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NABC REPORT 12

The Biobased Economy of the Twenty-First Century: Agriculture Expanding into Health, Energy, Chemicals, and Materials

Edited by Allan Eaglesham, William F. Brown, and Ralph W.F. Hardy

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The heartening success of the 12th annual meeting of the National Agricultural Biotechnology Council resulted from the superb efforts of the planning committee at the University of Florida, Gainesville, headed by William F. Brown and Judy F. Kite: Jerry Bennett, Dan Cantliffe, John Davis, Dean Gabriel, Charles Guy, Maria Gallo-Meagher, Glen Hembry, Lonnie Ingram, Shelly Schuster, and Rosalia Simmen.

Special thanks go to the facilitators who ably guided the discussions of the workshop attendees: Walter Anderson, Matt Baker, Jeff Burkhardt, Christine Chase, David Clark, Bill Dawson, Walt Fehr, Mike Fields, Dean Gabriel, Maria Gallo-Meagher, Dennis Gray, Charles Guy, Ed Hoffmann, Tracy Hoover, Marjorie Hoy, Lonnie Ingram, Tracy Irani, Jane Luzar, Joe Schaefer, Shelly Schuster, Rosalia Simmen, Mickie Swisher, Ricky Teig, and Indra Vasil.

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In addition, I wish to recognize the five years service of Jane Baker Segelken as Executive Coordinator of NABC, and offer her NABC's best wishes in her new endeavors. I am pleased to welcome Allan Eaglesham as Executive Director.

Ralph W.F. Hardy
NABC President

January 2001

When the National Agricultural Biotechnology Council (NABC) was established in 1988, its goals were the early identification of agricultural biotechnology issues and their discussion in an open forum; the safe efficacious and equitable development of the products and processes of agricultural biotechnology; and the development of public policy recommendations. Today, with a membership that includes thirty-three of the leading not-for-profit agricultural research and educational institutions in Canada and the United States, the NABC continues to strive to identify and consider in open forum the major issues, and provide all stakeholders — including representatives from academia, government, industry, public interest, farming, and others — the opportunity to speak, to listen, and to learn. Through its meetings, the NABC has addressed many major topics: sustainable agriculture in 1989, food safety and nutritional quality (1990), social issues (1991), animal biotechnology (1992), risk (1993), public good (1994), discovery, access, and ownership of genes (1995), novel products and new partnerships (1996), challenged environments (1997), gene escape and pest resistance (1998), and the impacts of biotechnology and industrial consolidation on world food security and sustainability (1999).

In 1998, the NABC Council issued a *Vision Statement* for agriculture and agricultural research in the twenty-first century. It envisions improved food, feed, and fiber, but most importantly sees agriculture expanding into energy, chemicals, and materials. This biobased economy of the twenty-first century, 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. In 2000, the NABC's twelfth annual meeting, hosted by the University of Florida, Gainesville, and held in Orlando, May 11 to 13, focused on these opportunities. It was the first discussion to explore benefits from, and concerns about, the biobased economy, and how they may best be managed. Attendees were able to visit the *Village Green* exhibit at Disney World's Epcot Center (the theme of which is biobased, renewable resources) that is expected to be viewed by 10 to 15 million people during its 15 months of opening. Almost simultaneous with the meeting, the National Research Council published *Biobased Industrial Products: Priorities for Research and Commercialization*.

The NABC12 presentations and discussions addressed many of the underpinning and ancillary issues of the development of a biobased economy nationally and internationally: the roles of academia, industry and government, farmer-industry relationships, bioethics, effects on the environment including climate change, energy security, and effects on food production in a world of expanding population.

Leaders from relevant and diverse organizations — academia, the chemical industry, farmer cooperatives, the USDA and the DOE — shared their views with an even more diverse group of attendees that included traditional and organic farmer/growers, industry representatives, consumers, university faculty, students and administrators, state and national agency/government representatives, elected representatives, and leaders and members of public activists groups. This report contains the summary of the workshop discussions and the plenary presentations.

Concerns ranged from whether farmers will benefit, to whether a biobased economy is viable against a backdrop of increasing scarcity of arable land necessary to feed the expanding population. We believe the reports herein, both workshop and plenary, provide excellent sources of information and coverage of the salient issues regarding the development of a biobased economy.

The forums provided by NABC foster meaningful communication on agricultural biotechnology, hence they promote understanding amongst diverse viewpoints, and allow the sharing of concerns. The 2001 NABC annual meeting — *High Anxiety and Biotechnology: Who's Buying, Who's Not, and Why?* — hosted jointly by the University of Illinois and Iowa State University, will be held in Chicago, May 22–24. Participants will have opportunities for discourse and debate on the safety, ethical, and environmental issues that influence the acceptance of biotechnology, especially by consumers.

