anyone think that biological would be the better way to reach viability in this market?

Bransby: It's neither gasification nor pyrolysis. It's catalytic cracking involving particle-size reduction of the raw material down to probably between 1 and 10 microns—a fine powder—then using catalysts to break it down further into molecules and catalysts re-synthesize these into the alkanes or gasoline or diesel. You do need elevated temperature, but nowhere near what you have in gasification.

McCutchen: Based on what we've seen, it may be a combination of both and composition of the feedstock is going to provide byproduct opportunities beyond fuels. For example, one of the companies we are working with actually wants more lignin, so you can imagine what they might be using that for.

Long: As a plant biologist, I'm not an expert on either route, but I certainly wouldn't take the risk at this stage of ruling out either one. David mentioned grinding down to a fine powder, which means you have to put in a significant amount of work and if you are going to reduce to alkanes your catalytic process has to remove a significant amount of oxygen. There's got to be an energy cost there. On the biological route, we know, for example, that the cow's rumen or the termite gut are efficient at releasing the sugars from cellulose and hemicellulose, but are not so good with lignin. But we do know that there are biological solutions out there that we haven't managed to harvest. A bug in a termite's gut can be sequenced now in a couple of hours, so biology is changing rapidly. It's dangerous, to rule out the biology option at this stage.

David Koetje (Calvin College): Municipal waste streams have been mentioned. On the other hand, these are far more complex biologically and chemically than crop biofeedstocks. I wonder if you could address that and the question of whether landfills, as huge storage basins of municipal waste, could be tapped as sources of energy and/or other bioproducts.

Richard: Landfills are a resource. It's good that we have them and we will mine them for lots of different things. Energy is only one. Materials are there as well. And there's some rich ore. But it's going to be a while before we actually tackle that. Opening them will be opening a big can of worms. No pun intended there. The current organic waste stream needs to be looked at carefully. Yes, it's diverse, but of the first-generation commercial facilities that are going to be built in this country, several are targeting low-hanging fruit in terms of consistent supply, large volume, as a concentrated low-cost resource. We are going to learn a lot more about how they will work on a practical and commercial scale in just the next few years.

Michel: There are two approaches to looking at that. Here in Columbus we have a landfill that is producing gas. Some say that the efficiency is low at 20 to 25%. Some say that that 70 to 80% can be collected. The other approach is to separate feedstocks either after collection or, better, at the source. For example, waste paper is an ideal feedstock for ethanol production; you can get higher yields than from most of the feedstocks we've been talking about. Waste paper does have value in the market when separated. Different grades of paper, ranging from \$100 to \$200 per ton, can be purchased as a commodity. So, these are opportunities. One of the difficulties is being in agriculture without experience in dealing with waste collectors. New types of government structures are involved in the waste-collection industry and landfills. How do you broach that and find a champion in that industry willing to work with you to develop new, possibly risky, technologies that will lead to production of energy and/or other bioproducts?

Bransby: Getting back to the plant that is being built. In Alabama they are starting to develop a feedstock supply. It's in a small town that couldn't possibly afford what has just been described as separation. Recycling costs money, but if they are getting paid for that feedstock that can pay for the whole system, and in fact that's exactly what we are looking at. This small town already recycles paper and plastics. Wet material is more difficult, and the glass and metals have to go to the landfill. There is definitely an opportunity here. But coming back to the need for feedstock flexibility—you can operate with relatively small amounts.

Getting back to wet storage—the technology that I'm talking about needs no more than 20% moisture. So, I did see both storage and conversion technology—sorry, I am totally influenced by this technology because I think it is so good.

Ravlin: A friendly amendment on this question here and I guess I would direct it back to Tom and Fred and anyone else. We've talked a lot about low-hanging fruit and feedstocks we can start with that are already available and just haven't been tapped into. If you were to rate the top three feedstocks available today, what would they be?

Richard: I would say our solid-waste stream, our native forests and our crop residues, each of which has different associated challenges, but they are all out there right now. We wouldn't have to ask a single landowner to do anything radically different from what they are doing today.

Michel: I would definitely say paper going to the landfill. It's a large fraction of many landfills. Also, food-processing waste. I think for anaerobic digestion it's another low-hanging fruit we can look at especially in Ohio and other states that have diverse agriculture. And I like the energy crops like miscanthus. Twenty tons per acre sounds like a lot of biomass.

Bransby: What would you do if you had a processing plant ready for operation and flexible with respect to feedstock. You're going to look for the cheapest. First, municipal solid waste is the cheapest. I've heard that clean wood chips are available in the southeast for around $30 a dry ton. So wood's got to be next. It's out there. But this doesn't reflect negatively on energy crops. I'm in that business myself. The billion-ton report assumes 55 million acres of dedicated energy crops. If we were asked to plant 1 million acres of switchgrass next year, we wouldn't have enough seed. It's just not there. So, it's going to take a bit of time to integrate. We will integrate it in time, but if we were to start now, those are the feedstocks.

Irwin Goldman (University of Wisconsin): I understand the drive towards an ideal crop model like a C4 grass, like miscanthus or even corn, but there's also a desire for diversified agricultural systems and the fact that we will have to have rotation crops. Could the panel comment on root crops that might make good energy crops and whether there is potential for that kind of cropping system for biomass?

Long: Diversification was part of our initial motivation. Farmers in the region showed interest in diversification, particularly those growing corn and soybean. Of course this was when prices were lower. Putting a crop like miscanthus or switchgrass on poorer soils has the potential to boost soil organic matter levels and diversify income stream. When you then take that crop away and plough, you see considerably higher yields from your corn or soybean. At current prices, of course, farmers on the best land are going to think twice about doing that. With respect to root feedstocks, China is using cassava to make ethanol. They banned the use of grains for making ethanol although I'm not sure that cassava circumvents the food-versus-fuel issue. Syngenta has developed what they call a tropical sugar beet. It is a true *Beta vulgaris*, but it has proved quite productive in areas of the tropics. Obviously, it doesn't flower. Although it doesn't give the sugar yield of sugar cane, it's being used in Europe for ethanol. Even in the upper Midwest, yields of sugar beet are reasonable. With the prices we are now seeing for oil, you can envisage a viable system based on sugar beet. If we can get close to 100 gallons per ton from lignocellulose, then I feel the solution is to go with the highest-yielding material to avoid the conflicts that are causing problems at the present time.

Richard: Sugar beet and fodder beet are pretty interesting for the United States. If you look at gallons per acre, they could beat corn in Pennsylvania and I suspect in Wisconsin, Ohio and Michigan as well. That's pretty easy technology—starches and sugars. So that could happen today. I do think that the question of diversity and rotations is important, and I'm not sure that below-ground options work for the winter time. Above ground, we are interested in winter barley and winter canola, both of which we can convert with grain and oil technologies available today and with cellulosic technology coming online I think it will open up a lot of other winter cover crops that are fast growing and high yielding, albeit not as high as a dedicated energy crop. Putting something on the ground in the winter will improve the soil, reduce erosion and make the land look pretty. Those are all things to be thinking about as we grow this industry.

Module IV: Policy Issues Impacting Agriculture and Bioenergy

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Food vs. Fuel

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Agricultural Biofuels: Two Ethical Issues

Paul B. Thompson
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East Lansing, MI

The science and engineering of developing biobased energy alternatives comprise known capabilities, highly plausible conjectures and problems yet to be solved. But scientists and engineers need to pay attention to the timeline implicit in this simple statement, for it suggests that we should think of biofuels in terms of a trajectory that begins in the past and arrives at some not-fully-determined point in the future. The ethics and values relevant to biofuels can be articulated through the ways in which this trajectory is represented. Backward-looking elements of the trajectory frame crucial questions about motives and intentions, while forward-looking elements frame questions about consequences and trade-offs. Statements about the past and prospects of biofuels will eventually converge in the collective imagination of the broader public. In this way, the ethics implicit in any given conceptualization of the trajectory for biofuels will play a role in forming the storyline for biofuels that helps non-specialists form opinions that will eventually play a crucial role in both marketplace and political decision making (Thompson, 2008).

It is also important to recognize that while any given statement about this trajectory can play a role in shaping the storyline that comes to dominate the thinking of the broader public, the total shape of that storyline is beyond anyone's control (Herrera, 2006; Pearce, 2007). Two ethical issues are now emerging in the storyline for biofuels. The first is the food-fuel trade-off. Rising global food prices have accompanied rising gasoline prices, and we should not be surprised that people make an association between reports about food riots in Haiti or Mexico and the thought that farmers are devoting larger and larger portions of their output to ethanol production. The second ethical issue is not currently in the headlines, but is very much on the minds of people who consider themselves to be active participants in pursuing a more sustainable future for our children. It concerns the environmental implications of the push toward biofuels.

The ethics of emerging technology, from stem cells to nuclear-power plants, is almost always situated within an attempt to make adjustments between norms and traditions that were helpful in negotiating a situation in the recent past, on the one hand, and an uncertain future that challenges established patterns of thinking and speaking, on the other. Philosophers and social scientists who work on technology generally end with a call for more participatory conversation and discourse because it is through arguing out our differences on an uncertain future that the discovery and development of more adequate ethical responses happens. I will not offer solutions or prescriptions to these ethical issues here. Instead I will outline some alternative ways of conceptualizing and articulating the ethical dimensions of these two emerging issues.

Food vs. Fuel

Only a few months ago, political leadership at the state and federal levels in the United States was viewing biofuels primarily as a jobs program, and secondarily as a homeland-security issue. In the wake of a 6% rise in domestic food prices, well-publicized food riots and bleak projections for poor people in dozens of nations, the rhetoric has shifted. Michigan Governor Jennifer Granholm recently expressed a need to "stay away from food crops" in thinking about biofuels for the future. The ethical challenge is aptly represented by the image of wealthy Americans nonchalantly fueling gas-guzzling SUVs while hungry people in other parts of the world starve, (Brown, 2006). There is, thus, one ethical point that must be stressed at the outset: it is ethically irresponsible to promote technologies that utilize agriculture as a manufacturing system for non-food products without simultaneously and pointedly admitting that such technologies have the potential to cause severe harm to some of the world's must vulnerable people. The fact that this deprivation and harm involves food is also ethically significant above and beyond its severity. Virtually all human cultures attach some sort of special moral significance to food.

As a second point, we must recognize that "staying away from food crops" or trying to utilize plant matter not currently used for human consumption is simply not an adequate response although we currently use sizable amounts of our land base that could be used for food production for other purposes, including producing timber and fiber crops. Put bluntly, if also over simplistically, encouraging farmers to change from corn to switchgrass will also affect global food supplies. Diversions of biomass will almost certainly have impacts on soil quality that will also affect food productivity. All these impacts are tied together (Kim and Dale, 2005; Pimentel and Patzik, 2005; Hill *et al.*, 2006). A closely related point follows, though perhaps it is too obvious to need stating. Land-management decisions on whether or not to grow a food crop are not made on ethical grounds. Farmers would happily grow more food for hungry people, if growing more food is what needs to happen, but they do and will continue to base this decision based on their expected monetary returns. The ethical decisions here occur in terms of how policies and technology affect farmers' incentives. It is, thus, wholly appropriate for executive decision makers such as Governor Granholm to adjust their planning in light of the now seemingly apparent link between biofuels and hunger, even if she is mistaken in thinking that shifting away from corn ethanol is an adequate response (see also Daschle *et al.*, 2007).

But it is also important to stress that the realities of global hunger and food availability are much more complex than this initial set of ethical responses suggests. The ethical significance of hunger or food deprivation has often been analyzed as a component of human welfare. Human welfare has, in turn, often been conceptualized through measures such as infant mortality, life expectancy and GDP. These are aggregate measurements that tell us how populations fare in response to events. They prove very useful for policy evaluation because they allow a number of comparative judgments to be made. If one can develop a proxy measure for hunger, for example, then one can analyze the food vs. fuel question through an economic-modeling exercise. Various scenarios for land use are tested to ascertain their expected impact on this proxy measure. If using land for biofuels increases hunger as reflected in a given measure of human welfare, there is an ethical problem.

Yet these measures of welfare are crude. One of the simplest is to estimate calories per person based on global, regional or national harvests, but all aggregate measures invite inferences that are subject to several well known ethical problems. First, they can easily conceal relevant distributive justice issues that may exist within the population. The global calorie measure is a particularly egregious example of this problem, because the fact that there might be enough calories produced on a global or regional basis does not reveal whether some subset of the population is getting much less than they need to survive and thrive. Second, there may be other variables such as waste and spoilage that interfere in some subset of the population's ability to obtain food. Finally, even when these problems are corrected, aggregate measures may conceal a trade-off where hunger is shifted from one sub-group to another. Such trade-offs can even seem ethically justified when they involve a reduction in the total amount of hunger, but here it may seem as if the vital interests of one person are being sacrificed as a means to secure the interests of another.

The alternative way to conceptualize the ethics of hunger is to frame the issue in terms of rights. The Universal Declaration of Human Rights includes a "right to food." Although the concept of human rights is itself somewhat controversial, this language implies that no set of political or economic circumstances can be considered morally satisfactory or legitimate unless every individual has secure access to an adequate supply of food, (Pogge, 2005; Sandøe *et al.*, 2007). "Secure access" has been analyzed in terms of an entitlement that might take any of several forms. Individuals who can reliably utilize arable lands, water and adequate tools to produce food may be said to have such an entitlement. Monetary income sufficient to purchase food can also be understood as an entitlement. Both types of entitlement may be vulnerable under unusual conditions, and may require supplement in the form of institutions such as a well-established informal network of charitable relief or a state-supplemented welfare title such as the United States Department of Agriculture Food and Nutrition Service Food Stamp Program (Sen, 1981).

It is doubtful that the global food system has ever met the moral standard of adequacy implied by a right to food. At present, food entitlements in various parts of the world are vulnerable to short-term fluctuations in natural conditions, such as drought or plague, and to human-caused events such as warfare and economic forces, which, almost certainly, present far greater challenges to food entitlements. What is more, poverty leaves millions of individuals in a perennial state of insecure access to food, (Pogge, 2003). The significance of all this is that the right to food remains an aspiration, and the moral duty to achieve this aspiration takes the form of what Immanuel Kant called an "imperfect duty"—one that falls on humanity collectively, but on no person in particular. And the satisfaction of food entitlements is notoriously difficult to monitor. In response, many contemporary analysts of hunger have urged that responsibility to secure food entitlements must be met as a condition of social justice, that is, as an ethical responsibility that must be met through institutional reform, (Pogge, 2003; 2005; Sandøe *et al.*, 2007).

How do these two ways of framing the ethics of hunger pertain to harnessing agriculture for energy or manufacturing? In short, the impact is likely to be ambiguous. Any displacement of land currently used for food production can be expected to interact with a number of other forces that will contribute to a steady increase in the price of food. Because they spend a greater share of their income on food, this will disproportionately harm the poor. Despite sophisticated economic models that disaggregate the impact of different variables, the cognitive and political availability of a shift to biofuels will almost certainly result in a widespread tendency to place moral responsibility for the consequences of rising food costs squarely on the growth of biofuels (Brown, 2006; Runge and Senauer, 2007). This is exactly what we are seeing in the press today, and it is what politicians, like my state's governor, are reacting to. But here we are taking the aggregate approach and we are talking about impacts on populations.

When we focus on food entitlements, it is important to recognize that for an estimated two-thirds of the world's poor, the bulk of their food entitlement continues to be met through direct production of food, though in many cases they depend on cash crops that are not staples or are non-food agricultural commodities, such as cotton, to generate income to purchase food. These people have been getting poorer and hungrier because they must sell some portion of their production into local commodity markets in order to meet basic needs. Competition from imported agricultural goods, the production costs of which have been subsidized by developed-world governments, is arguably the greatest threat to their effective right to food, (Mazoyer and Roudart, 2004). Harnessing arable lands for fuels might reduce this competition and strengthen their right to food. It is the remaining one third whose right to food depends upon using cash or chits to purchase food, and who are unlikely to see any benefit from rising agricultural prices, that will have their food entitlement challenged, and it is these people who are currently rioting in the streets.

Here, we see that as long as we remain limited to aggregated measures such as total calories or price data, we are in a position of addressing the food needs of one group at the expense of another. This has been the reality of hunger for decades, as agricultural specialists have blithely told the public that simple technical increases in yield would "feed the world," while in reality they have been feeding some at the cost of the livelihood for other equally poor people. Responding to this trade-off is a complex business that will almost certainly involve different strategies in different places, as well as a much, much greater willingness on the part of rich countries and rich people to provide financial assistance. It will require what Jeffery Sachs (2006) calls "clinical economics" rather than one-size-fits-all prescriptions. In short, telling overly simple stories about world hunger is ethically irresponsible. I believe there are almost certainly ways to develop biofuels and other industrial products from an agricultural base that would be compatible with addressing hunger, but I am deeply concerned by the cavalier and simple-minded approach that scientists and business people who are pressing forward with these strategies take to the complexities of hunger. While the complexity of hunger leaves us in a deep dilemma with respect to media that seem to demand sound bites and happy endings, it is clear to me that any movement in the direction of non-food crops needs to be accompanied by a substantial commitment toward redressing the new round of challenges that poor people will face as a result.

Fuel vs. Nature

While the food-vs.-fuel question can be analyzed in fairly blunt terms, the fuel-vs.-nature question leaves us with a list of open-ended questions. It may be most useful to survey a few of these questions, and to state some reasons why they are likely to prove complex and difficult to resolve. The ethics of biofuels in this domain consists largely in a commitment to more democratic processes for addressing the political questions that must inevitably arise in connection with the fuel/nature tension.

It is important to begin by acknowledging the general presumption among biofuels scientists that this is an environmentally friendly activity. Like hunger, the rationale here is complex, and draws upon a number of scientific modeling approaches that are themselves highly contested. Two key claims are that deriving some portion of transportation fuels from biomass will help stabilize the release of carbon into the atmosphere, and that the use of perennial crops for fuel can eventually contribute to agro-ecosystems that provide more-sustainable habitat and ecosystem services than current crop agriculture (Kim and Dale, 2005). Both claims depend on a trajectory for biofuel that shifts from reliance on using existing food crops, especially maize, to a new generation of cellulosic-ethanol production. These claims and others like them may have led many to think that if the technical questions can be answered satisfactorily, then advocates of the environment will also be advocates of biofuels.

But the fuel-vs.-nature question is vexed because the agriculture-vs.-nature question is vexed. The first difficulty concerns the overarching philosophical challenge in environmental ethics, which is the question of when and whether we can develop philosophical rationales for nature preservation that transcend human-use values. The second difficulty, then, arises in evident cultural differences that come up in connection with the significance of agriculture and farming. Specifically Americans, more than any other people, tend to see nature and agriculture in diametrical opposition (Thompson, 2007). This tendency has put Americans at odds with the rest of the world on a series of agriculture and food-system issues, and biofuels may be next. But each of these difficulties must be taken in turn.

The tension between conservation and preservation has defined environmental philosophy for the last forty years. Some have argued that the ethics of the environment is exclusively a matter of ethical obligations that humans owe to one another. The ethics of land use, wilderness conservation, pollution or environmental degradation all depend on the value that human beings derive from their use of nature. There is still a need for explicit articulation of environmental ethics for two reasons. One is that people value nature for many different reasons, ranging from commodity production to ecosystem services to aesthetic appreciation. Gaining a full grasp of these multiple values is a daunting task. The second is that our relatively recently derived ability to put the environment in danger through pollution and anthropogenic climate change means that we must articulate collective obligations to future generations, also a daunting task, (Norton, 2006).

In opposition to this view of the environment, which is sometimes referred to as anthropocentrism, there are others who argue that animals, plants and ecosystems have an intrinsic value entirely apart from the use that human beings might make of them. As such, these ecocentrists and deep ecologists argue that we owe obligations directly to non-human entities. The specific terms of the philosophical debate between anthropocentrists and ecocentrists can become quite arcane, but the relevance here is that those holding non-anthropocentric views are inveterate opponents of logging and mining. They tend to view a change in use of land or water that involves more intensive management of range, forest, wetland or prairie ecosystems as detrimental to intrinsic values associated with wild ecosystems (Rolston, 2003). They are, thus, very likely to conclude that cellulosic ethanol production will be more problematic in ethical terms than corn ethanol based on lands that are already intensively managed. It will not be enough to return forested or conserved areas to wildlife habitat in a timely fashion after harvesting biomass, because this still appears to treat an ecosystem exclusively as a means for achieving human purposes.

Although it is clear that lands currently under cultivation or managed for intensive animal production are not the primary focus of those who advocate ecocentric views, the ethics of agricultural land use has not been given a great deal of attention by those who articulate ecocentric views. Some clearly view agricultural lands as “unnatural” or as a buffer that is valuable insofar as it protects wild areas having value in themselves (Westra, 1998); others recognize that farming methods can affect wildlife habitat and ecosystem processes and tend to see agricultural lands as quasi-natural systems having some degree of the value associated with wild systems. What is more, private lands managed as infrequently harvested woodlots or for livestock grazing may be viewed as tantamount to wild systems. Outside the United States and Canada, there is a much more widespread tendency to view even highly managed agricultural ecosystems as a form of nature worthy of aesthetic appreciation and recreational activity. Although people associating such values with farmlands might be reluctant to articulate their ethic in ecocentric terms, it is clear that farms are expected to exhibit ideals of multiple use, ecological integrity and aesthetic beauty. There is, thus, a great deal of variability in what we might call the environmental ethics of agricultural lands.

One approach to understanding the ethics of agriculture is particularly significant. “Agrarianism” refers to an overlapping set of ideas that take agriculture to be of special moral significance in forming the habits and character of a people. Throughout history, agrarian ideas have emphasized the way that climate and soils tended to reinforce food-production practices that favored certain types of social and political institutions over others. Thus 19th-century figures argued that production methods conducive to self-reliant family farms were more conducive to the virtues of citizenship and patriotism needed to support a democracy, especially when compared to production systems that depended heavily on centralized management of large-scale irrigation works. Thomas Jefferson was among those political leaders who were persuaded by agrarian ideas. The Louisiana Purchase was executed in part because Jefferson held an agrarian, rather than an industrial, vision of the American republic (Thompson, 2000; Smith, 2006).