In 1999, NABC published the *Statement 2000 on Agricultural Biotechnology: Promise, Process, Regulation, and Dialogue* to provide a concise but comprehensive overview of agricultural biotechnology. This statement invites individuals and organizations with concerns and stakes in agricultural biotechnology to participate in discussion of pivotal issues. The goal of NABC in this effort is to ensure that society, in terms of quality of life, security of food supplies and environmental sustainability, will benefit maximally from agricultural biotechnology while incurring minimal risks. *Statement 2000* is included as an appendix of this report, as is the *Vision Statement*.

Allan Eaglesham
NABC Executive Director

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NABC President

PART I

THE BIOBASED ECONOMY OF THE TWENTY-FIRST CENTURY: AGRICULTURE EXPANDING INTO HEALTH, ENERGY, CHEMICALS, AND MATERIALS

NABC 12: An Overview

William F. Brown
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Introduction

With rapid world growth and changing consumer demands and attitudes, sustained economic and social development will depend upon a secure supply of raw-material inputs for manufacturing needs. Continued depletion of limited global natural resources supports the concept of supplying industrial production and energy needs through the use of renewable, or biobased, resources. The United States has a highly productive agricultural system, which, in addition to providing basic food, feed, and fiber, can produce significant plant- and animal-based resources for use as basic building blocks in industrial production. There is an opportunity for agriculture to become a major source for production of energy, chemicals and materials in the twenty-first century.

Many believe that movement toward a biobased economy is the most significant opportunity for agriculture in more than 100 years. Various national activities in 1999 and 2000, such as the Presidential Executive Order for a biobased initiative, the National Research Council Report on Biobased Industrial Products, and the Epcot Millennium Exhibit document the expanding enthusiasm for this opportunity. The use of biobased renewable resources as raw products for manufacturing holds potential utility for many industries including liquid fuels, organic chemicals, polymers, fabrics, and health-care products. Use of biobased resources for energy production may reduce our need for fossil fuels, impacting national and international security concerns. This will have major implications regarding our access to energy, and may influence balance-of-trade issues, jobs, and military expenditure to ensure our access to oil. Current industrial chemicals and materials are mainly fossil-based, and a shift to producing these from biobased materials shows promise. However, several economic, environmental and societal issues will develop from the use of plant and animal resources in a biobased economy. Issues such as removal of productive land, which would otherwise be used for food, feed and fiber production, and replacing it with crop and animal farming for non-food biobased products must be addressed. Related bioethics questions of a global food supply and distribution system along with the use of genetically modified crops and animals in health, material, chemical and related fields will be debated. Potential loss of crop diversity through contract farming and the equitable treatment of farmers in their interaction with biobased companies are areas of concern for many groups.

The widespread use of plant- and animal-based inputs for fuel and industrial uses will require research and development efforts to address modifications in current processing systems, modifications to plant- and animal-production systems, and integration of fossil-fuel/biobased approaches. Major plant and animal production areas are not geographically suited to traditional processing facilities. Transportation issues and location of processing facilities near plant and animal production areas must be addressed. Successful progress toward addressing these and other challenges facing biobased industrial production will be achieved by an integrated, multi-disciplinary approach to research and development that combines talents from traditional agricultural disciplines with those from engineering, health, information technologies, and many others.

To address the implications of this new invigorating technology, the National Agricultural Biotechnology Council's twelfth annual meeting, held May 11 to 13, 2000, hosted by the Institute of Food and Agricultural Sciences at the University of Florida, focused on "The Biobased Economy of the Twenty-First Century: Agriculture Expanding Into Health, Energy, Chemicals and Materials." Keynote and plenary presentations, along with participant-driven workshops, debated the research and development, regulatory, public policy, industrial and economic issues surrounding our society moving toward greater production and utilization of biobased products.

Keynote Session

Two opening keynote presentations set the stage for the plenary presentations and workshop sessions over the subsequent two days. Ralph Hardy, President of the NABC, served as moderator for the session. He told the audience about the *Vision Statement for Agriculture in the Twenty-First Century*, published by the NABC in 1998. The statement emphasizes that, in addition to food, feed and fiber production, the "mission statement" for agriculture in the twenty-first century will include the production of energy, chemicals, and materials. In addition to this publication, Hardy noted that the recent report by the National Research Council (NRC) documents the promise and opportunities that exist for increased use of biobased industrial products in our society. For example, the NRC report suggests that the potential exists for 50 percent of our liquid fuel consumption to come from ethanol produced from biobased raw materials.

The report suggests also that 90 percent of our organic chemicals should come from biobased materials in the twenty-first century. This technology has far-reaching social, environmental, and national/international security implications. Opportunities also exist for positive impacts on the environment, improved sustainability, and rural community development.

Hardy mentioned two additional recent activities that will have a positive influence on the biobased initiative. First was the Presidential Executive Order charging the United States Department of Agriculture (USDA) and Department of Energy (DOE) to jointly develop a plan for a biobased initiative. The second was the *Village Green* exhibit at EPCOT, Walt Disney World, which focuses on the biobased, renewable resources theme and will be viewed by 10 to 15 million people over a 15-month period.

James Woolsey, a partner in the law firm of Shea and Gardner in Washington, DC, and former director of Central Intelligence, provided the first keynote presentation, giving his perspectives on “Hydrocarbons to Carbohydrates: The Strategic Dimension.” Woolsey indicated that he first became involved in the biobased topic nearly five years ago when invited by Senator Richard Lugar to testify before Congress on national security issues related to energy security and energy independence. Woolsey discussed the existence, importance of, and our dependence upon, networks in our society. He emphasized the societal damage that would result if these highly interrelated networks were intentionally disrupted; recent computer-virus activity was cited as an indicator. Most of these networks are designed to be open and user-friendly, and, in many cases, plans have not been developed to respond to intentional disruption.

He discussed in detail our reliance on the hydrocarbons network, particularly petroleum, and four associated difficulties. The first issue is the impact of fossil-fuel use; burning petroleum contributes approximately 40 percent of global-warming CO_2 emissions. Woolsey discussed results from a recent DOE study, which indicated that, on a scale of 0 to 200 where 200 indicates the global-warming gases emitted by a gasoline-driven car (considering the entire process of mining the petroleum, refining it and running the automobile), an electric car has an equivalent rating of between 130 and 180 because of the fossil-fuel emissions necessary to generate the electricity. On the other hand, a car burning ethanol produced from biomass has a rating of approximately 0, because no net CO_2 is released to the atmosphere.

The second issue, also related to the environment, is the impact of burning hydrocarbons on air and water quality. The fuel additive methyl tertiary butyl ether (MTBE), which makes gasoline burn more cleanly, is now found to be a severe threat to ground-water quality.

The third issue is the impact of oil imports on our trade deficit. The United States must borrow approximately $1 billion every day to finance its petroleum consumption. This has wide-ranging financial implications for the United States, but even more so for less-developed countries.

The fourth area is national independence and wealth transfer in view of remaining oil reserves. The main issue here is that predictions indicate that oil reserves in many parts of the world will soon (within 20 years) be depleted to the half-way point beyond which peak production rates will no longer be possible, and production costs will rise. This will force greater dependency on the politically volatile Middle East. Furthermore, global demands for oil will increase commensurately with the development of economies in Asia.

Woolsey summarized by saying that in order to deal with the potential problem of oil supply, we must begin to produce substitute fuels from crops. Recent advances in genetic engineering of bacteria to more efficiently convert biomass to ethanol hold tremendous promise. However, additional research is needed to enhance efficiency to produce economically viable alternatives to petrochemicals. A final issue raised by Woolsey, and discussed in some detail, was the potential uses of industrial hemp as a biobased raw material. The cultivation of industrial hemp is currently banned in the United States, although there are many potential uses for it.

Ralph Nader, founder of the Center For The Study Of Responsive Law, gave the second keynote address, "Changing the Nature of Nature: Corporate, Legal and Ethical Fundamentals," and pointed out that in the 1920s there was a similar attempt toward a carbohydrate-based economy. In Nader's view, that effort failed because the petrochemical, fuel, and paper industries failed to "take up the cause" and petrochemicals and associated products became dominant. This highlighted one of Nader's main points: the role of power (government and corporate) in making choices and setting directions. As an example, throughout the past 60 years the research budget of the USDA directed toward carbohydrate research has been minimal, whereas governmental subsidies to the oil, gas, coal, nuclear power, and forestry industries have been large.

Another important distinction made by Nader was whether corporations will drive the biomaterial movement of the twenty-first century or if government and university research will drive it. He pointed to three problems associated with corporate science. First, it is surrounded by proprietary and confidentiality agreements that limit the free exchange of scientific information. Second, priorities, for the most part, are profit-driven and may not best suit societal needs. The third problem is that corporate science brings with it the political power of corporations, which can translate into unfair advantage from certain tax credits and subsidies.

In Nader's view, the "rush" toward genetic engineering is leaving behind important areas of science including ecology, nutrition/disease dynamics, and basic molecular genetics. Scientific understanding of the consequences of genetically altering organisms in ways not found in nature remains poor. He said he was disturbed to read in the *NABC Statement 2000 on Agricultural Biotechnology: Promise, Process, Regulation and Dialogue* that ". . . risk from a product is inherent to that product not to the process by which it is made," and

". . . if identical products are produced by either molecular modification or traditional breeding then they pose identical risks."

Another issue raised by Nader was whether the family farmers will survive as independent producers along with producer cooperatives, or whether they are heading the way of chicken farmers who contract with large corporations for production. This has serious implications for land use and ownership. Nader pointed to a newsletter he read recently that described the possibility that, in the not-too-distant future, there may be only fifty integrated production units in this country delivering food and fiber. Also, who will decide which products are developed and incorporated into the marketplace and will there be free public debate? Or will large corporations make these decisions?