Agrarian ideas are relevant in contemporary society primarily because they are in the process of being reformulated to emphasize a new set of overlapping themes. First, an ordinary citizen's connection to food and farming may be influential in forming habits of environmental stewardship and sustainability. Understanding one's connection to one's daily food may be a particularly effective way of connecting the often disconnected life of a city dweller or suburbanite to issues of water use, climate change and humanity's general dependence on the integrity of ecosystems. Second, a growing public interest in organic, locally produced and fairly-traded food commodities appears to be increasingly coordinated with issues that relate diet and health, on the one hand, and cultural or aesthetic food traditions, on the other. The practical implications are a rebirth of farmers' markets as well as school or community gardens and local food events, and the emergence of various direct-distribution methods that connect small and organic farmers with consumers (Thompson, 2008). Although one would sometimes be hard pressed to explain why these sometimes inconsistent ideals and practices have congealed into a growing social movement, the evidence that this is happening is now fairly strong. The emergence of this movement is a new resource for mobilizing social capital in pursuit of environmental goals. Thus, though loosely connected, new agrarian ideals represent a promising cultural trend that should be encouraged.

But what does any of this have to do with biofuels?

Indeed, that *is* the pertinent question. It is not obvious that using arable land to produce biomass for transportation fuels is contrary to any of these agrarian ideas. Indeed, it is conceivable that people could come to see their use of fuels through the lens of sustainability, providing a direct link to agrarian ideals. However, many analysts interpret all of the above themes as attaining significance as forms of resistance to the coalition of politically and economically powerful interests that currently control land use and food-system policy in the developed world. This coalition includes farm-input and grain companies, the food industry and major commodity organizations. This analysis holds that sustainability should not be understood as a set of substantive commitments to environmental or social goals, but rather as a social movement held together by the fact that food consumers, small farmers and advocates of rural community development can have influence only by resisting the power of the *status quo* coalition at every opportunity (Friedland, 2008).

The social-movement analysis of agrarian ideals involves subtlety and complexity that cannot be summarized in the present context. It is arguably the best explanation for a number of food-system controversies over the last two decades. That is, core political and market opposition to pesticides, GMOs or animal cloning would be seen as grounded in resistance to a hegemonic constellation of established interests. Because they see themselves as excluded from decision making, they feel justified in exploiting opportunities such as the alar controversy, Chernobyl, the Exxon Valdez spill, the foot and mouth outbreak in the United Kingdom, mad-cow disease and fears over genetic engineering to enroll members of the public in their social movement. What one might call the scientific merits of the case with respect to any one of these incidents are far less important than a persistent pattern of exclusion and marginalization, at least when viewed from the perspective of a social movement organized around resistance to the *status quo*.

The relevance to biofuels is now, I hope, more apparent. To the extent that shifting land use to production of biomass for fuel production is viewed as an action undertaken by established economic and political interests, it will be a natural target for the core constituency of a social movement that defines itself in terms of resistance to those interests. Because programs for cellulosic ethanol tend to involve advanced technologies including nanotechnology and genetic engineering, it is plausible to think that this core constituency will have opportunities to mobilize broader public opinion around these already controversial initiatives. All of the above adds up to an argument for seeing the shift in land use from "nature" to "biofuels" as an issue calling for democratic debate. I will recapitulate this argument, starting with the observation that the shift to biofuels is very likely to meet resistance from some of the same people and groups who have mobilized around GMOs and opposition to industrial agriculture.

The ethics of democratic decision making requires a process that produces a legitimate decision, and that the criteria for legitimacy be established through an iterative process of dissent, debate and public discussion. Sometimes well established conventions assign decision making to the private sphere. If any given landowner decides to allocate land for biomass production, this is a decision that lies largely in the private realm, subject to limited zoning and environmental regulations. But the development of biofuels has already attracted significant investment of public funding, and the potential controversy over biofuels may well involve challenges to property rights. Local ordinances to prohibit growing GM crops provide a model for this. As such, two of the elements that call for a democratic forum are in place: a potential political contest among competing interest groups, and a set of issues that fall within the public sphere.

Two other elements have been discussed previously. First, the ethical boundary between nature and agriculture is extremely murky, and there are a number of competing perspectives that are already established in public discourse, as well as in the philosophical literature. We need a robust exchange of views on how this boundary should be understood and possibly reshaped in light of new initiatives for biofuel production. Finally, the view that certain voices have been excluded from decision making contributes to the feeling that a more strategic posture on the part of resistance movements is justified. If some perspectives or interests are systematically suppressed, then decisions cannot be the test of democratic legitimacy. In conclusion, then, there is an ethical imperative to debate the fuel-vs.-nature conflict in a democratic fashion. This debate should involve both technical and philosophical considerations.

Conclusion

The ethical issues that arise in connection with proposals to develop biofuels can be represented in terms of two oppositions: food vs. fuel and nature vs. fuel. In the case of tensions with food production, the ethical imperatives for ensuring food security are clear, even if the means for doing so are not. However, a longstanding tendency to model food security in terms of food availability at the population level neglects the structural components of individual food entitlements. When these are taken into consideration, we see that shifting land use to production of biomass for fuels will strengthen the food entitlements of some, while weakening the entitlements of others. As such, the ethical imperative in connection with the food-vs.-fuel tension is to be vigilant in maintaining a focus on improving structural food security entitlements for all. This means, on the one hand, that a shift to biofuels is ethically acceptable on the condition that food entitlements are strengthened across the board. On the other hand, it would be ethically irresponsible to suggest that the food-vs.-fuel tension is a false one based solely on studies that model the problem at the aggregate level.

The fuel-vs.-nature tension is far less clear in terms of the multiple social and ethical goals being pursued under the aegis of nature preservation. Traditional agriculture can be seen as both inside and outside nature, given a host of contested ethical and cultural assumptions. Only a few of these ethical variables are currently well represented in technical models that attempt to assess the environmental sustainability of biomass production for transportation fuels. The track record of resistance to industrial agriculture and established interests suggests that biofuels are a likely target of opposition by individuals and groups who feel that their interests and values have not been included in decisions on agriculture, environment or rural development. As such, there should be a planned and publicly supported effort to stimulate an exchange of views on the fuel-vs.-nature boundary and on the public values appropriate for a democratically legitimate decision process in connection with biofuels development.

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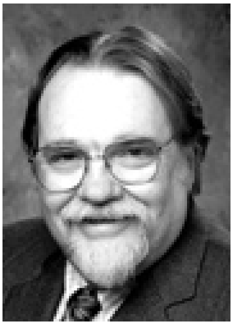

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The Social Cost and Benefits of US Biofuel Policies

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The most salient set of recent criticisms of biofuels relate to their impact on food prices and the environment. Rapidly escalating food prices have stressed many developing countries and poor households while recent studies argue that indirect land-use changes due to biofuels may enhance greenhouse-gas emissions (Runge and Senauer, 2007; Searchinger *et al.*, 2008). The potential misalignment of policy effects and stated objectives means it is important to understand the economic-efficiency and income-distribution effects of government biofuel policies on agricultural, biofuel and gasoline markets.

This paper summarizes the key aspects affecting the social costs and benefits of US biofuel policies. We first outline the various public-policy goals and categorize the concomitant policies adopted. We then analyze the social costs/benefits of alternative biofuel policies, determine who benefits and who loses and by how much, and how policy reforms can better achieve policy goals. We show that policies have been counterproductive in several instances and so can be much improved. We highlight the interaction effects between policies. For example, the sole cause of biofuel production in the United States historically, for the most part, was biofuel- and feedstock-production subsidies. Tax credits and mandates by themselves would have generated little if no ethanol production. Oil prices were so low that the intercept of the ethanol supply curve has been well above oil prices historically. This means tax costs were wasted and benefited no group. Tax credits, therefore, had minimal impacts on corn prices at low levels of oil prices. But at higher oil prices, tax credits then can potentially have a larger impact on corn prices.

We also determine that mandates are more efficient than tax credits for the same level of ethanol production because mandates result in higher gasoline prices and lower CO_2 emissions and miles traveled. When tax credits are used in conjunction with mandates, the effects of biofuel tax credits are reversed. By themselves, tax credits subsidize biofuel consumption, but with mandates the same tax credit subsidizes gasoline consumption. This has major implications for countries worldwide that also use both tax credits and mandates.

This paper is outlined as follows. After defining policy categories and objectives, we show how a tax credit affects the market. We assess historical data and determine that the United States ethanol policy was very uncompetitive unless substantial subsidies were forthcoming. We then explain how mandates work and compare their effects to tax credits. The key result that the effects of a tax credit are reversed when used in conjunction with mandates is then explained. After explaining how ethanol-import tariffs affect the market, we conclude with the lessons learned for future policy adjustments.

Policy Objectives and Instruments

The policy objectives are threefold:

- to reduce dependence on oil,
- to improve the environment (reduce local air pollution and mitigate global climate change), and
- to improve farm incomes, reduce tax costs of farm-subsidy programs and stimulate rural development (Rajagopal and Zilberman 2007).

Given the plethora of policy objectives, governments have implemented myriad policies. Biofuel policies generally promote biofuel production and substitution for petroleum fuels in consumption. The most important of these policies are fourfold:

- tax credits,
- mandates,
- import tariffs, and
- production subsidies for ethanol and corn.

It is difficult to determine *a priori* which of the tax credits (totaling $0.57 per gallon if we include both state and federal credits) or the mandates (several state and federal mandates exist, either explicit or *de facto* via environmental regulations) are more important. According to de Gorter and Just (2008b), over 65% of total fuel consumption is affected by tax exemptions for biofuels. Meanwhile, a recent FAO bulletin concluded that "virtually all existing laws to promote…biofuels set blending requirements, meaning the percentages of biofuels that should be mixed with conventional fuels" (Jull *et al.*, 2007). Most countries have huge import tariffs on biofuels while production subsidies for biofuels and biofuel feedstocks are very significant (Steenblik, 2007). We will, therefore, also touch upon the effects of production subsidies for biofuels and biofuel feedstocks and of biofuel import tariffs.[1]

[1]For a comprehensive documentation of all types of US ethanol policies including import tariffs and ethanol production subsidies, see Koplow (2007). A complete exposition of the welfare effects of US biofuel policy discussed in this paper is given in de Gorter and Just (2007a,b; 2008a,b,c).

How Tax Credits Affect the Corn, Ethanol and Gasoline Markets

The federal government offers a \$0.51 per gallon tax credit for the use of ethanol. State tax credits of about \$0.06 per gallon need to be added. The economic incentive of a tax credit is to have the ethanol price bid up above the gasoline price by the amount of the tax credit. Otherwise, blenders would be foregoing money represented in the tax credit. The tax credit is an ethanol-consumption subsidy, but because ethanol is a perfect substitute for gasoline and gasoline prices are assumed to be invariant to ethanol production, the incidence of the subsidy is such that ethanol producers get the full benefit. The market price of ethanol is, therefore, determined by the following equation (see de Gorter and Just 2008a for details):

$$P_E = \lambda P_G - (1-\lambda)t + t_c \tag{1}$$

where P_E is the market price of ethanol, P_G is the price of gasoline, λ is the ratio of miles per gallon of ethanol relative to gasoline and equals 0.70 when adjusted to an E100 basis, and t_c is the tax credit (higher than the fuel tax t in the United States). If the tax credit is eliminated, then the market price is equal to $\lambda P_G - (1-\lambda)t$. It is interesting to note in this situation that t is a disproportionate tax on ethanol because it is levied on a volume basis. Increasing the fuel tax reduces the market price for ethanol. Note that domestic and foreign producers of ethanol benefit alike from this tax credit.

The Link Between the Corn and Ethanol Markets

The corn price is directly linked to the ethanol price. Denote β as the gallons of ethanol produced from one bushel of corn and denote δ as the proportion of the value of corn returned to the market in the form of byproducts, then the price of corn (equal to P_{Eb}, the price of ethanol in \$/bu) is given by:

$$P_{Eb} = \left(\frac{\beta}{1-\delta}\right)(\lambda P_G - (1-\lambda)t + t_c) - c_o \tag{2}$$

where c_o is the processing cost. Estimates from Eidman (2007) indicate that β equals 2.8 and δ equals 0.31. The resulting value of $\beta/(1\text{-}\delta)$ is 4. A tax credit of \$0.51 per gallon translates into approximately a \$2.04 per bushel subsidy to corn farmers. This means that the corn price is very sensitive to a change in the price of ethanol (induced by either a change in the tax credit or world oil price). However, farmers historically have not been able to take advantage of such a large subsidy, because the intercept of the ethanol-supply curve is above the oil price. This means a significant part of the tax credit has been redundant. We call this "water" in the tax credit.

Because the intercept of the ethanol supply curve in the United States has been far above the price of oil, the resulting "water" in the tax credit generates "rectangular" deadweight costs. Rectangular deadweight costs are defined as that part of the tax cost of the tax credit that is not a transfer to domestic producers or any other domestic or foreign interest group. This exacerbates the social costs of ethanol policies compared to standard analysis.

Historical Price Relationships for Ethanol in the United States

There are several important conclusions when analyzing the historical experience of biofuel policies in the United States. First, the price premium for ethanol over gasoline has exceeded the tax credit for the past 25 years. This is shown in Fig. 1 where the actual ethanol price is higher than the price that otherwise would be if only a tax credit affected ethanol prices and consumers purchased ethanol only for its contribution to mileage. This means that because the "actual ethanol price" line in Fig. 1 is above the "ethanol price if tax credit only" line, the tax credit was dormant.[2] How can one explain the fact that the ethanol price premium was above the tax credit in these years? Mandates at local, state and federal levels always

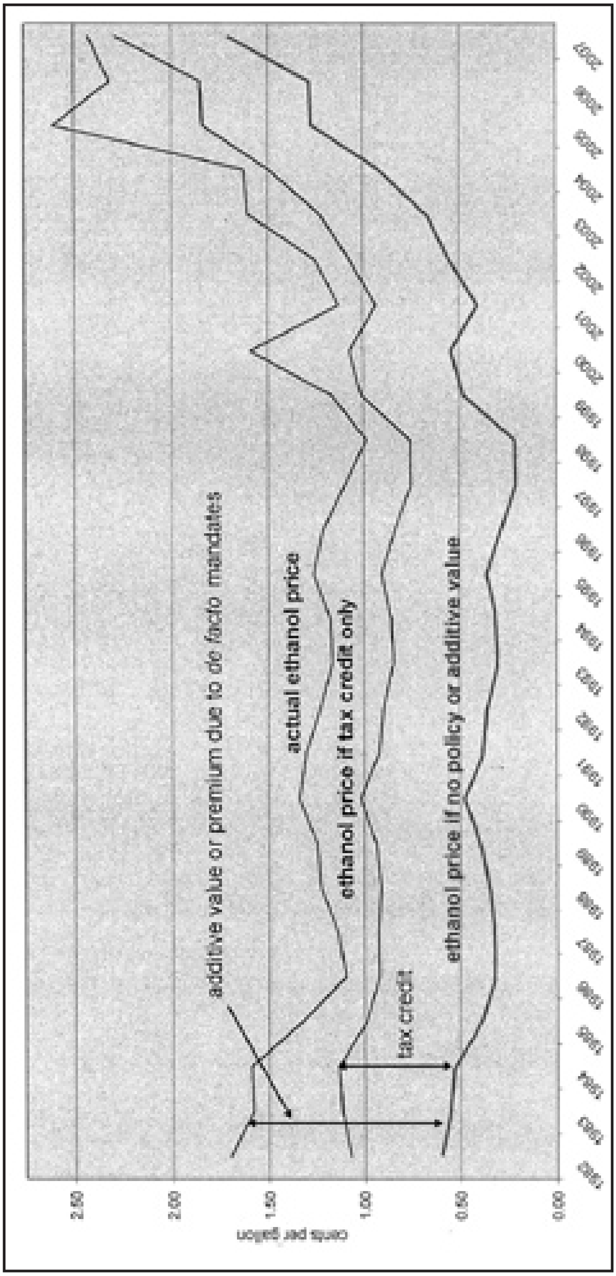

Figure 1. Ethanol prices: actual; with tax credit only; if no policy.

[2]Not exactly "dormant" because as we show below, when the ethanol premium exceeds the tax credit, a *de facto* mandate or ethanol purchased on the basis of its additive value necessarily implies that the effects of the tax credit are reversed: it subsidizes oil consumption!

existed, but were never binding. Two explanations are plausible (Tyner 2007). One is that there were *de facto* mandates due to environmental regulations (the Clean Air Act in the 1990s and the implicit ban on MTBE in this decade). Another explanation is that blenders purchased ethanol for its additive value as an octane enhancer/oxygenate. This means ethanol was purchased in fixed proportions to gasoline, implying a blend-consumption-mandate model.

Another important finding is that the actual observed corn price was always below the ethanol price premium until 2007/08 (Fig. 2). In fact, the corn price is observed to be lower than the tax credit itself in 9 of the 25 years! This is, at first glance, puzzling—how can the implied subsidy of the tax credit be greater than the corn price itself? We explained earlier that the corn price is to increase by the amount of the tax credit or ethanol price premium due to its additive value or *de facto* mandates.

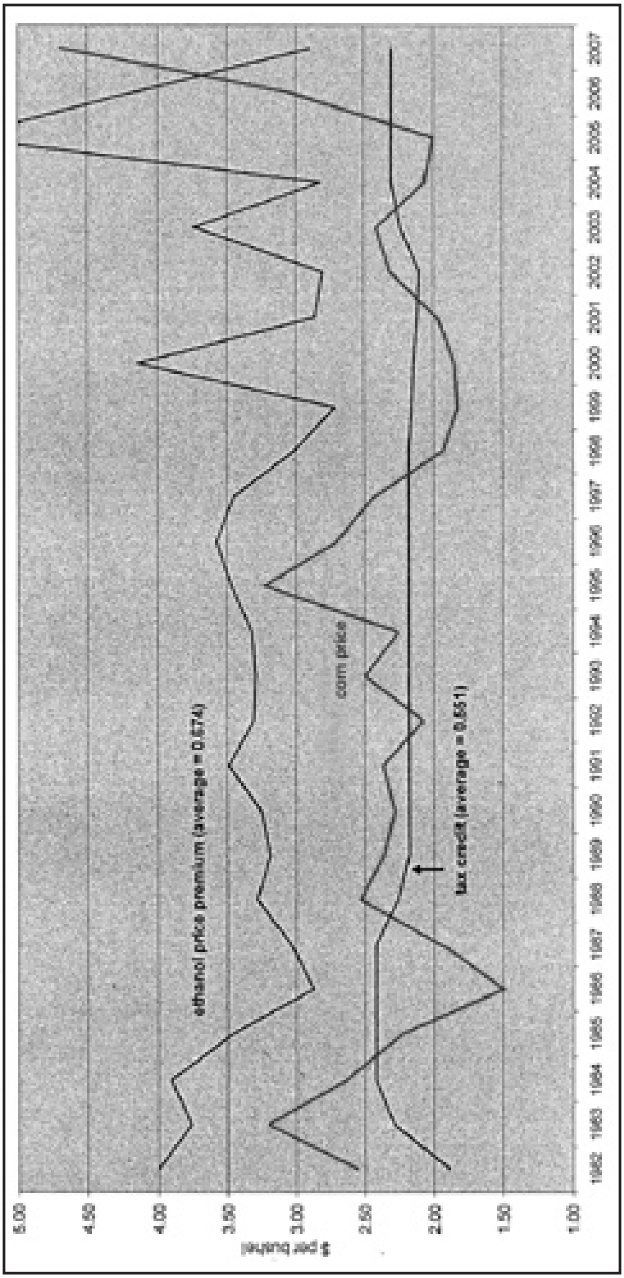

Figure 2. Ethanol price premium, corn price and tax credit in dollars per bushel.

The key to understanding this is twofold (see de

Gorter and Just 2008b for complete details). First, one has to recognize that the intercept of the ethanol-supply curve was above the gasoline price. In other words, if there were no ethanol price premium due to either its additive value or tax credits, there would be no ethanol production. Costs of production would exceed the price of gasoline. This means that part of the tax costs are what we call rectangular deadweight costs: it costs taxpayers, but nobody benefits as the gap between the gasoline price and intercept of the ethanol supply curve has to be closed first.

Second, not only was the intercept of ethanol supply below the price of gasoline, but it also was above the price of corn. The only way this can happen is with production subsidies for corn and/or ethanol. These subsidies are the only reason for ethanol production in these cases. In other words, even with the tax credit and premiums due to additive value, there would be no ethanol production unless there were production subsidies for corn and/or ethanol as well.

How the Tax Credit Affects the Taxpayer Costs of Farm Subsidies

Proponents of US ethanol policy argue that the tax credit reduces the tax costs of farm subsidy programs. There are two particularly important issues to analyze: the tax credit increases both the tax costs and economic inefficiencies of farm-subsidy programs like the loan rate program, and, *vice versa*, farm subsidies increase the tax costs of the tax credit and increase economic inefficiencies due to the tax credit. There are also increased environmental costs of increased agricultural production and adverse effects on consumers (livestock and poor developing-country consumers). Hence, one does not want to introduce biofuel policy to mitigate the effects of farm subsidy programs.

Effect of Tax Credits on Gasoline Consumption, CO_2 Emissions and Miles Traveled

So far, we have determined the effect of the tax credit on ethanol prices and production. If oil prices are assumed not to change with increased ethanol production, the ethanol production displaces gasoline consumption gallon for gallon. But if the supply curve for oil is upward sloping and so oil prices are affected by ethanol production, then the effects of the tax credit will be to increase fuel supply such that the price of gasoline falls. This means less ethanol production and more fuel consumption. Hence, the reduction in gasoline consumption is less than before with a fixed oil price. But the tax credit always increases fuel consumption (while lowering gasoline consumption). This means that the effect of the tax credit on miles traveled is always positive because consumers buy ethanol on the basis of its contribution to mileage. The impact of the tax credit on CO_2 emissions, however, is ambiguous.

The Economics of Biofuel Mandates

Understanding the effects of mandates is very important. First, many countries have mandates. Second, historical price premiums for ethanol above the tax credit in the United States, as shown in Fig. 1, suggest that a mandate existed (*de facto* due to environmental regulations or due to ethanol purchased for its additive value). Third, the new renewable fuel standard (RFS) in the recently passed Energy Independence and Security Act (EISA) mandates the use of 36 billion gallons of renewable fuel by 2022 in the United States.