Nader also made several comments concerning risk assessment and the lack of funding, and knowledge related to the long-term impacts of genetic engineering. He noted also that questions challenging claims of increased yields of genetically modified crops exist, and that there may be loss of crop diversity with a move to these crops. Furthermore, he suggested that in developing countries there is greater concern with food distribution than with yield, therefore, although technology may exist to increase yields, the national power structure may not allow its distribution.

He concluded by saying that he hoped his comments would not be taken as negative on the promise of biomaterials, because he is quite positive about it. He likes what it does for small farmers, the environment, and for poor people abroad. His main concerns center around the process by which technologies are delivered and the potential misuse and redistribution of wealth and power that can occur.

Plenary Sessions

The conference's second day focused on *Evolving Roles for Science, Technology, Business, Government and Education in a Biobased Economy*. Gregory Zeikus, CEO of MBI International and member of the NRC Committee on Biobased Industrial Products, gave an overview of the recently published NRC Report, *Biobased Industrial Products: Priorities for Research and Commercialization.* Zeikus pointed out that the NRC report states that, "Biological sciences will have the same impact on the formation of new industries in the twenty-first century as physical and chemical sciences had on industrial development in the twentieth century." This statement is supported by four concepts. First, before the advent of the petrochemical industry, agriculture in the United States was involved in making industrial products from agricultural feedstock. Second, the new tools of genetic and bioprocess engineering now enable economic improvements in feedstock utility and manufacturing systems. Third, real environmental problems, including air and water pollution and global warming, are associated with industrial processing of fossil fuels. Finally, the common-sense realization dictates that petroleum, a non-renewable chemical and energy feedstock needs to be replaced by renewable agricultural carbohydrates to drive the economy of the new millennium. The NRC report further states that, "What is needed now is a national awareness far greater than that used to launch the space program and being the first country to get a man on the moon. Here both our future economic and planetary well-being are at stake in developing this biobased industrial products society."

Zeikus pointed out that a wide variety of industrial products are already biobased, including materials, fuels, and chemicals. He stated that the NRC report targets various areas for increasing the amount of biobased industrial products manufactured in the United States. For example, approximately 50 percent of liquid fuels, 90-plus percent of organic chemicals, and 99 percent of organic materials should be produced from biobased materials by 2090. Sales of industrial products from biobased materials increased from $5.4 billion in 1983 to $11 billion in 1994.

An interesting observation made by Zeikus was that new kinds of genetically engineered crops currently entering the marketplace are meeting disapproval in foreign markets and by the public because they are viewed as "altered and unsafe." This false perception is not currently a problem in the marketplace for biobased industrial products. For example, genetically engineered enzymes are already being used for making cheese and high-fructose corn syrup, and are employed in pharmaceutical production.

The NRC report established research priorities for systems, biology, engineering, and research. Research priorities include: evaluate sustainability / environmental issues, integrate biological and engineering research, emphasize risk reduction / proof of concept, develop infrastructure of trained people, databases, demonstration facilities, etc., and consider incentives / preferences. Research priorities for biology included: the genetics of plants and bacteria that will lead to improved understanding of cellular processes and plant traits, the physiology and biochemistry of plants and microorganisms directed toward modification of plant metabolism and improved bioconversion processes, protein-engineering methods to allow the design of new biocatalysts and novel materials for the biobased industry, and maximization of biomass production. Research priorities for engineering include: principles and processing equipment to handle solid feedstock, technology to improve fermentation rates and yields and increase concentrations of biobased products, and downstream technologies to separate and purify products in dilute aqueous streams.

Robert Dorsch, Director of Biotechnology Development for Dupont, provided a business perspective on biobased-product development. Dorsch cited a specific example of the large-scale chemical industry's view of moving towards sustainable production of chemicals and materials. He suggested that, although this work is in its infancy and still hypothetical in some instances, biotechnology is impacting the chemical industry, particularly the organic chemical industry, in a very major way. He noted that the results of chemistry dramatically affect our daily lives, and biotechnology is generating new knowledge that will lead to the development of new chemicals and products, which in turn will lead to new business opportunities. One of Dorsch's main points was that we should not polarize the issues of carbohydrate- and petroleum-based production. We will have to transition from where we are today to where we see ourselves in the future, and this will be driven by the combination of both sources of raw materials.

Other important points surrounding Dorsch's theme of sustainable chemicals and materials development were:

- Sustainability in the marketplace; offering people new goods to make life better and which, at the same time, are attractive to business.
- The products have lower costs and investment so businesses want to pursue them.
- The products generate a smaller environmental footprint as we develop and market them.

He added that opportunities that encompass all three, although not necessarily in balance, would have a very strong pull coupled with a strong push, which generally leads to activity and progress.

Greater functionality in a product really says we are going to make new chemicals that give us higher performance materials. At Dupont that generally means polymers. The company recently introduced a new form of polyester that has many attractive advantages and special traits. Its molecular structure, in contrast with current polyesters, allows fabric to rebound to its original shape after being stretched or folded. Such new compounds result from genetic engineering of microbes, which become the industrial reactors. However, this particular product results from a combination of both worlds — a low-cost material from the petrochemical environment and a low-cost chemical from starch.