Consider a biofuel-consumption mandate of the level Q_E. Because no tax costs are involved with a mandate, the consumer has to pay the weighted average price of the biofuel and gasoline where the weights are formed by the required consumption of biofuels:

$$P_F = P_E Q_E + P_G(C_F - Q_E) \quad (3)$$

where P_F is the weighted average fuel price for consumers, C_F is the consumption of fuel, P_E is the market price of ethanol and Q_E is the mandated level of ethanol consumption.

If we assume that oil prices do not vary with ethanol production, the transfer to ethanol producers is completely financed by an implicit consumer tax on gasoline. For the same level of ethanol production, this necessarily implies that gasoline consumption is lower with a mandate compared to tax credit. Recall in the analysis of a tax credit there is no effect on total fuel consumption with a tax credit and fixed oil price. Total fuel consumption remains the same, but gasoline consumption declines by the level of ethanol production Q_E. But with a mandate, total fuel consumption declines, necessarily resulting in a lower level of gasoline consumption compared to a tax credit.

Now consider the case where the supply curve for gasoline is upward sloping. With a tax credit, total fuel consumption increases and world oil price declines. But in the case of a mandate, an upward-sloping supply curve for oil will now result in the mandate acting as a tax on oil producers but not always a tax on consumers, depending on market parameters. Sometimes a mandate will be a tax on consumers, but in other cases it will subsidize fuel consumers even though there are no taxpayer costs. In this case, oil producers are transferring income to both ethanol producers and fuel consumers.

Nevertheless, regardless of market conditions, compared to tax credits that achieve the same level of ethanol consumption, a mandate results in higher fuel prices and lower fuel consumption (even though a mandate can generate an increase in fuel consumption). This means a mandate is preferred to a tax credit when there is a sub-optimal gasoline tax like in the United States. A mandate also saves taxpayer costs and does not incur the inefficiency costs of taxation.

The Economics of a Biofuel Mandate and Tax Credit Combined

So far, we have determined the equilibrium with a blend mandate and compared the efficiency of a mandate to that of taxes and subsidies under different policy goals. But policymakers seem intent on using mandates and tax credits in concert.

President Bush signed into law the EISA on 19 December 2007, which established the largest increase in a biofuels mandate in history. The new mandate, known as the RFS, requires the use of at least 36 billion gallons of biofuels in 2022, a fivefold increase over current RFS levels. By 2022, biofuels could represent over 20% of US automobile fuel consumption.

Meanwhile, the new legislation calls for the continuation of the federal biofuel tax credit of $0.51 per gallon which, when combined with state tax credits, will potentially cost taxpayers over $26 billion by 2022.[3] Tax credits by themselves encourage ethanol production as a replacement for oil-based gasoline consumption. But with mandates in place, the tax credits will unintentionally subsidize gasoline consumption instead. This contradicts the new energy bill's stated objectives of reducing dependency on oil, improving the environment and enhancing rural prosperity. This result is independent of the issues related to indirect land use and CO_2 life-cycle analysis that is currently in the forefront of the public debate over biofuels.

The effects of current policies are mind-boggling. The billions of tax dollars to be spent will be a pure waste and will have profound consequences beyond that. Transfers of wealth to the Middle East will increase, leading to even more dependence on oil and energy insecurity. Air quality will decline while CO_2 emissions will increase. Meanwhile, the resulting rise in oil prices hurts farmers through higher input costs, while ethanol prices are unchanged as ethanol consumption remains at mandated levels.

The unintended result of a tax credit switching to a gasoline subsidy in the presence of a government mandate is easily explained. Consider first how the tax credit would work by itself. To take advantage of the government subsidy offered them, blenders of ethanol and gasoline will bid up the price of ethanol until it is above the market price of gasoline by the amount of the tax credit. If the price premium over gasoline is less than the tax credit, then blenders will be making windfall profits from the government subsidy by pocketing the difference. But competition among blenders will ensure that there will be no "free money left on the table," and the price of ethanol will, therefore, exceed that of gasoline by the full $0.57 per gallon tax credit.

Now consider the case where the ethanol price is determined by the binding mandate—36 billion gallons by 2022—and there is no tax credit. The consumer "fuel" price is a weighted average of the ethanol and gasoline prices. Implicitly, consumers pay a higher price for gasoline to finance the same ethanol production as before, when only the tax credit was in place. Now introduce a tax credit alongside the mandate. Because the ethanol price premium due to the mandate exceeds the tax credit, there is no incentive for blenders to bid up the price of ethanol as before. Instead, blenders will offer a lower fuel price to consumers to take advantage of the tax credit offered to them by the government. Because market prices of ethanol cannot decline due to the mandate, blenders will compete for the government subsidy by reducing the implicit price paid by consumers for gasoline in their fuel price. This increases gasoline consumption and, thus, increases the market price of gasoline and oil. The price of gasoline paid by consumers declines until the per-unit subsidy on ethanol is exactly exhausted on an adjusted per-unit basis of gasoline consumption—hence the reversal of the intended policy effects.

The expected social costs of having a tax credit when a mandate could have done the same thing for the year 2022 ranges from $28.7 billion in the short run to $48.5 billion

[3]The federal tax credit is $0.51 per gallon and national average state tax credit is about $0.06 per gallon (Koplow 2007; Steenblik 2007). Babcock (2008) predicts that corn-based ethanol production will exceed the 15 billion gallon mandate by 11 billion gallons in 2022. This means a projected tax cost of biofuels for 2022 of $26.5 billion.

in the long run (de Gorter and Just 2008c). Due to the unique way in which mandates reverse the market effects of a tax credit, the intentions of policymakers cannot necessarily be faulted. There is no other example in the economics literature of the interaction between a price-based and quantity-based policy measure that generates such a unique result as that of a biofuel tax credit and mandate (de Gorter and Just 2007b, 2008c). Furthermore, this policy mistake is not unique to the United States, but is a worldwide error of judgment as most countries use both mandates and tax credits simultaneously. The policy implication is clear: allow the mandate to work by itself, eliminate the tax credit and save billions in taxpayer monies. This involves only a modest change in biofuel policy while dramatically improving policy achievements.

Import Tariffs on Ethanol

Many controversies surround US biofuels policy, not least of which is the import tariff on ethanol of $0.54 per gallon. Congress implemented this import tariff to offset the tax credit. The key reasons why the United States and the world have increased their focus on biofuels include global climate change, increasing oil prices with dwindling reserves, political instability in oil-exporting countries and the desire for energy security. Because the import tariff affects exports from Brazil where ethanol from sugar cane contributes far more to reducing greenhouse gases than ethanol derived from corn in the United States, many commentators have remarked on how an ethanol tariff contradicts these goals (Doornbosch and Steenblik, 2007; Howse *et al.*, 2006; Jank *et al.*, 2007; Kojima *et al.*, 2007). Clearly, other political goals, such as enhancing farm incomes, reducing the tax costs of farm subsidy programs and promoting rural development are also very important (Rajagopal and Zilberman, 2007; Tyner, 2007).

Total US imports of ethanol in calendar year 2006 were 653.3 million gallons, almost all from Brazil of which approximately a third was routed through the Caribbean to avoid the import tariff. Through the Caribbean Basin Initiative, an import quota of 7% of domestic US ethanol consumption is tariff free. Brazil exports ethanol with 5% water content to the Caribbean, which is reprocessed so that the water content is 1% and then exported to the United States as a different product, thereby overcoming any problems with rules of origin in preferential trading agreements (Yacobucci, 2005). Imports from the Caribbean were only 65% of the maximum allowed so, apparently, the costs of obtaining tariff-free status through the Caribbean are significant.

Concluding Remarks

It is beyond the scope of this paper to analyze the many policies directly impacting the ethanol market and the efficacy of the associated multiple policy objectives. Nevertheless, this paper provides important insights into the social costs and benefits of key policy instruments. One key insight is how a change in the price of ethanol affects the corn price. Because one bushel of corn produces 2.8 gallons of ethanol and 31% of the value of corn is returned to the market in the form of feed byproducts, every one cent per gallon increase in the price of ethanol translates into a 4.06 cent per bushel increase in the price of corn. This means a tax credit of $0.57 per gallon (including state credits of $0.06 per gallon) that generates a price premium for ethanol of $0.57 per gallon translates into $2.31 per bushel for corn. The same outcome occurs if a consumption mandate is used instead to generate the same price premium. Because the corn market is now directly linked to the ethanol price, which is directly linked to gasoline prices, any change in oil prices that affects gasoline prices is now directly transmitted to the price of corn for a given level of the tax credit. On the other hand, once a consumption mandate is in place, any changes in oil prices will not directly affect the corn price (only indirectly affecting costs of production). Hence, a mandate will not transmit instability from the oil market to the corn market unlike a tax credit.

An immediate question is why the tax credit or mandates have not impacted corn prices that much until only recently. In fact, the corn price in the past has often been lower than this implied subsidy to corn farmers! The reason for why the price of corn was rarely affected by the tax credit in the past is either gasoline prices were too low, corn prices too high or costs of ethanol production too high for the tax credit to have any impact. Low oil prices or high corn prices and processing costs mean that the intercept of the ethanol supply curve was far above the price of oil. This "water" in the tax credit means the taxpayer costs were mostly wasted in rectangular deadweight costs—no transfers were made to any group in society. In fact, we show that the sole reason for ethanol and biodiesel production was for the most part due to production subsidies for either corn or ethanol. The tax credits by themselves would have generated little if any ethanol production. The historical data show how uncompetitive the US ethanol industry has been even with tax credits and mandates.

Because the per-unit tax credits are fixed, a spike in oil prices led to a spike in corn prices (with a lag because it took some time to get ethanol processing facilities online). Clearly then, fixed per-unit tax credits in the face of oil price spikes causes instability in the corn market. Because the corn market is linked to other markets through substitution in both demand and for land in supply, this price spike in corn markets is quickly transmitted to other crop prices. This is partially responsible for the current food crisis (Runge and Senauer 2007).

Careful inspection of the data, however, shows that the price premium for ethanol exceeded the tax credits. This means ethanol was purchased historically for other reasons. Because mandates at the local, state and federal levels do not appear to bind historically, we interpret the data to indicate that either *de facto* mandates in the form of environmental regulations (the Clean Air Act of the 1990s or the implicit ban in MTBE in this decade) were responsible for this excessive price premium or that ethanol was purchased for its additive value as an oxygenate/octane enhancer. This means refiners and blenders purchase ethanol in fixed proportions to gasoline. This necessarily implies a mandate model is appropriate to characterize such a situation and appears to be the case for US ethanol until at least 2007/08. More recently, the tax credit is binding, but the expanded federal RFS in recent energy legislation (in conjunction with continuing local and state mandates) may result in an ethanol price premium above the tax credit again in the future.

We also determine that mandates are more efficient than tax credits for the same level of ethanol production because mandates result in relatively higher gasoline prices and lower

CO_2 emissions and miles traveled. New US energy legislation mandates the use of renewable fuel but calls for continuing current biofuel subsidies that will cost taxpayers billions of dollars. The subsidies—tax credits—by themselves encourage ethanol production as a replacement for oil-based gasoline consumption. But when used with mandates, the tax credits will instead unintentionally subsidize gasoline consumption. This contradicts the new energy bill's stated objectives of reducing dependency on oil, improving the environment and enhancing rural prosperity. This also has major implications for countries worldwide that also use both tax credits and mandates.

Although tax costs of farm subsidy programs decline, farm subsidies increase both the tax cost and inefficiency costs of the ethanol policies while the latter increase the inefficiency costs of the farm-subsidy programs. Ethanol policies can, therefore, not be justified on the grounds of mitigating the effects of farm-subsidy programs. We also conclude that the US ethanol industry requires oil prices of at least $70 per barrel to be able to produce any ethanol without government support.

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Scientific Challenges Underpinning the Food-Versus-Fuel Debate

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Humanity has enjoyed a unique period of food surplus since the green revolution began in the mid-1960s. Since then, population doubled, food prices steadily decreased, and the proportion of malnourished has been reduced substantially. These conditions laid the foundation for sustained economic development in a large number of countries, including those with the largest populations. In the past two years, however, there has been an abrupt reversal of trends in food cost and availability as prices for the major cereals have tripled. This paper briefly reviews the factors responsible for this reversal and explores the implications for research and technology development in the basic and applied plant and crop-production sciences.

Megatrends Affecting Food Supply and Demand

Human population is projected to stabilize at something over 9 billion by mid-century (United Nations Population Division, 2008). From 2008 to 2020, however, population growth will average about 77 million people per year—equivalent to an annual growth rate of 1.2% of the current population (6.7 billion). Rapid economic development in the world's poorest and most populous countries is the primary factor contributing to the expected reduction in population growth because female fertility has a strong negative correlation with income, which, in turn, is highly correlated with education—especially for women.

Both per-capita food consumption and energy use increase markedly as incomes rise (Naylor *et al*., 2007). As incomes rise from low levels, people consume more livestock products, which increases total grain requirements because 1 kg of meat or dairy product requires 2 to 3 kg of grain as feed (Delgado *et al*., 2002). Per-capita energy use increases with rising incomes because people can afford improvements in comfort and quality of life through climate control (heating, fans, air conditioning), household lighting, cooking energy, and transportation. Thus, both cereal and energy production must increase more rapidly than population to meet demands of a wealthier human race on the road to zero population growth.

But current transportation technology requires enormous amounts of liquid motor fuels at a time when petroleum use exceeds petroleum discovery. Hence, the price of petroleum has increased more than five-fold in the past 10 years. Most of the world's known petroleum reserves are located in politically unstable countries, which further add to prices due to supply uncertainty. The high costs and uncertainty of supply provide strong motivation for investment in biofuels made from crops, and a number of countries have enacted favorable policies and incentives to foster a rapid expansion of biofuel production. In the United States, ethanol production from corn has doubled to 30 billion liters per year since 2005; biorefineries to produce another 20 billion liters per year are currently under construction. Brazil is rapidly expanding its production of sugar-cane ethanol, Europe and Canada are expanding biodiesel production from canola oil, and Indonesia and Malaysia expect to greatly increase biodiesel production from palm oil.

At current petroleum prices, the highest value use of corn is as feedstock for biofuel rather than for human food or livestock feed (CAST, 2006). As a result, the amount of corn used for ethanol is rising rapidly; about 25% of US corn production will be used for ethanol in 2008, which represents about 10% of global corn supply.

Because the amount of arable land suitable for intensive crop production is limited, the use of food/feed crops for biofuels is placing tremendous pressures on global food supply and on land and water resources. Although irrigated agriculture produces about 40% of global food supply on 18% of total cultivated area (Cassman and Wood, 2006), water resources available for irrigation are decreasing due to competition from other economic sectors (Postel, 1998; Rosegrant *et al.*, 2002) and climate change (Vörösmarty *et al.*, 2000). Moreover, the net effects of climate change on crop productivity appear to be negative in many cases because adverse impacts of higher temperatures offset benefits of increased atmospheric CO_2 (Peng *et al.*, 2004; Lobell and Field, 2007).

In the face of these megatrends, and given limited funding, research prioritization is crucial to ensure global food security and protection of environmental quality for future generations. Clear understanding of the most critical scientific issues to meet these challenges is central to effective prioritization.

Scientific Challenges to Ensure Food Security

Cereal crops account for nearly 60% of all calories in human diets. The area devoted to cereal crops has decreased by 1.8 million ha per year since 1980, while global expansion of urban areas is expected to require 100 million ha of additional land by 2030 (FAO, 2002). Most of this urban expansion will occur on prime agricultural land because cities were located near their food supplies before modern transportation systems and global food trade. Moreover, the relative rate of gain in crop yields has been declining steadily since release of the semi-dwarf crop varieties that initiated the green revolution in 1966 (Table 1), and these rates of yield gain are not sufficient to meet projected demand on existing arable land (Cassman, 2001). Therefore, ensuring an adequate supply of crop commodities for food, livestock feed, biofuels and biobased products without a large expansion of crop area into rainforests, wetlands and grassland savannahs will require massive increases in crop yields on existing farm land. Given these trends, there is an urgent need to accelerate crop yields to rates well above the historical trajectories of the past 40 years, while at the same time protecting soil and water quality and reducing greenhouse-gas emissions.

Table 1. Global rates of increase in yields of maize, rice, and wheat from 1966 to 2006 based on data from FAOSTAT (http://faostat.fao.org/site/497/default.aspx).

Crop	Mean yield 1966	Mean yield 2006	Linear yield growth rate[a]	Proportional rate of gain 1966	Proportional rate of gain 2006
	(kg ha^{-1})		(kg ha^{-1} yr^{-1})	(%)	
Maize	**2,260**	**4,759**	**62.5**	**2.8**	**1.3**
Rice	**2,097**	**4,235**	**53.5**	**2.6**	**1.3**
Wheat	**1,373**	**2,976**	**40.1**	**2.9**	**1.4**

[a]Linear growth rates in yield are based on regression of global average yield for each cereal on year over 4 decades, from 1966 to 2006. R^2 values for linear regression are: maize = 0.94, rice = 0.98, wheat = 0.97.

Accelerating yield growth while reducing the environmental footprint of agriculture is a process called "ecological intensification" (Cassman, 1999). It is one of the most difficult scientific challenges facing humankind and requires an integrated, interdisciplinary systems approach. For example, yield growth during the past 40 years has relied equally on crop genetic improvement and improved management of crops and soils (Fig. 1). But even with development of powerful new technologies that supported growth of US corn yields since 1966, the negative environmental effects from intensive agriculture were not avoided.

Another major challenge is to increase crop-yield potential, which is the maximum yield an adapted crop cultivar or hybrid can achieve when grown without limitations from water, nutrients, or pests (Evans, 1993). Because it is not possible for all farmers to achieve the perfect management required to reach yield potential, national crop yields stagnate when average farm yields reach 80–85% of the yield potential ceiling—as has occurred for rice in China, Japan, and Korea (Cassman *et al.*, 2003). It is, therefore, crucial to maintain an exploitable gap between average farm yields and yield potential. Unfortunately, yield potential of inbred rice has not increased since the International Rice Research Institute released the first modern variety, IR8, in 1966 (Peng *et al.*, 1999), and there is no evidence of an increase in corn-yield potential since 1975 (Duvick and Cassman, 1999; Cassman *et al.*, 2003). Eventually, yield growth will stagnate in a number of other key grain-producing countries unless yield potentials can be increased.

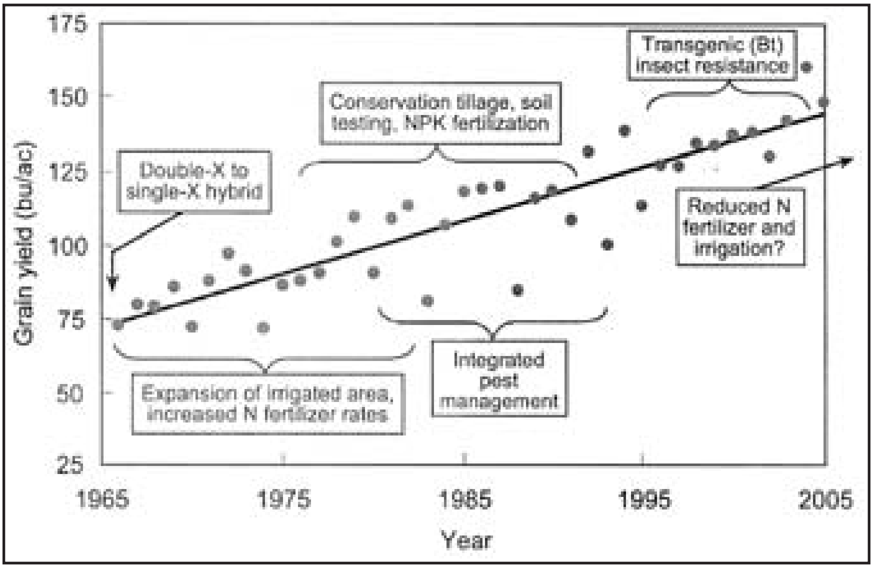

Figure 1. US maize-yield trends from 1966 to 2005, and the technological innovations that contributed to this yield advance. The rate of gain is 112 kg ha^{-1} yr^{-1} (R^2 = 0.80). Modified from CAST (2006).

Given these trends, the most critical scientific challenges are:

- closing the existing exploitable yield gap while protecting environmental quality,
- achieving large improvements in water and nitrogen use efficiency, and
- increasing the yield potential ceiling of the major food crops.

Opportunities for Biotechnology and Plant Molecular Sciences

Commercial success of transgenic crops and excitement about future contributions of genomics and metabolic engineering have motivated an enormous increase in funding for biotechnology research since the mid-1990s, in both the public and private sectors. To date, however, *Bt* insect resistance and Roundup-Ready® herbicide tolerance have had the major impacts from biotechnology, although both breakthroughs were made in the 1980s and incorporated into transformed plants in the early 1990s. Since the release of *Bt* and Roundup-Ready® crop varieties there has been relatively little commercial impact from biotechnology despite huge investments. At issue, therefore, is whether a framework can be developed to improve identification of plant traits that are amenable to transgenic solutions.

Denison and colleagues (2003) proposed a global hypothesis to address this issue. They hypothesized that traits conferring general advantages for individual plant fitness in competing against other plants of the same or different species would likely have been optimized by the evolutionary process over millions of years and would, therefore, not easily be improved by conventional breeding or biotechnology. Such traits include photosynthesis, respiration efficiency, drought tolerance, and nitrogen-use efficiency. They argue that selection pressure would have either accepted or rejected genetic modifications based on up- or down-regulation of gene expression, or changes in protein conformation and enzyme activity. Moreover, evolution is relatively efficient at fine-tuning a biochemical pathway to optimize performance under a given set of environmental conditions. For example, there are nineteen independent cases of parallel evolution that developed C4 photosynthesis from a C3 progenitor—a process that requires modifications to numerous genes. In contrast, evolution would not have had the time to optimize traits that confer collective advantages to a community of similar plants of the same species, as found in a farmer's field, because agriculture originated only 10,000 years ago. Hence, traits amenable to rapid genetic improvement, via both conventional means and biotechnology, include short plant stature (semi-dwarf rice and wheat), non-shattering grain, and resistance to diseases and insect pests that are more common in monoculture environments.