Dorsch concluded that, via agriculture, we can fix CO_2 with nearly free net energy, mainly from sunlight, to produce plant matter for fermentations to synthesize new commercial products. Many people are thinking about how to move this transformation process directly into the plant to synthesis products of interest there. These future endeavors will be challenging and very interesting.

Dan Reicher, Assistant Secretary in the Department of Energy, gave an overview of the DOE's contribution to President Clinton's bioproduct and bioenergy Executive Order. One of Reicher's key messages was that success with bioenergy and biobased products will require an integrated approach, and that the nation's colleges and universities will have a very large role to play, and government, industry, and academic partnerships will ultimately be the key to success in the production and use of bioenergy.

Reicher pointed to five "drivers" for the development of clean-energy resources in the United States: reducing our dependence on foreign oil, electricity restructuring, the impact on environmental quality, climate change, and economic competitiveness. About three million megawatts of power are installed in the world today. Projections suggest that, over the next 20 years, we must add two-plus million megawatts to almost double the existing three million megawatts built over the last 100 years.

While these drivers suggest a bright future for bioenergy, there are serious challenges also, including increased need for integration and communication across sectors that must work cooperatively to ensure the success of biobased-product development. Reicher believes the stars have aligned in pursuit of this goal. Examples of significant events over the past couple of years include NABC's *Vision Statement*, the NRC report on renewable bioproducts, and the President's Executive Order. Reicher noted an unprecedented level of bipartisan legislative interest and support for Senator Lugar's bill, adopted by the full Senate, which will lead to major legislation authorizing new work by the federal government on biomass. Reicher expressed hope that this legislation will increase appropriations; the President's goal is to triple the use of biobased products and bioenergy by 2010, and many agencies in the federal government are working together to ensure this goal.

As part of the President's Executive Order, an interagency council on biobased products and bioenergy, jointly chaired by the DOE and USDA, has been established. A new advisory committee is being formed that will include university representation to advise the government on approaches to bioenergy and biobased products.

Reicher discussed challenges facing bioproduct development and use. Technological challenges include securing reliable feedstock sources, development of new delivery systems, and reducing conversion and down-stream processing costs. Market challenges include requirements for, and cost of, capital and investment options, the price, quality, and availability of other kinds of power and fuels, and the replacement costs of facilities. Practical issues such as sales, distribution and service networks, trade opportunities, and foreign market access are important challenges. There are also key policy challenges such as taxation issues.

He summarized several projects that are jointly financed by government and industry, including co-firing coal and biomass to generate electricity, the production of ethanol from cellulosic materials, using biofuels as a source of hydrogen for fuel cells, and the development of energy products from wind. He concluded by emphasizing the broad array of funding opportunities that are available for universities and industry, including solicitations on biobased products, co-firing research, and analytical and bio-refinery projects.

Roger Conway, Director of the USDA Office of Energy Policy, provided an overview of the USDA's contribution to the President's bioproduct and bioenergy initiative. Conway summarized activities surrounding Presidential Executive Order 13134, the goal of which is to triple the nation's use of biobased products and bioenergy by 2010. The USDA is interested in this initiative for its impact on rural, farm and forest economies. This past fiscal year, $23 billion were made in direct payments to farmers, the highest sum ever. There is need to develop market-based solutions to provide new avenues for increasing agricultural income. Examples of markets in which biobased products could compete include lubricants ($5.1 billion in sales), composites ($14.6 billion), paints ($43 billion), and plastics ($77 billion). Conway pointed to similar drivers of this technology including enhancing rural life, positive environmental implications of the technology, and enhancing national security.

He said that the USDA has a long history of developing biobased products and can contribute to this biobased initiative. By virtue of its strong linkages with land grant institutions and other federal and state agencies, both from research and extension perspectives, the USDA can facilitate market-development. He gave several examples of collaborative USDA and DOE projects, including a switch-grass biomass power project for rural development, and one using willows as feedstock for co-firing and gasification.

Patricia Swan from Iowa State University gave her perspectives on the role of the land grant universities in developing a biobased economy. Swan pointed out that when asking what land grant universities should do regarding the development of a biobased economy, it is important to review current societal expectations of them as well as the evolution of their responsibilities. It is also necessary to consider how they receive financial support to fulfill those responsibilities, and to examine the nature of the present challenge and how these universities might meet it. She noted that, over the past century, land grant universities had a federal mandate to work on new uses for agricultural commodities, which continues to the present. The interests of the states, which fund a greater portion of the work of these universities than does the federal government, have been fragmented due to differing within-state interests. Swan said there has been no attempt to address a comprehensive program toward the development of the biobased economy. If there is to be such a program in which the land grant universities participate, there must be a concerted effort to impress upon the public and, ultimately, Congress and state legislatures, the need for such a seemingly futuristic endeavor. Traditionally, the federal government has taken the lead in establishing programs aimed at developing new industries. It seems reasonable, therefore, that it should assume leadership in programs for developing the biobased economy, which has the potential for spawning many new industries. Full participation of the land grant universities in fostering a biobased economy will require that they have both a clear and forceful mandate and adequate funding for the task.