Looking to the future, and given the need for average farm yields to approach the genetic yield potential ceiling, transgenic solutions are likely to help develop resistance to diseases that thrive in crop stands of high plant density, large leaf area, and high nutrient concentration—especially of nitrogen. A large, nitrogen-rich leaf canopy is essential for high yields, yet nitrogen-rich plants are more susceptible to a number of important diseases. Moreover, disease progression is more rapid and yield loss more severe in nitrogen-rich leaf canopies. Examples include blast and sheath blight in rice, grey leaf spot and several stem diseases in corn, and powdery mildew and rusts in wheat. Other promising traits for genetic manipulation include those that confer advantages to changes in climate or soil fertility that did not occur in pre-agricultural times, and thus variants adapted to these changes may have been rejected by past selection pressure (Denison, 2006). New objectives, such as improvements in grain quality for specific end uses or for biofuels and biobased products also are highly amenable to genetic manipulation, especially through biotechnology.

Validation of Transgenic Progress

The large investment in biotechnology research is yielding an increasing number of publications that declare improvements in yield, drought tolerance, or nitrogen-use efficiency. A common oversight in these reports is that transformed plants are compared only against the parent, which in most cases is not the best performing commercial cultivar or hybrid. Comparisons must, therefore, include the best-performing commercial varieties. Claims based on greenhouse or growth-chamber experiments are another concern. Sometimes plants are grown in a nutrient solution for comparisons of nutrient efficiency. While such studies provide controlled conditions for evaluating gene expression and physiological processes, they do not predict yield or efficiencies under production-scale field conditions. Even studies conducted in small field plots are not adequate, because harvest areas are too small to avoid border effects. Instead, valid documentation of putative transgenic crop improvements for traits such as yield, drought tolerance, and nitrogen-use efficiency must be made in large, replicated field plots with appropriate agronomic management. Such tests must also be conducted in the target environment, which adds the additional burden of regulatory approvals, field sanitation, and biosafety standards. In summary, all reports to date of increased yield or yield potential, drought resistance, or nitrogen-use efficiency—that I am aware of—are premature because they do not document improvement compared to the best commercial cultivars or hybrids under appropriate ranges of relevant field conditions.

Biofuels Derived from Non-Food Crops

Some suggest that a transition to second-generation biofuels made from non-food crops will reduce food-versus-fuel concerns because cellulosic biomass crops will be grown on marginal land and will not compete with food crops for prime agricultural land. In reality, there may be no such decrease in pressure on food crops. If petroleum prices remain high, biofuels will be made both from food crops and cellulosic crops, such as switchgrass and poplar. In addition, large-scale deployment of cellulosic crops to produce billions of gallons of annual biofuel production is at least 10 years away. In that time, biofuel production capacity from food crops like corn and sugar cane will build out rapidly.

Final Comment

Humanity is in a race against time to ensure global food security on a planet with limited supplies of arable land, water, and low-cost energy resources, and a rapidly growing human population. Biotechnology and plant molecular sciences provide critical tools for meeting the challenge of food security, but they are not silver bullets. Achieving food security and protecting natural resources will require scientific breakthroughs and technology developments from a large number of basic and applied disciplines. Too often, however, plant molecular geneticists and biotechnologists claim breakthroughs that lack theoretical justification or appropriate validation. This situation highlights the need for greater involvement of agronomists and ecophysiologists in the prioritization, review and implementation of biotechnology—especially for projects that seek to improve complex traits such as yield potential, drought tolerance, and nitrogen-use efficiency. Ecological intensification is possible, but it will take a substantial increase in research funding with appropriate focus and collaborations.

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KENNETH CASSMAN is the director of the Nebraska Center for Energy Sciences Research at the University of Nebraska, and the Heuermann professor of agronomy. He has worked as an agronomist in Brazil, Egypt and the Philippines, and as a faculty member at the University of California-Davis. His research, teaching, and extension efforts have focused on ensuring local and global food security while conserving natural resources and protecting environmental quality.

Dr. Cassman's current efforts include investigating the potential of corn-based cropping systems to produce biofuels, mitigate greenhouse-gas emissions and improve soil and water quality, and the optimization of water-use efficiency and crop productivity in moisture-limited irrigated agriculture.

He has a BS from the University of California-San Diego (1975) and a PhD from the University of Hawaii's College of Tropical Agriculture (1979) and is a fellow of the American Association for the Advancement of Science, the American Society of Agronomy, the Crop Science Society of America, and the Soil Science Society of America. He received the 2004 International Plant Nutrition Award from the International Fertilizer Association, and the 2006 Agronomic Research Award from the American Society of Agronomy. His work has been widely published, including in *Nature*, *PNAS* and *AMBIO*.

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Policy Issues Impacting Agriculture and Bioenergy

Panel Discussion and Q&A

Moderator: David Benfield
Ohio Agricultural Research and Development Center
Wooster, OH

Panelists:

Doug O'Brien
Ohio Department of Agriculture
Renoldsburg, OH

Matthew C. Roberts
The Ohio State University
Columbus, OH

Chris Schmid
JumpStart, Inc.
Cleveland, OH

Doug O'Brien: I've worked at the state level and as council on the federal Senate Agriculture Committee for the 2002 Farm Bill and I've done some teaching at the National Agricultural Law Center at the University of Arkansas. So, I bring a policymaking perspective.

The presentation on ethics was very helpful. Over the past 6 or 8 months, it has become clear that there is a real need to figure out how we deal with food-versus-fuel, nature-versus-fuel debate. Not surprisingly, an international forum on global hunger issues, in progress in Rome[1], is turning into a huge debate on food versus fuel. Also, it's maybe not surprising that policymakers, from USDA Secretary Schafer to the leaders of sub-Saharan Africa, are not on the same page. They are talking about different things, and a lot of work is needed in this area.

The big question is whether policymaking processes in the United States and globally will be able to react in a timely fashion to the energy—I'll just use the word—"crisis" that we find ourselves in. Can they react to this megatrend? In Ohio, a major energy bill, dealing mostly with electricity, was passed recently. In the next week or so, the governor will sign a major stimulus package with alternative energy and bioproducts as key components. On the national level there is the federal energy bill, part of the Farm Bill, and climate change is being debated in the Senate. A lot is happening. It is absolutely a teachable moment; the need for more research into crop productivity, *etc.*, is reported in the likes

[1]The United Nations Food and Agriculture Organization (FAO) hosted the *High-Level Conference on World Food Security: the Challenges of Climate Change and Bioenergy*, June 3–5, 2008. http://www.fao.org/foodclimate/hlc-home/en/.

of the *Columbus Dispatch* and the *Des Moines Register* almost on a daily basis. Things are moving, but there is a huge question mark for me on whether the policymaking processes can catch up. The answer has to be "yes," but how do we get there?

Matthew Roberts: About 4 miles from here, fifty-two undergraduates are sitting through my final exam in econ 200. The textbook I use is organized around ten principles of economics, the first of which is that life is about tradeoffs. This is the essence of why economics is commonly referred to as "the dismal science"; economists are forced to constantly point out the tradeoffs that people face in life. Discussion of biofuels, bioenergy, population growth and other megatrends brings us to a clear confrontation with the tradeoffs that we as humanity currently face, many of which are uncomfortable. This is an overriding force that we cannot forget.

To gratuitously self-promote my profession, I see economics as truly at the center of this discussion. I agree with Harry de Gorter that thresholds greatly oversimplify. When we state that there's a maximum or a limit of feedstocks that may be used to produce various energies or fuels, substitutions occur throughout the energy chain. However, I disagree with the comment that energy is energy. Were that the case, we would all be delighted to know that one medium-sized banana is fully equivalent to one Twinkie because both have 150 calories. Energy does have other characteristics. I point that out, not as a correction, but as a reminder that this is a discussion of tradeoffs. Further to Dr. de Gorter's remarks, I would like to emphasize import tariffs. There is so much discussion around them, and I don't think you would disagree with me that there is much discussion in the policy arena about federal biofuels regarding the VEETC, the Volumetric Ethanol Excise Tax Credit, and blending mandates and consumer mandates. But, in the long term, the import tariff is probably the most damaging and most distorting aspect of federal policy for US biofuel use, simply because as long as it's in place, the chart that Ken Cassman showed—relating the value of corn in fuel consumption to oil prices—will remain in place. The only way to fundamentally alter that is through relaxation or elimination of the import tariff, allowing fuels to be derived from their most efficient sources. It allows all economic players to specialize in what they are better at. And, frankly, Brazil is better than we are at sugar and simple starch production. We are better at oilseed, and complex starch production through soybean and corn. That is our comparative advantage. So, Dr. Cassman, the one point I would like to make, and I think you'll agree so it's merely a point of amplification, is that when you describe a yield converging on a theoretical maximum, and the difficulty, as you call it, of the razor-thin margin for error in production and management, we call this the law of diminishing returns. As we approach the theoretical maxima, each successive bushel becomes more difficult to obtain. And why I believe that this is important to point out is that corn, soybean, wheat, sugar—all of these crops—are globally fungible commodities and, therefore, we must realize that changes in production and yield in other countries are economically equivalent to changes in this country and that the lowest hanging fruit may not be to attempt to move US yield in corn from 152 to 158 or 168 bushels but it may be to improve average yield in the developing world from 38 bushels to the acre to 42 bushels or 46 bushels. Greater returns on investment are more likely to be through education and infrastructure construction in the developing world, in areas that currently have low yields yet their potential is similar to ours.

Chris Schmid: JumpStart was founded 4 years ago to improve the entrepreneurial and economic climate in northeast Ohio and help make it a nationally recognized center of innovation. Funding is from the state, federal government, foundations and corporations and we are working this field through an Evergreen Fund, assisting businesses through outreach and networking. Our website[2] allows mentors, investors, idea people and service providers, to connect in a social-networking environment and then through follow-on funding going through the United States and beyond trying to find capital so that our companies can continue to grow. Significant emphasis is on women and minority entrepreneurs.

Since 2007, we have connected about 25,000 entrepreneurs in northeast Ohio. We've vetted about 1,280 business ideas, approximately one idea per weekday. We have assisted 160 companies, including investment of $10 million in twenty-nine companies, creating a total economic impact of $56 million—not a bad return. And we have generated follow-on funding from outside sources, many on the East and West Coasts, of $41 million. We have created 175 jobs with incomes in the range $70,000 to $80,000 a year and moved the national entrepreneurial ranking of northeast Ohio from 61, which was dead last, to 24. In 4 years we've made significant progress.

We are really on the investment side, working with companies in the idea stage, the dream stage, with which the yield is probably 10 years out, maybe even longer. We are looking at ideas that have high growth potential.

As investors, we are quite often accused of having no ethics; in fact, we care a lot about ethics because they determine what will be acceptable in the future. The ethics debate was interesting and I learned a lot from it. When we make an investment decision today we really are making a decision for the future and if ethics are changing—and yes, they are changing—and people are thinking differently about certain investments, then we need to know that. Underlying economics are extremely important and, therefore, in all of our decisions we typically strip out tarrifs and barriers to entry imposed by the government because they all can change, even at a moment's notice. I was recently in Europe attending meetings on biorenewable energy and the total market is dead. There is no investment in Germany for the simple reason that subsidies ran out. The subsidies did not keep up with the cost of feedstock, the cost of the raw materials. No one can afford to invest before the new subsidies are established again. Clearly, building a whole industry based on subsidies is dangerous. Also, we know that the next bubble will probably be one of "dot com" size, in the renewable energy area. A lot of money is chasing new ideas, some of them crazy ideas. Of course, we consider crazy ideas. Every idea that won't make money for 5 to 10 years is crazy. Nobody knows what will eventually survive. We invest in ideas that we think make a little more sense, and, hopefully, one of them will take off.

[2] http://www.jumpstartinc.org/

The total investment climate around bioenergy, in my mind, is very, very risky. Because of the bubble mentality, everybody runs in the same direction. Everybody ran towards ethanol, and currently no ethanol plants are going up. Biodiesel plants are not going up either. Actually they are being shut down or plants that have been started are not continuing. It cannot be done in Europe where a kilowatt-hour of electric energy costs 3 cents and a gallon of gasoline costs $10, and it's no surprise that we can't do it here either. The reason they cannot do it is because feedstocks cost rose. Materials that were considered to be waste before, have become valuable commodities. While I was over there I was interested to follow the so-called paper war. Companies go into communities and collect paper from households. Municipalities are now fighting them in court because that removes the most valuable part of the waste and municipalities can no longer continue free waste collection. This shows that when waste becomes a commodity, it becomes a race to the bottom. Economists have pointed this out very clearly; whether prices are bid lower or prices are bid up, there is no money to be made. Any resource that is limited in the energy market should be viewed with caution. Renewable energy will be viable from resources that are guaranteed free forever like sun, wind, water and geothermal energy. Those are basically the four forms of energy we are investing in. We haven't really found anything in bioenergy. We are hoping for a big breakthrough, but the problem is that as soon as there is such a breakthrough, there will insufficient biomass to keep the prices low forever. The prices will go up and it will eventually become a game of what is the content of the raw material, of the biomass, and what is the cost of conversion? And a huge part will be the costs of distribution and logistics. One of the speakers talked about this; most people underestimate the cost of collecting raw materials at a huge plant—only huge plants will eventually be successful. And then distribution of the energy material becomes an issue. That will rely to a great extent on the companies that are currently serve our energy markets, the Exxons and the electricity-generating companies. There won't be a lot of shift because those large plants cannot be built by anybody else. Who else has a $100 million or a billion dollars handy to build another manufacturing plant?

So, we are not really shifting the paradigm, we are just shifting the game to a different area. And then we will deal with the same market forces again. From our viewpoint, it's an exciting time. It will be a lot more exciting when we know what really shakes out and when the politicians step out of it and let the markets drive it. And I think that the ethics debate will be critical for us as investors, to see what the general population will accept in the long term.

David Benfield: We've had interesting presentations from our keynote speakers and good comments from our panelists. Now, I'll open this up to questions and comments from the audience.

John Glaser (US Environmental Protection Agency): I've been told that people are in the practice of landing biodiesel from South America and the Gulf Coast areas and mixing it with petro-diesel and then reloading it on vessels to take to Europe and pocketing the extra fee that is available to them. This is outrageous and I can't understand why in the world we designed ourselves into this set of circumstances. Would you care to comment?

Harry de Gorter: The list of policies that I put up was only a subset of the total policies directly affecting biofuels in the United States. You are referring to “splash and dash,” where you have a dollar tax credit for biodiesel. I just used ethanol in the United States as an example. My framework analysis is applicable to any kind of tax credit for any kind of biofuel in any part of the world. So, yes, in the United States we have a dollar tax credit for biodiesel; if you mix it with normal diesel, you will get that dollar for the biofuel component, then you can sell the mixture anywhere you want. The tax credit for biodiesel in Europe is higher, as is the price, so why sell it in the United States? It’s a scam. Taxpayers lost some $300 million dollars this past year on that. The beneficiaries are, of course, the people who are doing it, US exporters. Some of it obviously goes to Asia, because they import palm oil from there, and transport it over to Europe. And of course the European biodiesel producers are hurting. It’s such a bad scam. I don’t study it because by the time I write a paper on it, surely it will be gone.

Roberts: I think if we attempted to make a list of all the unintended consequences of policy in just the energy field, we would need a few more days at this conference.

Tony Shelton (Cornell University): Regarding Chris Schmid’s statement about Europe looking for resources that perhaps will not be taxed as commodities—wind, solar—I’m wondering if there’s a negative aspect of that, which will come out in some sort of policy. It sounds free, but are there consequences of that? Will there be taxes on them or will the technologies to harness those sources of energy be such that it will not play out quite as free as we might want to think?

Schmid: Absolutely right. The sources are free. The wind is free. The sun is free. But what we are doing with them becomes a tax on the environment, becomes a tax on people, on their living conditions. For example, large wind farms are now undesirable in Europe because people know what it means to have a big rotor blocking out the sun every so many seconds, creating noise and impacting wildlife; there is now policy to discourage them. Or maybe it’s an agreement. It’s more or less an ethics issue; people say, “We don’t want this in our backyard any more, so where do we put it?” We had the long discussion on Cape Cod. If we put a wind farm in the Atlantic Ocean, it would be a great way of harnessing the wind, but, on the other hand, we are losing other things and it’s one of those tradeoffs. The only thing I looked at was the availability of the raw material in itself. That will be free. Now how we are going to convert it, that’s different. Just like coal is free, but the smokestacks and emissions have an impact on the environment. We need to look at the whole system, whereas, as investors, we look at the fundamentals. How much does the raw material, the feedstock, cost? What is the expected long-term development on the feedstock? And what are the cost of conversion and logistics? Those things taken together determine whether we want to invest or not, especially since we at Jumpstart invest in ideas, not expecting any return on our investment for 5 years.

Benfield: Paul, I know you talked predominantly about biofuels, but in terms of other forms of energy how would that fit into your model in terms of ethics and so forth?

Paul Thompson: I'm not sure I understand.

Benfield: Chris said that there might be some tradeoff between nature versus wind power.

Thompson: That we need to face tradeoffs is certainly right and these alternative energies are proving to be much more difficult to implement than expected. Certainly wind power was embraced early on by what I would broadly describe as the environmental community, whereas it's turned out to be divisive within that community. These are things that, as we learn more, will require what I was calling "democratic discussions." And, frankly, the more that we do that up front—before deeply investing in a technology—the better off we will be. We will have an understanding of where people's sentiments really are.

Steve Howell (Iowa State University): Paul, with reference to the conflict between industrial and agrarian cultures with respect to biofuels, if you have read the *Wall Street Journal* in the last 3 or 4 years, you will have a feeling for the industrial support of biofuels. In editorial after editorial it has called biofuels a boondoggle for the Midwest. What we have here is a situation where the industrial community views biofuels as a very strong agrarian activity. I'd also like to comment on Ken's comments on biotechnology. This is the National Agricultural Biotechnology Council and I think there is a message that we need to convey to young people who are working in this field to understand the role of biotechnology in the future of agriculture. In an important paper about a year ago in *Science*, Enrico Coen asked whether nature and evolution have thoroughly explored genetic space. And he came up with the concept that no it had not, and so one of the problems we face today in improving agriculture is to go beyond what natural diversity and other natural components and characteristics that are out there at this point and to expand allelic diversity in our genetic systems, *etc*. And that's something that can be accomplished through biotechnology. And I think that is why there is great hope for biotechnology improving agriculture in the future. I would like to leave our young people at least with a fairly optimistic note about what can be done in this area and what the opportunities are.

Thompson: I see the logic behind the comment that biofuels are an agrarian strategy. In the book, *Sacred Cows and Hot Potatoes*, we had a Doonesbury cartoon with Doonesbury's mother, who is a farmer, showing up in a gingham dress to defend farm subsidies before Congress. The point of including the cartoon was to play up the way agrarian symbolism is often used in a self-contradictory way to support a set of policies that support an agriculture that is organized much more on industrial principles. I recognize that there are important positive norms behind this agrarian vision, but there are also important positive norms behind the industrial vision. The industrial vision is the vision that helps us think about internalizing environmental costs. It actually is the vision that helps us think much more productively about meeting food needs of poor people. What we really need—and here I'll quote F. Scott Fitzgerald who said, "The mark of a first-rate intelligence is the ability to keep two opposed ideas in mind at the same time and still function"—is to learn how to do that in agriculture. My concern about biofuels is that, to the extent that they resonate with a kind of agrarian mentality, it is purely at this fairly cynical and ironic kind of level and its not really connecting with that aspect of the agrarian mentality that is trying to link up with food consumers and people who are enthusiastic about going to farmers' markets and people who are subscribing to food magazines and reading the food sections in their local newspapers. That component of agrarianism is all about food. I don't think it necessarily has to be all about food, but right now, at the same time that there is this sense that ethanol is a kind of bailout for farmers who are looking for some way to squeeze the last little bit out of their corn production and maybe preserving a kind of agrarian economy in that sense, the way that is being integrated into the larger economy and the way that is connecting with the lives of the vast majority of Americans, at least, is simply when they drive up and pump gas. And that is not something that makes people feel connected to nature. So, I don't know where to go with this point, but part of my comment is that we need to explore that tension and we need to figure out where we go with that point. And part of my warning is, to the extent that biofuels become seen as antagonistic to the whole agrarian ideal, suspicion, distrust and opposition are engendered to rational biotech and biofuels policies.

Kenneth Cassman: I would like to recapitulate the key point, because I'm not sure you got it. I was making a moral argument that if we are not going to be able to meet human food and fuel needs, then food should be first with the current national and global research priorities and with the current amount of funding. Now, one option would be to triple the amount of funding and then we could continue doing what we are doing without increased thought as to what is right or wrong and then start funding some of the other things that were lacking. I doubt that will occur. So my call was for a better prioritization of what we are doing, based upon a much more realistic and theoretically justifiable investment in biotechnology at least in the public sector. Let the private sector do what it wishes. So, it follows that there are traits that are not likely to be successful through biotechnology intervention for strong theoretical justification and I quoted the work of Denison[3]. But it doesn't mean that biotechnology isn't a critical part in addressing the long-term challenges that we face and the opportunities. It's just in the prioritization of it. One of the basic tenets is that no large gains are to be made in improving some of the more complex traits like yield potential, nitrogen-use efficiency and drought tolerance from simple up-regulation or down-regulation of existing genes or through modifications that change existing enzyme activities, protein confirmations, *etc*., because those would have been tried and tested vastly by evolution. One example, C4 photosynthesis: there are nineteen different cases of parallel evolution of C4 photosynthesis from C3

[3]Pages 174–175.

photosynthesis where there was competitive pressure for that particular construct to be advantageous. And in those, C4 photosynthesis involves numerous genes. So, nature can do amazing genetic engineering under the right circumstances with enough time. It's a matter of prioritization; biotechnology is a critical part of the toolbox.

David Sylvia (The Pennsylvania State University): Ken, I thought I heard you say that the better way forward is through ecological intensification. I'm not sure what you mean by that, but it sounds to me like the industrial model and I wonder, in terms of the growing agrarian sense in developing countries, if we will be able to implement that.

Cassman: I found Paul Thompson's dichotomy between industrial agriculture and agrarian very interesting because in many ways we have an agrarian movement for sure. However, in many ways society at large has made the decision. Only about 1.4% of our population has anything to do with agriculture or wants anything to do with agriculture. There's a larger population that romanticizes agriculture, but very few want to actually move manure and husband livestock and crops. Internationally, you have two major forms of agriculture. You have the industrial agriculture. Even though farm size is small in the rice-wheat systems in Asia, the corn systems in China, the rice systems throughout Southeast and South Asia, these are industrial models. The other is true subsistence agriculture, which is non-commercial. Farmers are farming for their own needs mostly, and mostly without inputs or access to infrastructure. A lot needs to be done there and this gets to the comment that they are so far down the yield curve that it would be better to invest in raising their yields as opposed to those that are higher up the yield curve. The problem is that the reason they are in subsistence agriculture is because of failure of governments, failure of infrastructure, lack of access to markets, corruption, *etc*. Sub-Saharan Africa is the best example. And science is on the shelf for major advances in productivity in those systems; we're not lacking in science there. The problem is solving the other constraints that haven't allowed that science to be used. Until those conditions can change, it's not likely you will see significant increases in yields in those areas

Thompson: Certainly in terms of the producers, that's right. But my sense is that the segment of the urban population now interested in agriculture—I call them agriculture's potential fan base—is growing. Probably, it's the first time that it has been growing in 50 years. Can it grow in a way that is healthy, beneficial to farmers and helpful to agriculture? Part of my message is that this movement hasn't had much help from the agricultural establishment. It hasn't had much help from land-grant universities. It hasn't had much help from agricultural input firms. And that it's crazy to treat your fan base this way would be the quick thing that I would say. But, neither can one invest all of one's time and energy in that component of agriculture. Certainly, from a global standpoint, that would be an ethically irresponsible thing to do. Again, part of my sense is that the mindset of many of my colleagues in the land-grant colleges of agriculture, and virtually everybody I run into from the commercial side, is strictly in the industrial framework. On the other hand, a lot of farmers are of two minds about this. They are industrialists when they are making their basic production decisions, but then they are agrarians when they show up in Washington and lobby for farm policy. But we have to learn to think in these, if not contradictory at least somewhat intentional, kinds of ways. And find ways to re-imagine agriculture. It may well be that we need to foster this agrarian component, which I think will bring beneficial things for agriculture. It will make people interested in agriculture again. It will make people think about where their food comes from. It will change some of their dietary habits and it will change some of their buying habits, albeit as a small component of the total agricultural production system. It may never exceed 5 or 7% of the actual land use in agriculture, and it may never actually exceed more than 2 or 3% of the population in terms of where their primary income originates. There's a long-standing view that these folks producing on 5 acres of land and making a living selling at farmers' markets don't count as farmers, and I think that's something that should change.

Sivaramakrishnan Muthuswam (The Ohio State University): Dr. Cassman, you expressed concern that present-day science will not take us to the next level to meet food and fuel needs. I don't know whether to agree with that. The role of the scientist is to think outside the box. For example, I am a plant biologist and we use the enzyme polymerase, which is everywhere. But the PCR revolution came by taking this enzyme from a thermotolerant bacterium, illustrating how science can solve problems. Natural selection doesn't work that way; it works in a given environment, in small increments. Scientists compare and contrast two environments, bringing fusion that can lead to revolution, which is what Borlaug and Swaminathan did.

Cassman: There's a bit of semantics in there, but I don't think we disagree on that.

PART IV–BANQUET AND LUNCHEON PRESENTATIONS

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Biobased Economic Growth in Ohio

Ted Strickland
Governor's Office
Columbus, OH

This is a transformative time in Ohio's economic history. Two great industries—agriculture and polymers—are rooted here for different reasons, and for some time have evolved along separate tracks. But, thankfully, these sectors are now coming together, aided by circumstance: the high cost of energy, concerns over climate change and growing understanding of what can be gained when we merge efforts in agriculture and the polymer industry. With the vast experience of our companies and academics, some of the technical capacity has already been achieved, and many more revolutionary breakthroughs await us. I have no doubt that we can build new prosperity in Ohio and contribute to the prosperity of America and that bioproducts will be an essential part of that growing and emerging prosperity. With the foundation that has already been built on the agricultural industrial sector of our economy and the great academic strengths possessed, Ohio is poised to lead the world in the production of biobased products.

The Ohio BioProducts Innovation Center

That may sound grandiose, but I mean what I say because I believe that Ohio will have this capacity, if we make the right decisions, make the right investments and pursue the right course of action. Agriculture and food, when combined, is the number-one industry in Ohio with receipts of more than $93 billion annually. And Ohio's polymer industry includes over 2,800 companies and generates more than $49 billion in annual sales.

The Ohio BioProducts Innovation Center (OBIC), funded by the Third Frontier, brings together our universities and the private sector to work toward the development of renewable specialty chemicals, polymers and advanced materials. Polymer companies are expanding in Ohio, such as Zivex Performance Materials, Inc., which relocated in Columbus from Texas to continue its development of technology for the formation and use of nano-materials. The Ohio Department of Development (ODOD), helped to track that company with assistance including the Third Frontiers Targeted Industry Attraction Program, to benefit R&D activities and to facilitate equipment upgrades. A second example is Romark, a growing supplier of specialty plastic-sheet materials. Another Columbus-based company, Plastic Suppliers, recently introduced a plastic wrap for packaging made from corn. Romark and Plastic Suppliers have won the Excellence in Exporting Award, recognizing their status among Ohio's top exporters. Plastic Suppliers was assisted in developing their new technologies by OBIC.

Economic Stimulation

We are facing challenges economically just as the nation is facing such challenges, but we are trying to do something about our situation that is positive and that will lead to job creation and economic growth. We have worked in a bipartisan way on a major job-stimulus package with investments in our communities, particularly for improvements in critical infrastructure, expansion of green spaces and restoration of historic properties. Workforce development is part of the stimulus package via investments in internships and cooperative-education programs linking academic institutions with business, to assist in the training of workers for tomorrow's emerging needs.

Part of the job-stimulus package is a $50 million investment in bioproducts to help businesses transition from petroleum-based products to more economically and environmentally sustainable renewable products. In the future, many of the products currently being made from petroleum will be made from resources grown on our farms. We are very happy about that. This $50 million investment—albeit not as robust as many of us would like—is a major step forward in recognizing the importance of this sector to Ohio.

As part of the job-stimulus package, $150 million will be invested in advanced energy initiatives and $100 million will be invested in Ohio's logistics and distribution infrastructure. As mentioned, the internships and cooperative education efforts will be supported by $250 million so that the young people trained in Ohio will be more likely to remain here after they obtain their degrees. We have a wonderful higher-education system, from lower levels of technical training through advanced graduate studies. But too many of the young people whom we educate find greener pastures elsewhere. We want to reverse that trend. We not only want to retain the students that we educate, but we want to attract some of those educated elsewhere. We think that the internship and cooperative education investment of $50 million per year for 5 years will result in more of these young people being hooked into Ohio's existing economy and, therefore, more likely to stay here.

Task Force

In early 2008, I signed legislation creating the Ohio Agriculture to Chemicals, Polymers and Advanced Materials Task Force. Although their report will not be released until the middle of June, 2008, ten specific recommendations were made in May, 2008, including support for biorefineries to ensure that the state has the capacity to grow this emerging industry. Another recommendation is to assist entrepreneurs and innovators through our ODOD programs, to which we certainly are committed. A third recommendation is that we should support R&D to ensure that this industry evolves to respond to the market—a practical recommendation that I'm sure we will also pursue. And the fourth recommendation that I will mention is that we encourage the development of academic and other training programs to serve the industry, which we will do beginning with our community-college system all the way through, as said, to graduate education. I look forward to working with Ohio's General Assembly in reviewing the report and considering the Task Force's recommendations and working with you and the Assembly to make sure that they are implemented.

Common-Sense Regulations

Let me share a couple of other things that we think will be good for this emerging and growing industry. We've made a commitment to common-sense regulations in Ohio. We want to create a smoother, quicker and fairer regulatory process for business, which we think can be accomplished while protecting human and environmental health. And we are trying to view those who are subjects of the states regulatory mechanisms as customers to be served rather than as enemies to be sanctioned. This change in attitude will go a long way toward accomplishing what we all want: healthy regulations fairly implemented and appropriately carried out. Over the next few months, I think we will see major improvements.

Investment in Education and Training

We are also making major investments in education. We have frozen college tuition in Ohio for 2 years and have strengthened links between our universities and the state economy through our Ohio Research Scholars Program. The Board of Regents and the ODOD recently announced the awarding of $143 million in grants to Ohio universities to attract scholars working in areas with promising economic applications. That's a lot of money, but we see it is a wise investment. The bioproducts industry will benefit from some of that investment.

We are making changes in workforce training to be more relevant and more responsive to the needs of Ohio businesses, by shifting many of our workforce development programs to the Department of Development, such as the Targeted Industries Training Grant Program. This program supports up to 75% of the total costs of training and related services for companies with fewer than a hundred employees and provides 50% of the costs for companies with more than a hundred employees.

Ohio Leading the Way

We are well on our way towards helping Ohio have a more promising economic future. And we are doing that by investing in areas where we see growth, where research will lead to new and better products and where we can capitalize on the fact that Ohio has a diverse economy within which are a thriving agricultural industry and an emerging biopolymer industry, and as we put these together we can make jobs available. We can improve our economic circumstances and Ohio can continue to lead the way when it comes to using our agricultural and polymer sectors to make life better for all.

TED STRICKLAND became governor of Ohio in January, 2007, having served as a member of the US House of Representatives, a minister, a consulting psychologist at the Southern Ohio Correctional Facility and assistant professor of psychology at Shawnee State University.

In Congress, he helped author the Children's Health Insurance Program (CHIP), and led efforts to keep promises to America's veterans and to ensure that troops have life-saving equipment. He brought millions in investments to Ohio for roads, technology, economic development and health initiatives.

He came to public service not as a lawyer or investor, but as the son of a steelworker born in Lucasville, OH, one of nine children. After graduating from Northwest High School, he attended Asbury College in Kentucky, receiving a BA in history in 1963. He went on to attend the Asbury Theological Seminary, receiving an MD, then continued his studies at the University of Kentucky, where he obtained a doctorate in counseling psychology in 1980.

Governor Strickland is guided by his *Turnaround Ohio* plan, which focuses on the unbreakable link between economic growth and educational achievement.

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Agriculture: The Foundation of the Bioeconomy

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These are some of the most exciting times in agriculture. Agriculture is in the news practically every day, and not just in the United States. It is also in the news in Asia, Africa, South America, and Europe because of developments not only in food production but also in terms of leveraging agricultural products for biomaterials and renewable fuels. It is my thesis that if we get agriculture right, it is possible to meet—sustainably—many of humanity's needs, independent of whether a person is living in the United States or in Timbuktu.

Key Issues

Number one, of course, is the energy issue. The economic growth that is occurring in many parts of the world, especially in the BRICK[1] nations, is causing a huge surge in demand for fuel. Resultant uncertainty over access to fuel is creating its own set of issues including the need to create enough storage of liquid transportation fuels.

The number-two issue is food. This economic growth is not only driving energy consumption but also demands for improved quality of food. In fact, within the next 20 years, we have to produce 50% more food from the same amount of land with similar inputs, which will require significant inputs of technology. Debates about food versus fuel, (non) acceptance of genetically modified (GM) crops and a number of other issues will continue via the Internet with massive dissemination of misinformation. It is possible

[1]Brazil, Russia, India, China and Korea

that many technologies that should see the light of day will not be accepted readily. We have the job of improving public acceptance via education, if these technologies are to serve society on a global basis.

A key point is that genetics has come of age. Native traits present in crop species coupled with molecular breeding technologies will deliver significant increases in agricultural productivity. Lignocellulosic technologies will be critical. Significant innovations are needed to help agriculture meet societal demands for biofuels, bio-chemicals and biomaterials not only in terms of sustainability but also to meet required quantities.

Revolution

The biotechnology revolution is occurring before our very eyes, driven, in part, by developments in DNA sequencing and DNA synthesis. Ten years ago, it took billions of dollars to finance the sequencing of the human genome. Within the next 5 years, it is likely that an individual can have her/his genome sequenced for less than $10,000.

This remarkable progress in the arena of sequencing has implications for our ability to discover traits, whether for crops or for microorganisms. New disciplines in biology are possible, allowing us to look at systems as opposed to isolated biochemical reactions. In fact, 30 years ago when I was doing my graduate research, if you isolated a protein, purified it to homogeneity and studied its properties, you would get a PhD. Sometime later if you isolated and sequenced a gene, that was sufficient for a Ph.D. Today, we can sequence a gene in a matter of minutes. And today, we are asking questions about how systems are put together with a host of biochemical reactions in the context of the cell they are a part of. Systems biology is going to have profound implications not only for crop genetic engineering but for microbial genetic engineering as well.

Usable Solar Energy

Sunlight is abundant. In one hour, the sun emits more energy than human society consumes in one year; there is enormous potential for solar energy to be converted into usable forms. Microbial and plant systems have the ability to transform light into chemical energy, the most portable known form of energy.

Renewable fuel standards have been established on a global basis. I am not sure which of the regions of the world meet these standards and which will revise the mandates that they have set for themselves. Whatever, the number projected in terms of biofuels use is huge. Whether it is 50 billion gallons or 100 billion gallons, it is a significant number that we should work towards if we are to address climate change and the need for sustainable renewable energy, for which everyone is clamoring. This is also important for the economies of nations in Africa and Asia if they are to grow, because they have the potential to contribute to the energy needs of the planet.

Fundamental Considerations

As we look at biofuels or biomaterials—or even vitamins and other types of organic molecules—three fundamental considerations emerge. Number one is the feedstock, the source, whether it is sugar or lignocellulose or starch. The feedstock is going to be region-dependent. In the Midwest, corn is as good a feedstock as any. On the other hand, in India or Brazil, sugar cane is the ideal crop. In arid environments, jatropha, sweet sorghum or some other crop tolerant of moisture stress could be the feedstock of choice.

Second is the technology. The technology that we have today is mostly focused on biochemical methods, but thermochemical and chemical approaches are also being refined. In fact, nanotechnology and nanocatalysis are coming into play; I expect that these will make significant inroads and effectively compete with biotechnology in this space.

And third is the fuel itself. Many of my friends say that ethanol is good for human consumption, but not so good for automobiles. Better fuels are to be made. Butanols are the first step in this direction, but there is no reason why we cannot make the very same fossil fuels that we already put in our gas tanks. My message is: stay tuned. We are in the first inning of a nine-inning game.

For agriculture to reliably meet the demands being placed on it—whether related to food, feed or fuel—it has to take care of itself first. Farmers in many nations already cannot afford fertilizers or pesticides. We will not be able to afford to continue to use fertilizers synthesized by today's highly energy-intensive processes. Likewise, we cannot continue to discharge nitrous oxide gases, methane and a number of other effluents from agriculture. If agriculture is to be a major contributor to renewable energy, it needs to take care of inputs. It also needs to make sure that productivity is consistent, sustainable and reliable.

The International Panel on Climate Change predicts rapid further accumulations of carbon dioxide, methane and NO_X gases in the atmosphere in the near future. Agriculture's role needs to be addressed urgently. Fertilizer use is a major contributor to atmospheric NO_X. Methane comes mainly from paddy fields and cows. We need to address these molecules if agriculture is to play increasing roles in our society in terms of materials and energy.

I alluded to the fact that breeding and biotechnology will make major contributions to enhancement of agricultural productivity. Indeed, we now have the base sequence of the corn genome. We have sequenced several plant species and with molecular techniques it is possible to move genes and traits from one type of corn to another. Corn of tropical origin was rarely used in the breeding of temperate genotypes until about 10 years ago because it took breeders about 15 years to get rid of imported deleterious traits. With molecular tools, we now can do in 2 years what used to take 10. Over the past 50 years, corn yields have grown at 2% per year. Utilizing biotechnological methods, yield increases as high as 5% per year are projected.

Biotechnology's Potential

Biotechnology has had a major impact on agriculture over the past 12 years. It had zero value in 1995 whereas in 2007 it was a $7.5 billion industry. It has the possibility of being a $60 billion to $120 billion industry by the year 2020. Of course, it is important to make the discoveries, but technology alone will be insufficient if regulations and policies do not keep pace. Now is the time for modification of agricultural policies that hinder international movement of agricultural goods and stand in the way of people feeding each other and meeting each others' fuel needs. In fact, if 800 million people on this planet are hungry today, it has nothing to do with agricultural productivity or technology. It has everything to do with the local politics and the local systems that prevent food movement across boundaries.

Agricultural biotechnology has the potential to create even more value if GM crops are accepted, provided, of course, that they meet scientific and other types of regulatory standards. About twenty-two nations are cultivating genetically engineered crops. The latest entrants to the scene are in Asia; China and India, in particular, are adopting biotechnology in a major way. Expect India to accept biotechnology in an even more significant fashion in the foreseeable future as *Bt* vegetables and *Bt* rice, and other crops of that ilk, come into the market place. South America, which resisted the adoption of biotechnology, is now witnessing the benefits to its farmers and to agribusiness in general, from Roundup Ready corn and Roundup Ready soybean. Europe, especially France, remains problematical for those promoting biotechnology. I hope that science and wisdom will prevail upon the regulatory authorities so that GM crops will soon be cultivated by French farmers.

Bt and Roundup Ready

The first major biotech product was insect-resistant corn (*Bt*), aimed at controlling the European corn borer, which damages the stalk and ear, and can lower productivity by up to 20 bushels per acre. When the product was being developed at Monsanto, we thought that it would have application on 2 million to 3 million acres. Today it is grown on nearly 50 million acres across the United States because the damage from European corn borer was vastly underestimated. Furthermore, we have come a long way since 1999. Today, we don't talk about controlling one insect like European corn borer, we talk about controlling black cutworm, corn earworm, western bean cutworm—a series of caterpillar insects that lower productivity depending upon region—as well as rootworm, a major pest that damages the roots of corn. Products now on the market—"triple stacks"—have two *Bt* genes, one for above-ground insects and another for below-ground insects and a gene that imparts resistance to the herbicide Roundup, which helps in weed control.

The Roundup Ready trait (resistance to the herbicide glyphosate) is available in soybean, corn, cotton and canola. When I was with Monsanto, people asked why we were wasting our time and resources working on this product, since weed control had been adequately accomplished. They did not appreciate the importance of no-till farming, which has seen wide adoption by soybean growers. No-till practices are now used on 90% of the soybean that is cultivated in the United States, and it is making inroads with corn as well. If we are to reduce farmer-dependence on fuel, especially for their tractors, no-till farming is a great way to go. It is also helps prevent topsoil loss, which is essential to sustainability.

New Technologies

As we stack insect- and weed-control traits, we are beginning to recognize that they work in synergy in terms of yield protection. When we have a triple stack, the value to the crop isn't 3×, but more like 3.6×. In fact, we are beginning to recognize that these are outstanding abiotic-stress protectors, shielding crops against the effects of drought, heat and other environmental insults. For example, resistance to corn rootworm, concomitant with the *Bt* trait, results in greater absorption of soil moisture than from a root treated with chemical insecticide. Three years ago, for example, a major drought in Illinois led to predictions of 60 to 65 bushels of corn per acre, whereas many farmers who planted *Bt* corn harvested 140 to 150 bushels per acre.

Drought tolerance remains a major objective for a number of companies. Both of my former employers, DuPont and Monsanto, are working on technologies to improve it. In fact, water use is a major issue that all biotechnological processes need to address. Whether it is the cultivation of a crop or the conversion of the sugar from that crop into end-products like ethanol or butanol, water management is fundamentally important. Of course, in agriculture if we have deprivation of water even for short periods of time, it can have major implications for productivity. One of the reasons for the current food-versus-fuel debate is because Australia, Africa and parts of Europe suffered droughts simultaneously, causing global shortages of wheat and rice grains.

Moisture deficiency lowers yields of corn also. Although hybrids have been bred to improve productivity, especially in terms of the water responsiveness, we need better traits than what we have been able to find within the corn germplasm. At Pioneer, they evaluate their corn genotypes in terms of water responsiveness in "managed crop plots" in California where there is no rain. The amount of moisture in the soil is directly proportional to what has been provided through the sprinkler system. Monsanto and Syngenta have their own managed trials in which genes are being tested for drought-tolerance attributes. I predict that, by the year 2012, drought-tolerant genotypes of corn, canola and rice will be commercially available.

There is much excitement among researchers also with respect to nitrogen-use efficiency. Corn and rice genotypes are being developed that, with 75% of current fertilizer-application levels, show no yield penalty. Similarly, genes are being discovered that, when introduced singly into canola or soybean, have the potential to increase yields by 10% to 15%. I expect these products to reach the marketplace in the 2014–2015 timeframe.

On a global basis, agricultural productivity is less than what it could be. For example, the productivity of corn in China is about half of what it is in the United States. If new technologies are not deployed in other countries and if fertilizer and water-management capabilities are not available, there is no way we can use available arable land with optimum efficiency. Genetic engineering and a number of other technologies have not found full acceptance, and, of course, in many developing countries fertilizers are unavailable and/or soil fertility is low. We must find ways to reverse these trends.

This leads me to the thesis that it should be possible to improve US corn productivity more than the 3% per year seen over the past decade. I believe that it will be more like 5% to 6% very quickly, because we now have access to genomic tools unavailable just 5 years ago. We now have access to a large number of plant DNA sequences, and comparative genomics, bioinformatics as well as improved understanding of the synthetic relationships between plant species will allow much more rapid crop improvement than was possible by traditional breeding alone.

Extended Gene Pool

Traditional breeding has harnessed less than 10% of what is possible. Furthermore, wild relatives of crop plants contain genes that can protect their domesticated counterparts against disease and insect predation. These "interesting" genes can also increase growth rate, yield, photosynthetic efficiency and other attributes. The time has come to dip into this reservoir of genes and traits.