Swan said that there is an opportunity for land grant universities, if they will seize it, to conduct research on biobased product development that will result in important innovations. The universities have the responsibility for broad-based evaluation of the consequences of implementing these innovations. Also, there is a need to capture the minds of the current generation of students who will be the innovators, evaluators, and implementers in the biobased economy in the future. However, Swan noted also that scientific innovation alone is not enough. Thoughtful and broadly based evaluation of innovations must take place. This requires that individuals from several disciplines work together, communicating effectively and informing each other of the understanding and perspective of each discipline as it examines the potential consequences of an innovation. For only with informed multi-disciplinary evaluation will it be possible to fully imagine the consequences of implementing a particular innovation. All the required disciplines are within each university, but their researchers have little experience in working together. Moreover, these researchers are frequently distrustful and depreciating of contributions from other disciplines. These barriers will be overcome only if there is effective leadership from both scientists and administrators.

Lynn Rundle, CEO of 21st Century Farming Alliance, provided a view of the producer's role in a biobased economy. Rundle said that the vision of the structure of the biobased economy of twenty-first century agriculture is still a fuzzy picture of how genetics, production, processing, distribution, and marketing to consumers will work together. Agricultural producers want to know if they will be serfs or partners in the new biobased economy.

Statistics provided by Rundle show that production agriculture historically averages 1 to 3 percent return on investment. Since 1980, the food processing industry has averaged a return on investment greater than 15 percent. In addition, government payments to farmers in the United States in 1999 were $23 billion. These trends have driven farmers in his cooperative to look for ways to receive more dollars from the marketplace. The new biobased technologies will provide such opportunities, and the alliance structure allows farmers to be full partners.

Rundle indicated that the Alliance is a prototype of what committed groups of farmers will look like. They want to be partners, he said, vertically integrated in the production of biobased agricultural products. He provided examples of the Alliance's activities over the past four years. In 1997, 375 farmers invested $3.2 million in equity to purchase a flourmill in New Mexico. In 1998, a pinto-bean processing facility was acquired with equity from sixty farmers in Colorado, Nebraska and Kansas. Also, Alliance members have raised $3.3 million in equity and built two new commercial dairies with a milking capacity of 4,300 cows. These farmer investments are geared toward adding value to commodities the members are already producing. Farmers in the Alliance must deliver a specified number of bushels of corn, sorghum, wheat or beans to the processing facility per share of stock they own. This guarantees that the facility has the raw material, and the incentives are in place because of ownership that reward farmers for delivering their best quality commodities, identity-preserved, to "their" processing facilities.

In new biobased agricultural businesses, guaranteed supplies of quality, raw biomass products are critical to success. According to Rundle, the traditional methods of getting farmers to produce for specific end-uses (i.e., contracting for acres, bidding up the market to get premium quality) are less effective than partnering with stakeholders who happen to be producers of a manufacturer's most important resource: the raw product. With regard to biobased business startups, he has observed adversarial relationships between business people and farmers, such that partnerships failed to develop. Rundle said that farmers who partner with agribusiness will fare better in the long-term than those who participate in contract production. It is likely that raw materials will need to be grown close to processing plants, giving rural communities a unique role in these new industries.

The second day of the meeting included an evening at Epcot at Walt Disney World to view the *Village Green* exhibit, located within the Millennium Exhibit. *Village Green* visualizes the sustainability of the biobased economy through CO_2 recycling, and provides examples of the biobased economy in the transportation, apparel, and construction industries.

The last day of the conference focused on "Issues Surrounding the Biobased Economy." Paul Thompson from Purdue University provided comments on bioethics. He began by saying that there has been a 25-year debate over ethical issues regarding genetic engineering, although those associated with medicine have been treated separately and have received greater public acceptance than those associated with agriculture. Thompson believes that new biobased technologies that are not directly geared to food production may continue to enjoy wider consumer acceptance.