My colleagues at Pioneer have used tropical corn as a source of disease-resistance genes for temperate germplasm, to facilitate no-till farming. (No-till temperate corn is usually subject to disease and insect pressures.) With molecular breeding tools, this was achieved in just 2 years. We can expect further rapid progress of this kind in the future, including exploitation of genes in teosinte, one of the precursors of modern corn.

Implications of Increased Crop Yields

If we can increase yields of corn significantly, what is the potential in terms of biofuels production? At current yields of 150 bushels per acre, ethanol productivity (from endosperm, pericarp and stover) is approximately 510 gallons per acre. If we can push corn yields to 250 bushels per acre, with improved lignocellulosic technology to convert some of the stover and the cob to ethanol, there is no reason why we can't achieve 1,000 gallons per acre of corn over the course of the next 12 years.

For those who ask where 15 billion gallons of ethanol will come from, we actually have the potential to produce anywhere from 30 to 50 billion gallons of ethanol by the year 2020. We have some things to attend to, including the major byproduct of ethanol (and butanol) fermentation: distillers dry grains (DDGs). Today, DDGs are used to feed ruminant animals and with dilution with corn it can be fed to non-ruminants. However, if we produce 15 billion gallons of ethanol we do not know what we will do with the resultant DDGs other than drying and sending them to China, an expensive proposition. Application of lignocellulosic technologies to DDGs for additional biofuels production is an exciting proposition; the protein by-product can then be used as feed for a number of species, monogastric and ruminant.

If you are in Brazil and you are looking at corn, you are looking at the wrong crop. Sugar cane is the right crop for Brazil, which has the potential to be the Saudi Arabia of biofuels. Few of the technologies that we are applying to corn have been applied to sugar cane. By applying technologies developed for corn to sugar cane, there is no reason why we can't double or even triple sugar-cane productivity. Improving traits, like drought tolerance, has the potential to further improve the productivity of sugar cane. Also, applying lignocellulosic technology to sugar cane bagasse, might double biofuel productivity beyond what is obtained today. If I were in the business of starting companies I would concentrate on improving sugar-cane germplasm. Brazil already has mountains of bagasse next to the sugar-cane factories that is burned to generate electricity that is fed to the grid. But, there is huge potential to make liquid transportation fuels using bagasse.

Another crop that has potential in relatively dry regions, including southern Texas and across the tropics, is sweet sorghum. Sweet sorghum is capable of producing sugar and grain as well as producing biomass, all of which can be fed into the biofuels/biomaterials industry. In fact, this crop is now being promoted by ICRISAT[2] and other research institutions.

Unacceptable Loss of Carbon

John Pierce[3] and his colleagues at DuPont are working on lignocellulosic technologies. I hope they succeed because if these technologies can be made to work economically—producing sugar at the same price as that from sugar cane—it augurs well for the development of a new bioproducts industry. We need this technology very badly.

However, whether the sugar is of lignocellulosic origin or whether it's from sugar cane or is cornstarch glucose, when fermented by yeast or bacteria, 35% of the carbon is lost as carbon dioxide. The plant has already done the hard job of fixing the carbon dioxide and giving up a third of that carbon is simply unacceptable. Those interested in winning the next Nobel Prize should work on this challenging aspect.

Butanol

Currently there is an ethanol glut. Although available in many locations, it cannot be moved economically to where it is needed, like Delaware and California. For this reason, ethanol may not be the ideal fuel, which is where butanol comes in.

Butanol has many advantages over ethanol. It has higher energy density, is noncorrosive, and is readily miscible with gasoline so that it can be premixed and shipped. Also, it does not require a flexible-fuel engine. It has all the attributes that one would look for in an ideal biofuel. Two isomers, n-butanol and isobutanol, are being investigated, which have the added possibility of conversion to kerosene jet fuel as well as biodiesel. We do not have to wait for the production of biodiesel from algae or jatropha. We can actually use the lignocellulosic substrate, produce the butanol and polymerize it to diesel, kerosene or jet fuel. The most important breakthrough needed is the cost-effective production of these isomers. Scientists at a company DuPont has invested in, Gevo, are close to demonstrating cost-effective production of isobutanol. And I'm sure that DuPont researchers will soon report developments in this area as well. Stay tuned.

Biodiesel

Fatty-acid esters are being investigated from the perspective of B2 and B10 supplements to the diesel engine. The reason why the ethanol industry grew so rapidly in the United States was because it became the oxygenate replacing MTBE. We had to go to anhydrous ethanol as opposed to the hydrous ethanol, which the Brazilians use with their flex-fuel systems. Now there is opportunity to have the low-sulfur standard or the no-sulfur standard in diesel and to provide lubricity with fatty-acid esters. However, the problem is an insufficient supply of vegetable oil, even globally. The most efficient vegetable oil crop available is palm, which produces between 4½ and 6 tons of oil per hectare. It is the most efficient photosynthetic conversion available. In fact, being in the humid tropics,

[2]International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India
[3]See pages 25–38.

they "work" 365 days a year and there is no shortage of water. Having its DNA sequence will have tremendous impact on breeding; palm has seen no genetic improvement for 30 years. Bringing molecular tools, including trait technologies, to bear with this crop could double its oil yield.

Similarly, opportunities exist to significantly increase yields of rapeseed, which might be cropped three times annually in some regions.

Several colleagues, especially in India, are focused on jatropha. However, although it grows in arid environments, to be economically productive, jatropha needs to be fertilized and drip-irrigated. With these inputs, why not develop a biofuel crop that has potential as a food crop in times of need? Jatropha also has safety issues: it produces phorbol esters and a ricin-like toxin. None of these issues have been addressed.

Interest has increased recently in algae as a feedstock for biodiesel production. There is potential to produce vast amounts of oil on only a few acres. However, economic analyses indicate costs in the range of $15 per kilogram of oil, which compare poorly with palm and soybean oils at around $1 per kilogram. Algae offer prospects of rapid genetic manipulation. Increasing photosynthetic yields is more likely in algae than in plants. And we can create fluxes through the lipid pathway with synthetic biology, and increase lipid productivity. We can also make molecules that are expressed in algae with application directly as fuels. My thesis is that algae have great potential, but it will take some time to realize it.

Renewable Materials

We have the opportunity to produce renewable materials as well as biofuels. In fact a number of monomers are already being produced. As a venture capitalist, I get to review a lot of business plans. We see every type of possibility, including diacids, diols and diamines. It is almost as though we are looking at nylon and polyester development in the chemical industry 30 to 40 years ago.

Take-Home Messages

Regarding food versus fuel, 90% of what we read in the newspapers is erroneous. To get the facts, go to the sources, read the original articles and make up your own mind. Corn is being blamed as responsible for global food shortages. Although the United States has consumed significant amounts of corn for biofuel, this usage is unconnected to shortages of rice, wheat and fruits and vegetables. At most, corn may account for 20% of the current food shortage. Corn is less efficient than sugar cane or sweet sorghum in terms of its biofuel-energy content, but it's a good starting point on which we can build.

Applications of biotechnology have created value. Ethanol use by US transportation systems along with carbon dioxide savings from tractors (resulting from no-till practices) means that carbon dioxide reduction in the United States has been significantly greater than in Europe over the past 10 years through deployment of superior technologies.

Grain shortage is an important issue. Grain stocks are at all-time lows in the United States, India and parts of Latin America. A crop failure will constitute a major problem. We cannot address this without deploying modern technologies.

A hundred years ago, we were asking whether we should use ethanol and biodiesel in our engines or fossil fuels. Ford, Diesel and the Rockefellers had that dialog when the discovery of tetra-ethyl lead changed the direction of that particular history. With the development of biotechnology tools we have the potential to get back on track with renewable systems similar to those that prevailed for 10,000 years of human development. During two ice ages, 10,000 years ago and 5,000 years ago, human beings resorted to agriculture to survive. Mesopotamian agriculture, initiated 10,000 years ago, and further expansion of agriculture by the Romans 5,000 years ago were related to climate change. We must look at biotechnology as an opportunity to address climate change again.

We can silence the tsunami of food versus fuel. The prospects for agriculture are bright provided we learn how to apply innovation, provided we learn how to imagine and provided we create policies that allow that innovation to manifest itself.

GANESH KISHORE is managing director at Burrill & Company and CEO of the Malaysia Life Sciences Capital Fund. After receiving a PhD in biochemistry from the Indian Institute of Science, he obtained postdoctoral training in chemistry and biology and served as a Robert A Welch Fellow at the University of Texas at Austin. He then joined Monsanto as a senior research biochemist responsible for developing processes for the synthesis of aspartame, the active ingredient of NutraSweet and Equal. He subsequently led the development of the technology behind Roundup Ready.

He was named a distinguished science fellow, the highest honor bestowed upon scientists at Monsanto and was appointed assistant chief scientist. He also won the Queeny Award. As the leader of Plant Sciences Research at Monsanto, he directed the development and commercialization of most of the agbiotech products on the market today.

Dr. Kishore joined DuPont in 2002 as chief technology officer for its Agriculture and Nutrition Platform and took over the role of chief biotechnology officer in 2005. He guided the acquisition of several key technology companies and bolstered the biotech competence within DuPont, which he left in 2007 to join Burrill.

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Supporting Cross-Cutting Research: The Agricultural Bioproducts Innovation Program

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I was asked to talk about the Agricultural Bioproducts Innovation Program, which was established in order to coalesce research in Canada on bioproducts. I will begin with background on how that program came into existence.

Canada's Bioeconomy

Canadian interest in the bioeconomy isn't driven primarily by energy-related considerations. Canada is a net energy exporter, producing many forms including hydro, nuclear, oil and natural gas. The main reasons for interest in bioenergy are environmental and social, with the development of rural economies and improvement of farm incomes as desirable outcomes. The Canadian agriculture and agri-food industry is characterized by the production of commodities with very little transformation; participants are largely price-takers. With the emergence of developing economies such as India and China, which have significantly lower labor costs, Canada's competitiveness in commodity markets is at risk. The need to add value to Canadian agricultural products is becoming increasingly obvious.

The federal government has identified a few major priorities, including:

- Human health
- National security
- A strong economy
- The environment

Of these four priorities, agriculture plays a direct and significant role in three. It is recognized that food, which is produced by agriculture, has an important impact on health.

Agriculture is already a strong part of the Canadian economy, responsible for one job in eight. And agricultural practices can make contributions to the environment, for instance in carbon capture. As biofuel development was gaining momentum, the Canadian government recognized the opportunity to have a positive impact on the environment while using technology to develop new markets and enhance the agricultural economy.

At the same time, the government was developing a new *Strategy on Science and Technology*. Research in Canada is conducted mostly in the public sector; the private sector lags behind that in other countries in terms of tangible contribution to R&D. Too little of the knowledge resulting from Canadian R&D is translated into innovative commercial products. Therefore, the *Strategy on Science and Technology* focuses on translating research into innovation by forming multi-partner clusters, including government, universities and industry, to move technologies out into the marketplace.

The government has mandated efforts in renewable energy, with the following targets:

- An annual average renewable content of 5% ethanol in gasoline by 2010 and 2% in diesel fuel and heating oil by 2012.
  - This will require 2.3 billion liters of renewable ethanol, compared to the current 600 million liters.
  - It will require 500 million liters of renewable diesel compared to the current 100 million liters.
- It is estimated that biomass could provide up to 20% of Canada's energy supply by 2030 since the country has:
  - 7% of the world's land area,
  - 10% of the world's forests,
  - 68 million ha of farmland.

Agriculture's Role

The forestry sector is already a strong contributor to biofuels and is in a good position to diversify its bioproduct output. The agricultural industry is interested in increasing its share and decided to step up and be players. However, bioenergy is challenging in the Canadian context. The country has a fairly cool climate and many ecozones with long distances between them. The crops that are being considered as bioenergy sources on a world scale, such as sugar cane and corn, will not be major contributors to Canada's bioenergy portfolio for climatic reasons. Also, the population is small and urban, concentrated in five major cities spread across the country. Transportation between these cities or from production points to urban centers is a major challenge. And, as mentioned, there is relatively little private-sector investment in R&D. Many of the large companies that are players in the Canadian economy are subsidiaries of large multinationals—US- and EU-based—with little R&D performed in Canada.

On the other hand, Canada has the advantage of being a major producer of agricultural crops and forestry biomass. Farming occurs in diverse environments and on various scales.

There are large farms in the western prairie region, but there are also specialized, much smaller-scale farms in the eastern regions particularly in the Maritimes and on the coast in British Columbia. This provides flexibility to meet various markets. In general, the economic and regulatory climates are open to technologies such as genetically modified organisms, which are widely grown. There is general acceptance of the manipulations that are likely to be necessary to achieve a significant bioeconomy. Finally, industries that are important to the economy—automobile, construction, aerospace, *etc*.—are open to the potential improvements that bioproducts could bring.

Importance of Co-Products

It is recognized that energy on its own will not be economically viable in most aspects of the Canadian context. Neither ethanol nor biodiesel will provide major economic opportunities for Canadian agriculture; cost of production versus cost of transportation to market make it less competitive than in other countries. Value must accrue from biorefinery co-products. Canadian agricultural industries will need to extract all possible value before using what amounts to the waste stream for energy production. If at least some of the extraction and processing occurs in rural environments, it will provide new employment opportunities in the agricultural sector. The hope is to create high-skill jobs in areas such as engineering in addition to those that will help to keep family farms viable.

At the same time as the federal government was developing its *Strategy on Science and Technology*, Agriculture and Agri-Food Canada's research branch (somewhat analogous to the US Agricultural Research Service) was developing its own *Science and Innovation Strategy* through extensive consultations; seven priority areas were identified for future research:

- Enhancing human health and wellness through food and nutrition, and innovative products
- Enhancing the quality of food and the safety of the food system
- Enhancing security and protection of the food supply
- Enhancing economic benefits for all stakeholders
- Enhancing environmental performance of the agricultural system
- Understanding and conserving Canadian bioresources
- Developing new opportunities for agriculture from bioresources

Developing new opportunities for agriculture from bioresources is, in essence, developing the bioeconomy, *i.e.* making the transition from being a supplier merely of food and feed to a supplier of many value-added products.

In order to get there, the sector will need to innovate in many areas, including the identification of appropriate feedstocks for the climate, and systems for producing feedstocks to the desired standards. High-value multi-use crops will be needed and it would be ideal if they had environmental advantages such as perennial habit and the ability to fix nitrogen. Although that's not necessarily the material that is currently available, research on harvesting and processing technologies must advance.

Work is needed on product diversification and sustainability. For example, a group of researchers has bred lines of oats for particular physical and chemical attributes to facilitate biorefinery processing: hull-less oats that have few hairs are more amenable to separation and are usable, because of their specific chemical composition, in several applications including specialty foods, specialty feeds, cosmetics and cosmeceuticals. But we also need to know how much of a feedstock crop can be removed from the field in order to avoid a negative effect on soil organic matter, and we need to understand the energy inputs that are required to extract the various products. Research on these issues is in progress within Canadian universities and the federal system using various models including flax, triticale, and brassicas.

Focusing Resources

It is interesting to compare work being done in the ARS[1] to that being done in Canada with about a tenth of the population. A small economy has to be strategic. Canada must focus its public resources, but also encourage industry to be more of a research contributor and collaborator early in product development. It will have to take advantage of technologies created elsewhere while maintaining capacity for research, in order to remain attractive as a research collaborator.

Canada has developed several collaborative models. For example, the Canadian Biomass Innovation Network involves all of the federal departments that have an interest in biomass and bioenergy. It is led by the Department of Natural Resources, and it provides funding to other departments to carry out research that supports the overall objective of supporting bioenergy development and within the recipient department's mandate. There are other networks of centers of excellence, for example the Green Crop Network, which is comprised mostly of universities that collaborate to create the critical mass and complementary skill set required for larger comprehensive initiatives; the funding supports the networking activities rather than the research itself. In another initiative, the National Research Council (NRC)—a special operating agency of the Department of Industry—has designed a program of research with participation of the Department of Natural Resources and AAFC; it is anticipated that each department will bring its expertise as well as its stakeholders to the same table. The NRC works with the automotive, forestry, construction, *etc*., industries that are potential users of bioproducts supplied by agriculture and forestry. By bringing these departments and their stakeholders together, we believe we can achieve a better match between the supply and demand sides of research.

ABIP

AAFC developed the Agricultural Bioproducts Innovation Program (ABIP) with the aim of bringing entire value chains together in research, development and commercialization. ABIP's core concept is to develop valuable nontraditional products from agriculture through interdisciplinary research with innovation all along the chain. Eligible areas of focus areas are:

[1]Reported by Robert Fireovid, pp. 83–87.

- Better feedstocks—The development of crop platforms and cropping systems relevant to production of raw materials suitable for conversion to bioproducts.
- Better processing—The development of effective and efficient technologies for converting biomass into intermediates that can subsequently be converted into new products and fuel.
- More products—Product diversification through technologies relevant to production of a range of co-products that can increase the feasibility of biorefinery development.

The goal is to encourage the formation of networks that can focus on comprehensive projects. Therefore, ABIP is designed to support projects, portions of which may be carried out within federal government departments and other portions may be done outside of government, in universities or the private sector, according to need. The ability to support work in this range of organizations is unusual because of the rules governing the administration of federal funds. Program administration is, predictably, demanding, but is believed to be worth the effort particularly if we can set successful precedents.

A single call for proposals was issued. Selection criteria were designed to favor projects that were likely to have a transformational impact on the sector. Of course, scientific merit and return on investments were among the evaluation criteria, as was degree of collaboration. More value was placed on networking that was likely to be effective and was likely to ensure that all the pieces were in place to bring the product to market. Consideration was given for the ability to draw industry into the research and to get it sufficiently involved to start taking more of the initiative. Consideration was also given for the likelihood of creating high-skill employment.

A panel of a dozen international experts evaluated about a hundred proposals; because of the size of the networks only a small number could be recommended for funding. Some networks that had common interests joined together to form more comprehensive and robust projects. Some networks will develop bioproduct platforms based on specific crops. Some are developing platforms based on animal products. For some networks, the focus is on developing biobased materials including energy and composites, from various crops. Funding ranges from $1 million to $23 million per network, amounting to approximately $100 million over the next 3 years.

In order to get as much benefit as possible from this program, a twinning exercise was instituted with the European Community where their Seventh Framework Program had identified similar objectives. At a workshop, the principal investigators from ABIP networks got together with those from the EU networks to discuss issues of common interest. In cases where they discovered their overseas counterparts had a particular, useful technology or methodology, networks committed to exchange information, to exchange personnel or use common methodologies. Thus, benefit accrues to both sides through coordination with very small incremental investments.

CHRISTIANE DESLAURIERS'S training and interests are in plant breeding and biotechnology. She has worked within Agriculture and Agri-Food Canada (AAFC) in regulatory, research and management roles. Most recently she has focused on the bioeconomy and on research policy and planning.

Dr. Deslauriers has spent much of her career in Atlantic and Central Canada. She is currently responsible for AAFC's Charlottetown and Saskatoon Research Centres. She is working within a collaborative agreement between the University of Prince Edward Island, the National Research Council's Institute for Nutrisciences and Health and AAFC, developing more effective models for the delivery of cross-cutting multi-disciplinary research.

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Energy Transformations in a Land-Grant College: The Great Lakes Bioenergy Research Center

Irwin L. Goldman
University of Wisconsin
Madison, WI

> *The scientists of the DOE Great Lakes Bioenergy Research Center are eager to help solve what is arguably the largest socially, environmentally, politically, and economically significant challenge of our time—the need for new, renewable sources of energy.*—Tim Donohue[1]

In August of 2006, the College of Agriculture and Life Sciences (CALS) at the University of Wisconsin-Madison welcomed a new dean, Molly M. Jahn, from Cornell University. Dean Jahn joined CALS shortly after publication by the US Department of Energy (DOE) of a document titled "Breaking the Biological Barriers to Cellulosic Ethanol" and DOE's subsequent call for bioenergy research centers (DOE, 2006; Fig. 1). Several CALS faculty and colleagues at Michigan State University had participated in discussions and development of the DOE document and were carefully following the steps this agency was taking to develop bioenergy research centers in the United States. Earlier that summer, I had a visit from two of those faculty members who were anxious to begin discussions about a proposal to develop a strong and strategic thrust in bioenergy in our college. Among the faculty with an interest in this area was Tim Donohue, a microbiologist whose work included photosynthetic bacteria and energy production from microbes. These scientists were anxious to develop a large-scale effort within CALS and on the UW-Madison campus as a whole on bioenergy, and the DOE request for proposals fit perfectly in the framework of their thinking.

Within a week of her arrival, Dean Jahn convened this group of scientists to discuss opportunities at the federal level in bioenergy. These meetings led to the eventual submission of a proposal to DOE. The group formed partnerships with colleagues at several universities, including Michigan State University, Illinois State, Iowa State, University of Florida, and with two national labs as well as businesses. To form the core academic

[1]Professor of bacteriology in the College of Agricultural and Life Sciences, University of Wisconsin-Madison, and principal investigator, Great Lakes Bioenergy Research Center.

partnership, the group decided that the best arrangement would be to locate the primary centers of effort at Wisconsin and Michigan. Working closely with scientists and administrators at Michigan State University, including Steve Pueppke, Mike Thomashow, and Ken Keegstra, the group put forward a proposal for a Great Lakes Bioenergy Research Center (GLBRC), the purpose of which is to remove bottlenecks in the bioenergy pipeline.

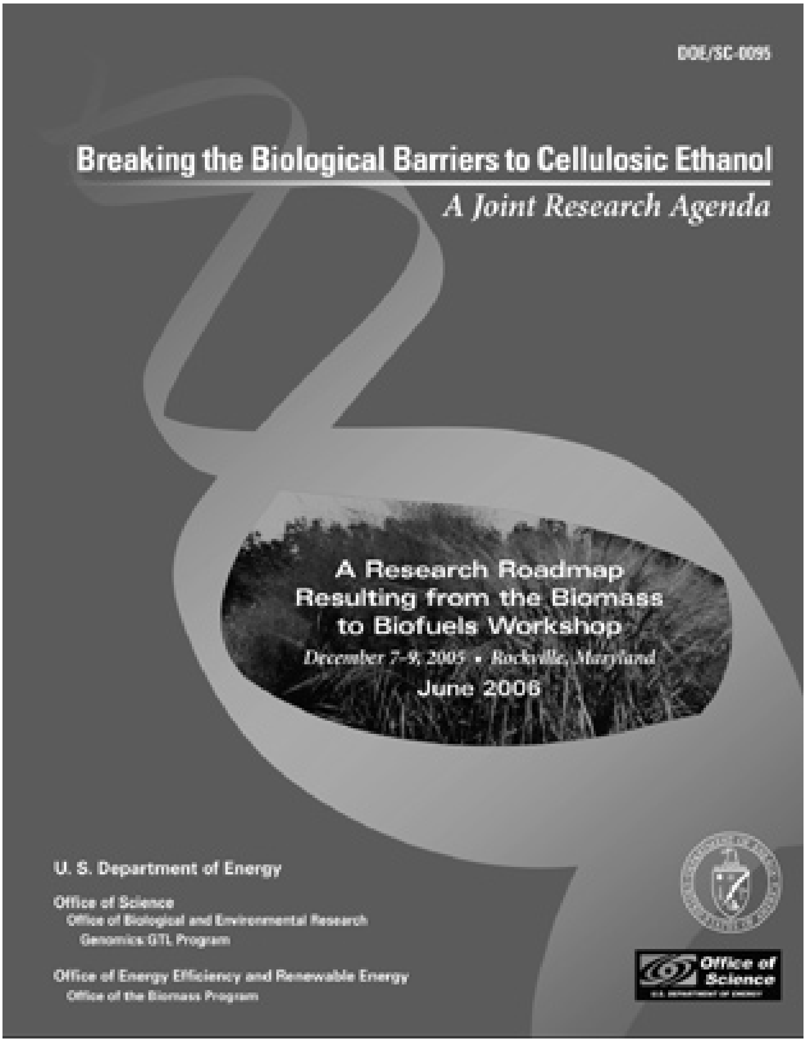

Figure 1. "Breaking the Biological Barriers to Cellulosic Ethanol," published in June, 2006, was a primary document used by the GLBRC to map out its proposal to the Department of Energy.

Dean Jahn led an effort to secure state support for the proposal through extensive conversations and partnership-building with the University of Wisconsin System, the Office of the Governor, the Office of Energy Independence, and other state agencies. Similar efforts were led by Dr. Pueppke in Michigan. Ultimately, substantial matching support was offered by the States of Michigan and Wisconsin towards the GLBRC proposal in the form of additional faculty positions to work on bioenergy, new facilities in which to conduct research, and funding to support research collaborations. The proposal included a unique emphasis on sustainable practices throughout all aspects of the bioenergy pipeline, as well as an education and outreach thrust to take information from the Center out to students and citizens, as well as to the broader scientific community. Notification of funding was received in the summer of 2007, and work began in the fall of 2007 on the campuses of the University of Wisconsin-Madison and Michigan State University. The work of the Center is conducted under the leadership of Professor Donohue and a management team, and is carried out by a cadre of several dozen scientists on each of the two main-partner campuses.

Location and Objectives

The GLBRC is located in one of the world's most productive agricultural regions, and, as such, is able to draw strength from expertise in public- and private-sector interests in agriculture. Center scientists are exploring diverse approaches to converting sunlight via various plant feedstocks—agricultural residues, wood chips, and grasses—into biofuels. In addition to its broad range of scientific research projects, the GLBRC is collaborating with agricultural researchers and producers to help develop the most economically viable and environmentally sustainable practices for bioenergy production. Formal partners in the GLBRC include the University of Florida, Iowa State University, Illinois State University, Lucigen Corporation, Oak Ridge National Laboratory, and the Pacific Northwest National Laboratory.

The GLBRC brings together expertise in grain-crop production, forestry and paper production, engine manufacturing, agricultural equipment manufacturing, abundant natural resources, and world-class university campuses (Fig. 2). Together with industry partners, this coalition of scientists and their institutions makes up a formidable team to advance the cause of bioenergy in the United States.

Research Thrusts

To increase the contribution of biofuels to the US energy portfolio, the GLBRC will conduct fundamental, genomics-based research to remove bottlenecks in the biofuel pipeline. There will be five major research thrusts, each of which has a leader on one campus and a complementary partner on the other campus.

Improved Plant Biomass

Among the bottlenecks in using biomass for bioenergy production are the inability to degrade the major constituents of cell walls (cellulose, hemicellulose and lignin) and the inability of many plant species to store carbon in energy-rich hydrocarbons. The GLBRC

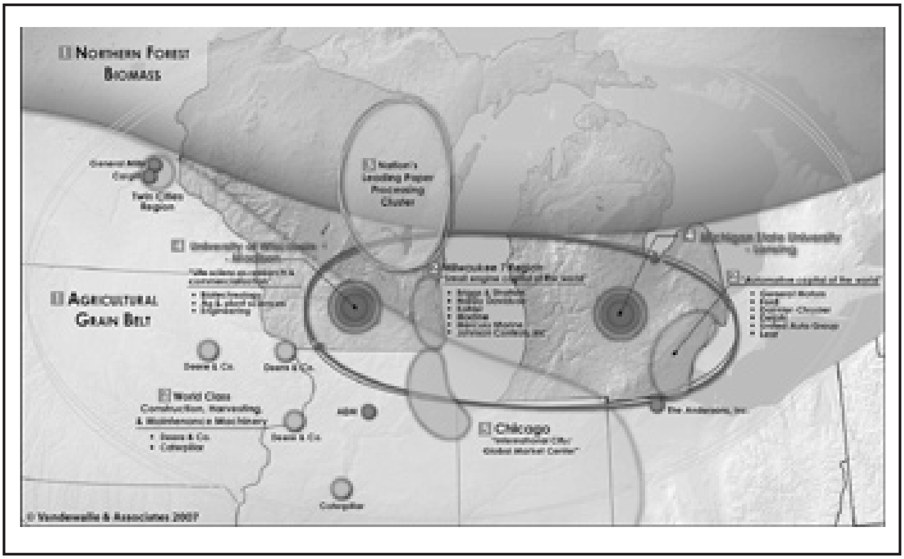

Figure 2. The Great Lakes Basin is one of the world's foremost economies, rich in academic expertise, engine and equipment manufacturing, natural resources, and highly productive agricultural land.

will strive to increase the yields of easily degraded polysaccharides within cell walls and to increase the yields of hydrocarbons in biomass tissues.

Improved Biomass Processing

Processing plant biomass into sugars is another biofuel-production bottleneck. The long-term goal of the GLBRC will be to develop new physical and biological strategies for processing plant-biomass feedstocks (corn stover, switchgrass, poplar, *etc*.) envisioned for the bioenergy pipeline.

Conversion of Biomass into Energy Products

To increase the contribution of biofuels to the US energy portfolio, plant-derived chemicals must be efficiently converted to bioenergy compounds. The long-term goals of the GLBRC are to improve methods for conversion of cellulosic biomass into ethanol and to develop novel ways to convert plant material into hydrogen, electricity and other chemical feedstocks that can replace fossil fuels.

Development of a Sustainable Bioenergy Economy

For a bioenergy economy to positively impact the US energy sector, it must be integrated into agricultural, industrial and behavioral systems. The GLBRC will develop economically and environmentally sustainable best practices for the entire biofuels-production cycle.

Enabling Technologies for Bioenergy Research

To realize these goals, the GLBRC will deploy high-throughput technologies, integrate

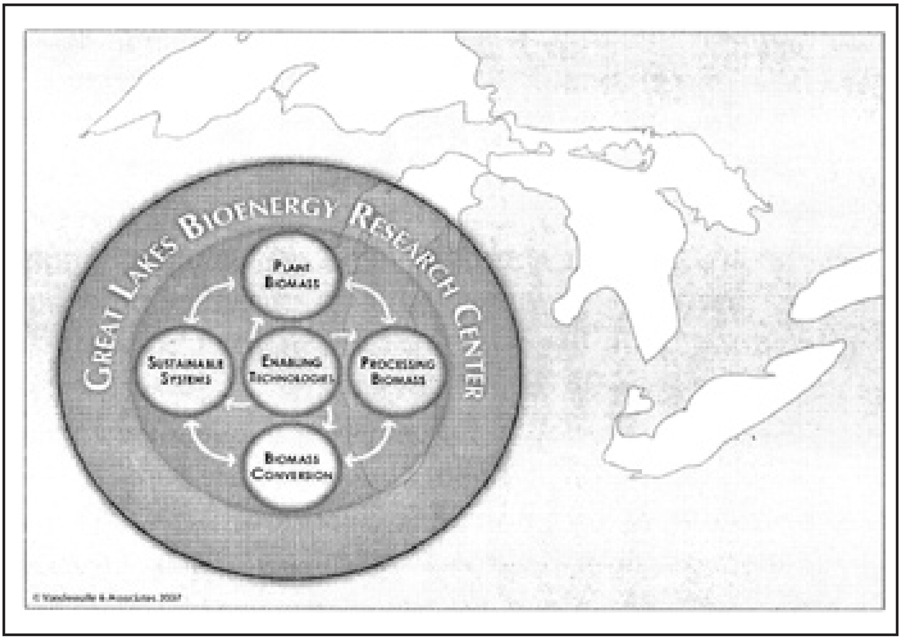

Figure 3. The five thrusts of the Great Lakes Bioenergy Research Center.

information from computational, physical, and biological approaches, and develop predictive models for relevant enzymes, pathways and networks. Thus, the center's success hinges on the application of enabling biological and physical systems and computational approaches to biomass production, processing, conversion, and sustainability.

Industry Partnerships

The GLBRC will generate linkages with the private sector that will help bring technologies to the marketplace. New technologies developed at the GLBRC will be tested in production-line facilities.

Education and Outreach

With a history of excellence in the land-grant missions of education, training, and outreach, GLBRC academic partners are deeply committed to training the bioenergy leaders of tomorrow while removing today's bottlenecks in the biofuels pipeline. The partners will offer new bioenergy-focused summer research programs, laboratory training, seminars, and special courses. Working within existing programs at partner universities, GLBRC scientists will develop workshops and educational modules for K–12 teachers on carbon chemistry, sustainability, and biodiversity issues related to biofuel production. Additionally, Center researchers will develop informative materials and host public forums to raise awareness of, and generate support for, biofuels among farmers and communities.

Explanation of Partnerships

The establishment of the GLBRC on our university campuses represents a new model for large-scale research and development with a federal partner. Achieving the objective of removing bottlenecks from the bioenergy pipeline is a monumental national goal. The urgency of this new national goal and the scope of the funding and oversight by the DOE require a new approach to engagement on the university side. The GLBRC has assembled a team of scientists across the United States with relevant expertise.

To create a better understanding of the larger context that ultimately influences the direction and acceptance of new biotechnologies, the GLBRC's lead partner, the University of Wisconsin–Madison, will draw on world-renowned expertise in genomics-enabled analyses of plant and microbial pathways, networks, and systems; computational analysis of bioenergy proteins, organisms, and ecosystems; and discovery, production, and improvement of bioenergy enzymes. However, the work of the Center will not be accomplished without extensive partnerships with both the public and private sectors. Accordingly, the University of Wisconsin-Madison entered into subcontracts with a number of partners with complementary strengths.

The primary partner and subcontractor is Michigan State University (MSU), East Lansing: MSU researchers are experts in the breakdown and synthesis of plant cell walls, oils, and other polymers; the breakdown of cellulose in plant stems, stalks, and leaves, including trees and other woody plants; and the development of biofuel-production practices that are both environmentally and economically sustainable. The University of Florida, Gainesville, as a GLBRC partner institution brings expertise in the conversion of lignocellulosic biomass into ethanol using novel bacterial agents. Iowa State University (ISU), Ames, brings expertise in constructing economic models of biomass practices. Scientists at Illinois State University, Normal, work on genetic and molecular analyses of switchgrass. Lucigen Corporation, Middleton, Wisconsin, provides valuable expertise in bioprospecting for new biomass-deconstruction enzymes. DOE's Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, will enable the GLBRC to evaluate biomass sustainability by modeling ecosystem changes that could result from the biofuel-production cycle. DOE's Pacific Northwest National Laboratory (PNNL), Richland, Washington, will enable the GLBRC to complete high-throughput analyses of bioenergy proteins and organisms and analyze the entire life cycles of bioenergy practices.

A major push will be the search for cellulose-degrading enzymes. To discover and improve enzymes for biomass deconstruction, GLBRC researchers are conducting high-throughput screens of genetic material from specialized ecosystems such as bacteria that live in association with tropical leaf-cutting ants. University scientists plan to examine the environmental and socioeconomic dimensions of converting biomass to biofuel. To determine the best practices for biofuels production, GLBRC researchers will study issues such as minimizing energy and chemical inputs for bioenergy-crop production; reducing greenhouse-gas emissions from the entire biofuel-production life cycle; and understanding the environmental impacts of removing leftover stalks, stems, and leaves of food crops. They will also study the social and financial incentives needed to promote adoption of more environmentally beneficial practices.

Flexible Management

Establishing the GLBRC on university campuses requires a flexible approach to research administration. Unlike individual-investigator grants and contracts, the GLBRC bears more similarity to a large commercial enterprise run from university facilities in that its sponsor, the Department of Energy, has a much greater hand in the development, progress, and workflow for the Center than a typical sponsor would have for an individual grant. A cooperative agreement between the university and DOE sets out terms and conditions that are more stringent than a standard grant, but perhaps less stringent than a standard contract. This middle ground provides enough flexibility for discovery, but also enough accountability to justify the level of investment. For example, per DOE requirements, revenue streams that will be created from licensing technology produced in the Center will be returned to the campuses in a conventional manner; however, the revenue will be returned to the Center at greater percentages than standard royalties produced from standard intellectual property on our campuses. Thus, the Center has a greater chance of being self-sustaining through additional royalty flow as a result of discoveries by its scientists.

Likewise, the development of a management team to run the Center is of utmost importance to the DOE. As such, great emphasis has been placed on the development of an over-arching managerial and administrative structure. Participation in the management of a center of this magnitude puts added strain on the time that faculty members have to participate in their programmed duties of research, instruction, and outreach. In this case, it is incumbent upon the institution to work with faculty and their departments to find solutions to problems previously not encountered. An example would be teaching or mentoring activities that require large time commitments in particular semesters, in conflict with management-team duties. The faculty member must be able to participate in faculty activities, but fulfill the management team's requirements as well. In such cases, it is important that departmental, college and campus administration seek solutions to assist faculty achieve these goals. In some cases, this assistance may come in the form of financial support to hire teaching or research assistants, but in other cases it may require modification of faculty appointments to reflect additional administrative duties imposed by the Center's management. In either case, flexibility on both sides is important in order to harness the intellectual contributions of outstanding faculty while maintaining the high standards for traditional research, instruction, and outreach that have made our campuses internationally recognized.

In a similar vein, progress reporting, material transfer, conflict-of-interest management, and other administrative actions become more-substantial challenges when sponsor requirements are stricter or more detailed than standard campus practice. Such is the case for the reporting of outside activities and conflict-of-interest management, which are more stringent under DOE management than usually practiced on the campus of the University of Wisconsin-Madison, despite the fact that the latter has a well developed, robust process for managing potential conflicts for research staff. This additional layer of scrutiny requires more vigilance on the part of the Center's management team and administrators in departments, colleges, and the campus.

The overall research strategy employed by the GLBRC is described below, organized according to the five thrusts previously described.

Improving Plant Biomass

In addition to investigating how genes affect cell-wall digestibility in model plants—cornstalks, and switchgrass—GLBRC researchers will breed plants that produce more hemicelluloses, starches, oils, or new forms of lignin that are easier to process into fuels. Plant oils have twice the energy content of carbohydrates and require little energy to extract and convert then into biodiesel. In the United States, biodiesel is produced primarily from soybean; however, oil yields per acre of soybean need to be improved. GLBRC researchers aim to increase the energy density of grasses and other nontraditional oil crops by understanding and manipulating the metabolic and genetic circuits that control synthesis and accumulation of oils and other easily digestible, energy-rich compounds in plant tissues.

Improving Biomass Processing

Located at the intersection of America's agricultural heartland and its abundant northern forest biomass, the GLBRC has access to a rich diversity of raw biomass for study. GLBRC biomass-processing research will discover and improve natural cellulose-degrading enzymes extracted from diverse environments. Improved enzymes created by the GLBRC protein-production pipeline will be used in analyzing a range of plant materials and pretreatments. Scientists will strive to find conditions to identify the best combination of enzymes, chemicals, and physical processing for enhancing the digestibility of specific biomass sources. Researchers will identify and quantify small molecules generated in various pretreatment methods and examine how they impact biofuel yield. Decreasing the costs of producing and using enzymes to break down cellulose in plants will involve collaboration with plant-biomass researchers. They are expressing biomass-degrading enzymes in the stems and leaves of corn and other plants—essentially designing plants to "self-destruct" on cue in the biofuel-production facility.

Improving Biomass Conversion

Biomass-conversion research is driven by the need to increase the quantity, diversity, and efficiency of energy products derived from plant biomass. Cellulosic ethanol is a major focus for GLBRC research, along with improvements in biological and chemical methods for converting plant material into hydrogen, electricity, or other bioproducts that can replace fossil fuels. In addition to converting plants into energy, researchers are developing microbes that directly convert sunlight into hydrogen or electricity. To create a microbe capable of carrying out all biologically mediated biofuel-production steps, scientists are taking a somewhat novel approach. Instead of modifying an effective biomass-degrading microbe to produce ethanol, they are engineering efficient ethanol-producing microbes to produce enzymes and pathways to break down cellulose.

Fostering Sustainable Bioenergy Practices

The GLBRC will take a holistic approach to evaluating the economic and environmental sustainability of transforming biomass to biofuel. Leading this area of endeavor is G. Philip Robertson, professor of crop and soil sciences at Michigan State University. As an ecologist, Robertson focuses much of his research on the role that agriculture plays in greenhouse-gas dynamics, for which he has an international reputation. He has been the director of long-term ecological research (LTER) at the Kellogg Biological Station in Hickory Corners, Michigan, the only site in the national LTER network to focus on agriculture, for almost 20 years.

The overarching charge of the GLBRC's sustainability thrust is to improve sustainability of bioenergy practices. Researchers in this area will support the biomass-to-bioenergy pipeline by developing ecological, agricultural and life cycle practices that are economically viable and environmentally responsive.

Modeling systems will be used to predict the impacts that the biofuel-production pipeline will have both locally and globally (Figs. 4 and 5). The goal is to develop a comprehensive framework that enables the analysis of biomass cropping in reference to land-use requirements and competition, environmental consequences (*e.g.*, water balance, nitrogen balance, carbon balance, and soil quality), and competing energy technologies.

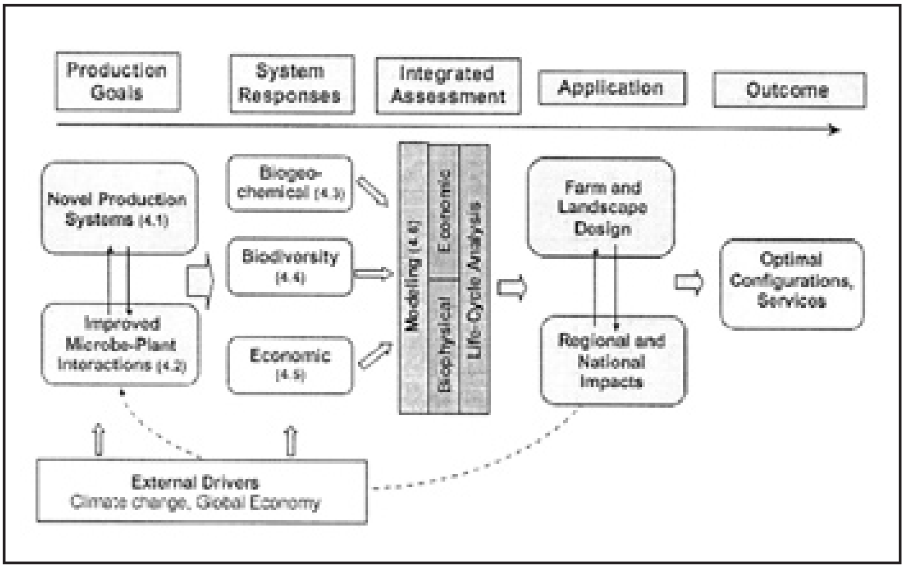

Figure 4. Determine elements of biofuel-production systems that can be optimized to improve environmental and economic sustainability. (Courtesy of GLBRC.)

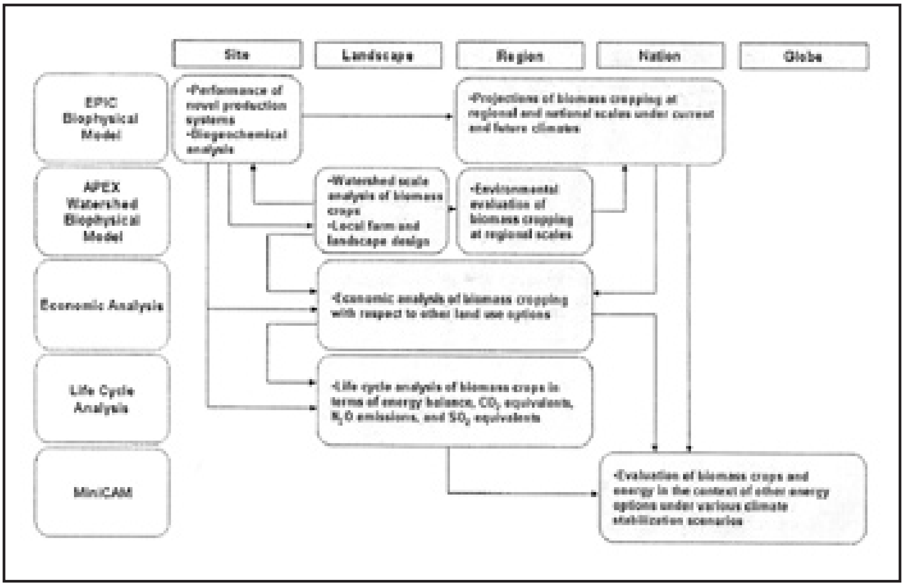

Figure 5. Determine elements of biofuel-production systems that can be optimized to improve environmental and economic sustainability. (Courtesy of GLBRC.)