According to Thompson, most ethical issues that are tied to agricultural biotechnology fall into one of four categories: food safety, environmental impact, animal ethics, or social consequences. Food safety is one of the hottest issues. Some argue that individual consumers must not be put in a position where they are unable to apply their own values in choosing whether to eat genetically modified organisms (GMOs). Others argue that the matter of whether genetic transformation has been used is immaterial to the underlying values (such as safety and healthfulness) that are the basis of consumer choice. Environmental impact of agricultural biotechnology has received a great deal of play in the media, with some critics arguing that we cannot even imagine the possible environmental consequences of genetic transformation. Defenders note there are procedures for environmental risk assessment in place and maintain that these provide adequate safeguards for the environment. Animal welfare issues have focused on domesticated rather than wild animals. Contentious issues include the possibility of using gene transfer in ways that increase suffering for domesticated livestock, or of using gene transfer to relieve suffering by creating animals that are more tolerant of conditions that animal-rights advocates currently find intolerable. Finally, there are those who have framed the debate over agricultural biotechnology in terms of its social consequences. Arguments for the deployment of agricultural biotechnology note its capacity to feed the poor and benefit farmers while keeping the cost of food low for all. Critics fear that biotechnology will only turn the crank of the technological treadmill that has caused many farm bankruptcies and has depleted the population of rural communities for 100 years.

Cynthia Rosenzweig of the NASA/Goddard Institute for Space Studies gave an overview of global climate change and agriculture. Rosenzweig noted that the burning of fossil fuels and deforestation have raised the atmospheric concentration of CO_2 by approximately 30 percent since the industrial revolution. She said that human-driven increases in atmospheric CO_2 concentration appear to be enhancing the natural greenhouse effect, and many scientists believe that these activities are leading to surface warming. Global surface temperatures have risen about 0.7°C over the last century.

Rosenzweig commented that many uncertainties exist as to long-term effects of global warming. How much warming will occur, at what rate and to what geographical and seasonal pattern? What will be the consequences for agricultural productivity in different countries or regions? Will some nations benefit, while others suffer? The major impact of the "greenhouse effect" of increased atmospheric CO_2 concentration will be increased temperature. Effects on agriculture may be positive or negative. Increased CO_2 concentration generally will enhance crop growth, but the magnitude of the stimulation will vary among species. Agricultural pests are likely to thrive under conditions of increased CO_2 levels. Optimal environmental temperature varies for different crops, which tend to respond negatively when the optimal range is exceeded. Precipitation is probably the most important factor determining crop productivity. Most global climate models predict overall increases in precipitation, but their results also show the potential for less rainfall in certain regions.

Rosenzweig summarized crop-growth model predictions assuming that emissions of greenhouse gasses continue to increase as they have over the past 10 years. There are likely to be shifts in agricultural production zones around the nation and the world that may necessitate on-farm adaptation to new crops as well as changes in supporting industries and markets. Rosenzweig noted also that climate change is likely to bring changes in patterns of climate events as well as changes in mean values for temperature, precipitation, etc. Model estimates show that if variability in temperature or precipitation is doubled, corn and soybean yields will decrease and the frequency of corn-crop failures will increase.

Rosenzweig stressed also that climate affects not only crops but pests (weeds, insects, and disease) as well, and the distribution and proliferation of pests is determined to a large extent by climate. Also, climate (especially rainfall) can broadly affect pest-control mechanisms (i.e., herbicides, pesticides). Because of large variations in pest-species' responses to meteorological conditions, it is difficult to draw overarching conclusions about the relationships between pests and weather. However, most analyses concur that, in a changing climate, pests may become even more active than they are currently, causing greater economic losses to farmers.

Rosenzweig concluded by saying that climate change will gradually (and at some point may even abruptly) affect agriculture at regional, national, and international levels. The range of options available for producers in any given region will change. Farmers' strategies grow out of experience, but they will find that the past will be a less reliable predictor of the future. The responses of individual producers to changes of climate regime will involve alterations in the selection of crops and in practices of cultivation, irrigation, and pest control. Changes on the farm may, in turn, modify regional energy use, water demand, storage and transportation providers, and food processing. National farm policy can be a critical determinant in the adaptation of the farming sector to changing conditions. In the United States, farm subsidies may either help or hinder necessary adaptation to the eventuality of a changing climate. An important policy consideration is the assessment of risk due to weather anomalies. If flood and drought frequencies increase as projected, needs for emergency allocations will also increase.

In closing, Rosenzweig said that with the advantage of extensive research capacity, American farmers might adapt effectively to climate change, at least initially. Where infrastructure for agricultural research is less effective, as in many developing countries, adaptation to climate change may be slower. The vulnerability of food-deficient regions in marginal climates is likely to be exacerbated due to increased climatic extremes, including more severe and prolonged droughts alternating with floods. An overall increase in global food demand may benefit climatically favored regions, such as parts of the United States, though that advantage may be offset by intensified competition from still more favored regions (possibly Canada and Russia).

Lois Levitan, Director of the Environmental Risk Analysis Program in the Center for the Environment at Cornell University, discussed the risks and restraints to realizing the vision of a biobased economy given the constraints to the quantity and quality of land, water, nutrients, and energy to propel the system. Her evaluations were based on a simulation model using energetics as the indicator of global sustainability. As did other speakers, Levitan noted that a fossil energy-dependent economy is not sustainable over time both from supply and environmental perspectives. She began her calculations by estimating world-food needs relative to estimates of crop productivity, the availability of arable land, and thus the total area of land needed to drive a biobased economy. Based on four scenarios of varying crop-yield estimates and area of arable land, she predicts that sometime between the years 2000 and 2070 the world will have an insufficient area of land to grow enough food to provide a basic diet for the world population.