Creating Technologies to Enable More-Advanced Bioenergy Research

This focus crosses all areas of research by providing cutting-edge, genomics-based technologies that enable the innovative discoveries and creative solutions needed to advance bioenergy research. GLBRC researchers will deploy high-throughput, automated screens for genes and proteins in plants and microbes that affect biomass and biofuel production; integrate information from multiple research approaches; and develop predictive models for relevant enzymes, pathways, and/or networks that can guide the development of new plants, enzymes, and/or microbes that would be useful in a biofuel-production pipeline.

Summary

The establishment of the GLBRC on university campuses represents a new model for large-scale research and development with a federal partner. Achieving the objective of removing bottlenecks from the bioenergy pipeline is a monumental national goal. The GLBRC has outlined five major thrusts that lay out a plan for improving plant biomass and its conversion to energy products for the United States. One of the unique elements of the center is its sustainability thrust, emphasizing practices throughout the bioenergy-production pipeline that focus on environmental and resource issues and sustainable practices. The thrusts are also complemented by an education and outreach effort to take information from the Center to students and citizens throughout the country.

Universities have been designed to respond well to national goals. However, this has primarily been achieved by individual investigators or groups of investigators working together in small to mid-size teams, often with great success. Through such programs, outstanding partnerships have been built between public-sector and federal-agency scientists. However, the urgency of this national goal on bioenergy and the scope of the funding and oversight by the Department of Energy require a new approach to engagement on the university side. For the GLBRC to be successful, we will need to advance our partnerships in new ways with the states where our campuses are supported. We will need to enhance our ability to be flexible with respect to faculty appointments and responsibilities in order to meet project goals. Ultimately, the paths that clear as this Center develops will blaze new trails for federal-state partnerships in science and technology for the twenty-first century.

Reference

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IRWIN GOLDMAN serves as vice dean and associate dean for research in the College of Agricultural and Life Sciences at the University of Wisconsin at Madison. His responsibilities include faculty hiring and development, budget, extramural grants, management of the college's Research Division, and research compliance. He is also a professor in the Department of Horticulture.

He has a BS in agricultural science from the University of Illinois, an MS in crop science from North Carolina State University, and a PhD in plant breeding and plant genetics from the University of Wisconsin.

Dr. Goldman served as a postdoctoral associate researching maize genetics at the University of Illinois before joining the faculty at Madison in 1992. He teaches courses in plant breeding and genetics, evolutionary biology and vegetable crops. Goldman is responsible for germplasm development and breeding and he conducts research on the genetics of cross-pollinated vegetable crops, primarily carrot, onion and beet.

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View from the President's Office: The Power of Partnerships

E. Gordon Gee
The Ohio State University
Columbus, OH

I am delighted that our Ohio Agricultural Research and Development Center (OARDC) is hosting this twentieth annual meeting. I visited OARDC in January and saw firsthand some of the remarkable research that is being conducted there, and each time I visited that place in my first tenure at the university I was very impressed by what they were doing. If my memory is right, nearly all of the research at OARDC is interdisciplinary in nature, involving external partnerships. The big ideas that we are confronting are the issues of food and sustainability, but also in that mix is the notion of external partnerships. And that notion of partnership is exactly the same thing you are doing here. I believe that through this conference and through your regular ongoing work together you are pursuing exactly the right course to assure America's future. And I mean this not just for your own impressive and growing industries, but for all of the conceivable kinds of enterprises. You have formed successful partnerships across industries and across the public/private sectors as well.

Competing Needs

The old silo approach—a good land-grant term—no longer works in higher education and I would suggest it no longer works in business or industry or in life in general, especially not in an industry where the issues are changing so rapidly. You are in a rapidly changing part of the world, intellectually. Not only that, two of the larger human needs that many of you seek to address—providing both adequate nutrition and an ample energy supply for the world's expanding population—seem to be in conflict. During the past few weeks we have all come to a fuller understanding of the world's immediate food crisis. The potential for political instability caused by scarcity of food is very real in many corners of the world. Certainly, we in the United States are not immune to the problems of hunger. We all share a concern that the basic needs of our neighbors are becoming more acute in this difficult economic period. At the same time, the earth's supply of fossil fuel is dwindling and we face an additional crisis with similar result: political turmoil brought about by diminishing resources. So, I think you are on the right track because I have a great deal of faith, and indeed hope, in what you are doing. I believe, for example, that biobased fuels offer much promise. In fact, we at Ohio State are proud that our campus buses run on soy biodiesel. Likewise, ethanol is increasingly used throughout many parts of the country. But this of course is what it is all about. It is the crux of the question that many of you are grappling with: how do we simultaneously meet growing food needs and increased energy needs? Others of you are balancing similar, if not quite so dire, competing needs. Creating biobased industrial products such as packaging, using soybean instead of foreign oil, is in itself a tremendous notion. But, choosing to grow crops for non-consumption purposes presents the issue of whether we are inadvertently taking food from those who need it most.

Pressing Global Problems

I'm a lawyer by training. I know little of the science underpinning what you are doing—although I am most interested in it—so I cannot pretend to know the answers to any of those difficult questions. But I do know this: we will find solutions to our most perplexing problems only by working together, only by joining together in the spirit of true collaboration. The full synergistic measure of our collective talents will be required to solve these problems. With us today are industrial scientists, entrepreneurs, faculty and graduate students from many different universities and leaders from Battelle and the Ohio Department of Agriculture. Finding solutions to pressing global problems, including balancing both food and energy needs, will surely require all of you and more. But with a 20-year history of working together, you have hit the ground running.

From an admittedly partisan perspective, I have to say that land-grant universities also have a long history of working in partnership to improve lives. That was the founding mission of those great institutions. As you may remember, land-grant universities were established under the Morrill Act of 1862, which was passed during the height of the Civil War. In the middle of those terrible days and months, President Lincoln had the foresight to invest in young people and communities. Perhaps more than any other kind of higher education institutions—I'll even be so bold as to say perhaps more than any other kind of institution—land-grant universities have a special covenant to meet pressing needs as they arise. Today, my own university's ability to help facilitate and develop solutions is important on several levels. It is, quite frankly, critical to Ohio's economic well-being. I believe that the American university is the essence and the stimulus for our economic future. The industries represented here are the state's top income producers.

Ohio Bioproducts Innovation Center

As you may know, agriculture is Ohio's' leading economic sector with a current value of some $93 billion. The polymer industry, with a proud history rooted in Akron and northeast Ohio, is the state's second leading economic sector with a current value of approximately $50 billion. To put it simply, agricultural biosciences are vital to Ohio's future. And there is much work to do, a great deal to accomplish in developing new bioproducts, devising more-efficient production methods, managing growing water-use needs, enhancing efficiency of biofuels and determining optimal renewable bioresources.

Each of the organizations represented here today is committed to addressing these issues. At Ohio State, we are fortunate in our work to have a strong partnership with the State of Ohio. Through its Third Frontier Program, the state has funded the Ohio Bioproducts Innovation Center as well as a facility dedicated to biomass-to-energy conversion. Those have been true collaborations and real success stories. The Ohio Bioproducts Innovation Center brings together Ohio State, Battelle, several corporations, the Ohio Soybean Council and PolymerOhio to drive the development of bioproducts. The Center, which has offices in both Columbus and Wooster, links genetics, biotechnology and chemistry to develop and commercialize new products. And the research conducted through the center is sure to act as a catalyst for additional investment and growth.

Waste No More

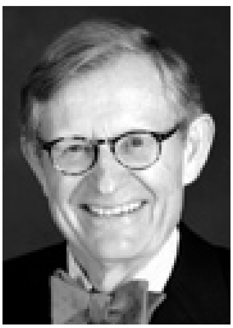
Another success story is the biomass-to-energy facility located at OARDC. As good fortune would have it, Ohio is rich in certain types of waste, which the biomass facility is putting to great use. Ohio State is working with Technology Management, Inc., and NewBio to create distributed scalable waste-energy conversion for use by farms and corporations. Their work is at the forefront of efforts to search for environmentally sound approaches to energy generation. Beyond the immediate gains, those partnerships have stimulated many scientists to think in new, creative ways to solve common problems.

Those are just a couple of Ohio State's partnerships. Increasingly we all are realizing the critical need to set aside zero-sum me-first thinking. I often say that higher education is the foundation for the future of this state, our nation and our world, and I believe that our well-being—economically, environmentally, artistically and politically—is closely tied to the generation of ideas. In saying that, I want to make one thing perfectly clear: we in higher education do not operate in a vacuum isolated from others of good intent and great ideas. Public universities are very much a part of the society that sustains them. We are truly a part of our communities and our communities—local and global if a distinction still exists at all—need us now as never before. I am personally committed to making my own university, this great institution we call Ohio State, even more aggressive in applying knowledge to real-world problems and conducting research for the public good and in fueling our economic prosperity.

Seizing Opportunities and Solving Problems

Turning again to our founding mission as a land-grant institution, Ohio State is duty-bound to act as a responsible global citizen. That commitment to rolling up our sleeves, to partnering with others, to applying ourselves to solving problems of the gravest concern, I submit, is the new American university. The global challenges we seek to resolve are vast and they are immediate. There's no doubt about it. But, I believe profoundly that the problems we face are surpassed by our enormous opportunities. I am utterly optimistic about our ability to seize opportunities and solve problems. To do so, of course, we must forcefully pursue the course of collaboration in which you serve as a strong example, indeed as a beacon on the hill. Many of us can remember a time when the worlds of academia and industry seemed light years apart, never to intersect. But yesterday's *status quo* will not light the way. Now there is mutual recognition of the power of partnerships. Now the world's commanding need for new solutions is at its strongest and now is precisely the moment to accelerate our own progress. Our strength in numbers and our cumulative power and our creativity are beyond measure.

I commend you on what you are doing. There was never a time when your work, your energy and your creativity were more needed, indeed sorely needed. One need only pick up a newspaper to know that what you are about is among the most important work that we can be about in this nation at this time. I thank you for letting me be here and I congratulate you on your good work.



IN OCTOBER, 2007, Gordon Gee was appointed president of the Ohio State University, the leading comprehensive teaching and research institution in the state, with campuses in Columbus, Lima, Mansfield, Marion and Newark, the Agricultural Technical Institute and Ohio Agricultural Research and Development Center in Wooster, and extension offices in every county. The university comprises close to 60,000 students, approximately 40,000 faculty and staff, and has an annual budget of $4.3 billion. The main campus in Columbus—the largest in the United States—has nearly 52,000 students.

Dr. Gee also has appointments as Professor of Law and Professor of Education. Previously he was chancellor of Vanderbilt University (2000–2007) and president of Brown University (1998–2000). He served a first term as president of the Ohio State University from 1990 to 1998, having been president of the University of Colorado (1985–1990), president of West Virginia University (1981–1985), and dean and professor at West Virginia University College of Law (1979–1981). At the J. Reuben Clark Law School of Brigham Young University (1975–1979), he served as associate/full professor and assistant/associate dean.

He has a BA from the University of Utah in history, a JD from Columbia University, and an EdD from Teachers College at Columbia.

PART V—THE STUDENT VOICE AT NABC 20

Student Voice Report 229
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The *Student Voice* delegates attended the plenary sessions and breakout workshops and then met as a group to identify current and emerging issues relevant to the conference subject matter. They were provided with four questions to help focus their discussions.

How does agriculture serve both food and fuel markets?

- Agriculture provides the economic basis of most countries. It is a key player in delivering a country's economic potential.
- Many developed countries have a paternalistic attitude about how agriculture should deliver economic well-being in developing countries. This "big brother" attitude may be counterproductive in producing sustainable agriculture.
- The problem of satisfying the economic demand for fuel in an ecologically sound program has no clear answers. For example, environmental damage occurs in Canada—the United States' main supplier—in the extraction of petroleum.

[1]To increase graduate-student participation at NABC conferences, the *Student Voice at NABC* initiative was launched ahead of NABC 19. Feedback from those involved was positive, therefore the program was continued for NABC 20. Grants of up to $750 were offered to graduate students at NABC-member institutions (one student per institution) to offset travel and lodging expenses. Registration fees were waived for the grant winners. Registration fees were waived also for some graduate students from NABC-member institutions who agreed to act as recorders for the breakout sessions; they also participated in the *Student Voice* discussions. Information on the *Student Voice at NABC 21* is available at https://nabc21.usask.ca/

[2]This article is a synthesis of a verbal summary provided at NABC 20 by John Schumm and of a subsequent written summary by Mary Carol Frier, Sarah Kiger and Susanne Lipari (NABC).

- A century ago, biomass was the most common fuel in the United States. The original diesel engine ran on peanut oil and the first Model T was fueled with ethanol. Biomass could become a common feedstock once again. How will we sustain the economic and population progress we have made in the Age of Petroleum as we return to biomass as an energy source?
- Is the public ready for large-scale use of biomass? Biomass is less energy-dense than a gallon of oil and currently less convenient to use. Will public sentiment allow more biomass to be packaged as fuel?
- It is important to remind the public that the major cost of food is not the raw product, but the handling, marketing and distribution to bring it from the field to the table.
- Biomass is only one aspect of our emerging total energy portfolio, which includes nuclear and renewables such as wind and solar. New technologies could be 30% or more efficient at producing energy than those based on petroleum.
- Land-use changes may be necessary to produce biomass for food and fuel, but they should not be drastic and should be sustainably managed.
- Development of multipurpose biomass feedstocks—oilseeds for example—from which food, feed and fuel can be derived, may ease the transition.
- We need more knowledge about crop residues in the field, particularly corn stover. Residues from alternative crops may or may not support soil fertility more effectively than corn stover. Crop residue should be considered a crop, with its own harvest problems/opportunities and profitability *vis-à-vis* the grain or oilseed or forage harvest.
- Biofeedstocks will increase in price as demand for them increases
- Biotechnology could play a key role in maximizing extraction of food, feed and fuel from biomass.

What systems are needed to optimize the impact of biofuels on greenhouse gases?

- As important as greenhouse gases are, the major issue is reducing oil dependence. Conservation and waste-product usage are necessary. We generate huge amounts of waste that could be used to produce biofuels. Landfills could be thus minimized.
- Greenhouse-gas emission profiles are wrapped up in politics.
- We should consider converting the desert to crops before converting the rainforest to crops.
- Optimize the current cropping systems to increase sequestration of carbon dioxide.

- Modify microorganisms used to produce ethanol to emit less carbon dioxide.
- Reduce field fallow time by growing short-season crops or winter annuals.
- Increase crop intensity, perhaps by intercropping.
- Use public policy to create awareness of the factors that contribute to greenhouse-gas emissions, *e.g.* a carbon tax.

Much research has been done to improve agricultural systems for the production of major crops (such as no-till planting). Should similar research be done for biomass crops?

- Yes. Similar research could reduce production cost and/or increase yields of biomass crops. It could also upgrade these lands to higher-valued agricultural uses. This research could include: optimizing irrigation and harvesting techniques and maximizing efficiency of use of pesticides and fertilizer.
- Land used to grow dedicated biomass crops should not compete with land used to produce food, feed and fiber. Such crops should be grown on non-prime land.
- Biomass variety selections should be based on end use, whether biofuels or other bioproducts. Examples of variation among varieties include cellulose, hemicellulose and lignin contents, water-use efficiency, pest and disease resistance, and place in rotations affecting crop intensity.
- Use of seed-delivered pesticides could reduce production costs and improve quality of biomass crop yield. They could favorably affect water-use efficiency.
- Seed for biomass energy crops is in short supply and must be ramped up to meet demand.
- Perennial biomass crops require patience in establishment. For example, switchgrass requires a 3-year investment in land and management before it will yield a saleable crop. Management includes comprehensive weed control until the crop is established by the end of year 2.
- Growing perennial crops reduces farmer flexibility in response to year-to-year changes in market demands.

What comments do you have on the NABC White Paper, *Agriculture and Forestry for Energy, Chemicals and Materials: The Road Forward*[3]?

- It outlines how traditional and new biomass crops can provide chemicals, materials, fuels and polymers that will provide sustainable improvements in homeland security and economic growth.

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[3]http://nabc.cals.cornell.edu/pubs/The_Road_Forward.pdf

- Its main focus is on using new biomass crops and unused residues and developing new processes to produce the next generation of energy, chemicals and materials. More emphasis is needed on current sources of biomass.
- Technological, social, and economic issues resulting from transitioning to new biomass crops still need to be addressed.
- Government and academia must provide not only R&D for new feedstocks and technologies, but also information and education for farmers, industry, and the general public.
- Farmers should be better informed about the best production decisions for their land.
- While farmers should be encouraged to grow new biomass crops, we shouldn't allow traditional farmers to become disadvantaged. It would exacerbate the food-versus-fuel controversy.
- New feedstock development, more efficient conversion technologies, and efficient transportation infrastructure must be encouraged.
- The short-term focus should be on replacing petroleum as a source of fuels and chemicals. The longer term should focus on biobased chemicals and biomaterials, as well as new crops that provide health benefits.
- Policy is needed to facilitate decentralization of energy production.

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On behalf of NABC, we thank Alan Wildeman (University of Guelph) for his leadership as NABC's chair for 2007–2008.

Ralph W.F. Hardy	Allan Eaglesham
President	*Executive Director*
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December 2008

[1]RWFH and AE also served on the planning committee.

PREFACE

The National Agricultural Biotechnology Council's twentieth annual meeting (NABC 20)—*Reshaping American Agriculture to Meet its Biofuel and Biopolymer Roles*—was the second in as many years to emphasize the importance of biofuels. The 2008 conference was built not only on the success of NABC 19 (*Agricultural Biofuels: Technology, Sustainability and Profitability*) but also on that of NABC 12 (*The Biobased Economy of the Twenty-First Century: Agriculture Expanding into Health, Energy, Chemicals, and Materials*).

The cover of this volume illustrates the challenge to agriculture to establish an equilibrium that will enable the needs of traditional markets (food, feed and fiber) to be met while also serving the needs of new markets (energy, chemicals and materials). The presentations and discussions at NABC 20 addressed the issues of food and feed, biofeedstocks, research and technology, economics, education and workforce development, ethics and policy, towards establishing this essential balance.

In 1998, NABC issued a *Vision Statement*[1] for agriculture and agricultural research in the twenty-first century. It envisioned improved food, feed, and fiber, but importantly it predicted agriculture's expansion into energy, chemicals, and materials (including biopolymers). This biobased economy, balanced with a reduced fossil-based economy, is projected to contribute to national security, sustainability, minimization of global climate change, expanded farmer-market opportunities, and rural development. Wording in the *Vision Statement* can be found in Executive Order 13134—*Developing and Promoting Biobased Products and Bioenergy*—signed by President Clinton in 1999. In 2000, NABC 12, which was hosted by the University of Florida, Gainesville, focused on these opportunities. It was the first conference to explore benefits from, and concerns about, the biobased economy. From that meeting grew the annual *World Congress on Industrial Processing and Biotechnology: Linking Biotechnology, Chemistry and Agriculture to Create New Value Chains*, the sixth of which will convene in Montreal, July 19–22, 2009[2], co-organized and sponsored by the Biotechnology Industry Organization, the American Chemical Society, the US Department of Energy, and NABC. In 2007, NABC issued *Agriculture and Forestry for Energy, Chemicals and Materials: The Road Forward*[3], an updated and expanded version of the *Vision Statement* describing opportunities for agriculture and forestry to be the basis for a hybrid bio-/petro-based economy with 100+ billion gallons of transportation fuel and value-added chemicals and materials produced from domestic biomass, and a structure for attainment.

[1] *Vision for Agricultural Research and Development in the 21st Century: Biobased Products Will Provide Security and Sustainability in Food, Health, Environment, and Economy*. http://nabc.cals.cornell.edu/pubs/vision.html.

[2] The *Summary Proceedings* from the 2008 *World Congress* is available at http://nabc.cals.cornell.edu/pubs/WCIBB2008_proc.pdf; information on the 2009 *World Conference* is available at http://www.bio.org/worldcongress/.

[3] http://nabc.cals.cornell.edu/pubs/The_Road_Forward.pdf; Hardy RWF Eaglesham A Shelton A (2007) Agriculture and forestry for energy, chemicals, and materials: The road forward. Industrial Biotechnology 3 133–137.

NABC 20's theme was biofuels and biopolymers, and Module I (*Megatrends Reshaping American Agriculture*) was held jointly with PolymerOhio. The themes of the other modules were:

II *Optimizing the Value of Co-Products and Byproducts*

III *Enhancing Productivity of Biofeedstocks*

IV *Policy Issues Impacting Agriculture and Bioenergy*

Hosted by The Ohio State University in Columbus, OH, June 3–5, 2008, NABC 20 had 107 attendees. Speakers comprised representatives of government, the agriculture and chemical industries, university administration and faculty, private companies and the US Department of Agriculture. At the conclusion of the formal presentations in Modules II–IV, panelists made brief presentations, providing alternative and complementary viewpoints, prior to Q&A sessions that included audience participation. Attendees then convened in smaller breakout sessions for further discussion of issues raised by the speakers and panelists and during the Q&A sessions.

To increase graduate-student participation at NABC conferences, the *Student Voice at NABC* initiative was launched ahead of NABC 19. Feedback from those involved was positive, therefore the program was continued for NABC 20. Grants of up to $750 were offered to graduate students at NABC-member institutions (one student per institution) to offset travel and lodging expenses. Registration fees were waived for grant winners. Registration fees were waived also for some graduate students from NABC-member institutions who agreed to act as recorders for the breakout sessions; they also participated in the *Student Voice* discussions. The student delegates attended the plenary sessions and breakout workshops and then met as a group to identify current and emerging issues relevant to the conference subject matter[4].

This volume contains an overview of the meeting, a summary of the breakout-workshop discussions and emerging recommendations, the verbal presentations—including those made during the banquet and luncheons—and the *Student Voice* report. Transcripts of the panel discussions and Q&A sessions are included.

NABC 21—*Adapting Agriculture to Climate Change*—will be hosted by the University of Saskatchewan, June 24–26, 2009, in Saskatoon, SK. Further information may be accessed via https://nabc21.usask.ca.

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NABC

[4]Information on the *Student Voice at NABC 21* is available at https://nabc21.usask.ca/student%20studentscholarships/student_index.htm.

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NABC 20
Thank you to our
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