Given these observations and predictions, Levitan then commented on other resources needed to drive not only these food production levels but also a biobased economy, including nitrogen fertilizer, water and energy required for non-food purposes. Renewable sources currently supply approximately 21 percent of worldwide energy needs. Biofuels are considered as a means of increasing the quantity of renewable energy. Levitan noted that, up until now, corn has been the primary biofuel feedstock. She also clearly pointed out that unless alternative biofuel feed stocks are successfully developed and marketed (e.g., cellulosic biomass), the vision of biobased fuel production may be a mirage.

Ann Thayer, of the *Chemical & Engineering News*, provided a summary of the meeting that was less a chronological overview than a search for common threads and possible disconnects among the ideas that were presented, many of which are mentioned above. She concluded by observing that NABC represents a high level of enthusiasm for a vision of a biobased economy that holds great potential and promises significant opportunities for expansion for farmers beyond food, feed, and fiber, to include industrial products and fuels, with improvements in terms of environment, health, security, and economics.

PART II

WORKSHOP REPORTS

NABC 12

Workshop Reports

At NABC meetings, all attendees are active participants. Exchanges of information and ideas occur at question and answer sessions following formal presentations, and during lively discussions at breaks and social functions. However, the workshops provide the most direct and most powerful means of participation with face-to-face discussions and debates. The 2000 meeting offered three workshop groups. Summaries of the deliberations are provided, with consensus views and recommendations on the issues that will underpin the expansion of agriculture into health, energy, chemicals and materials, as the biobased economy develops in the twenty-first century.

Workshop A

Roles of Academia, Industry and Government

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The expansion of agriculture into health, energy, chemicals and materials will require new skills and staffing, and additional investments in research, development and commercialization, along with specialized facilities. Participants in this workshop were asked to consider what role academia, industry and government should play in the development of a biobased economy. Three broad issue-areas were identified as important considerations in this development: partnerships, communication, and maintenance of research credibility/objectivity.

Partnerships

Well-organized partnering between academia, industry, and government, as well as between and among various disciplines within academia will be critical to the success of a biobased economy. Academia should promote (and not hinder, as has sometimes been the case) multi-disciplinary team approaches to research. These teams should engage not only biological and agricultural scientists, but physicists, chemists, and social scientists. Industry should form alliances to fund basic research and become affiliated more closely with academia in terms of articulating research needs, or in jointly conducting research with academic scientists. Government should be involved at all levels (federal, state, local) to facilitate linkages, to aid in planning, prioritizing and conducting biobased research with academia and industry, and in providing funding opportunities as well as other incentives that would foster the development of partnerships.

Recommendations

Assembly of multi-disciplinary teams within academia

- When research administrators are hired, it should be made clear that one of their responsibilities is to enable multi-disciplinary research. Also, their performance as productive administrators would be evaluated accordingly.
- An academic institution must value accomplishments made by multi-disciplinary teams by recognizing team members with full rewards and credits for their achievements.
- Academia should look to hire faculty who have an interest in collaborative research and who will make such connections a high priority in their programs.
- Seed monies are needed from all sectors (public, private and government) to establish multi-disciplinary teams.
- Stakeholders outside of academia should be active participants in the research when appropriate.

Development of funding consortia

- Funding consortia would consist of all three segments: academia, industry (including non-agricultural companies), and government (all levels, and possibly the largest contributor).
- One main objective of any funding consortium would be to create "Biobased Centers." These may be real or virtual laboratories for core, basic, long-term biobased research; they may also support more applied, short-term research. Scientists from academia, industry and government would be active researchers at these centers.

Communication

All sectors involved in funding, conducting and commercializing biobased research must increase their efforts to communicate not only the benefits but also the potential risks of biotechnology-based products and processes. Particular attention should be paid to communicating sound, science-based information to the general public, to particular clientele groups (farmers, processors, direct consumers), to the news media, and to members within their own businesses or institutions. To this end, scientists and administrators in academia, industry and government all need to be involved in developing communication strategies that promote scientific literacy — especially literacy about biotechnology — on local, national and global scales. Further funding for communications research in this area will be necessary, since many strategies for communicating science and technology in the past have not been successful. For the biobased economy to become a reality, people who are well versed in the pertinent issues must make informed decisions. This should result in responsible uses of biotechnology, and perhaps even eliminate the need for strong government scrutiny and regulations. Science can and should serve the public good, and effective communication of this fact is a key.

Recommendations

Communication workshops

- Workshops focusing on effectively communicating science and biotechnology issues should be developed in order to determine what techniques and methods of communicating science work best.
- Workshops designed to highlight and educate participants in risk communication (or risk/benefit communication) would be valuable to all sectors.
- Listening sessions should be conducted involving stakeholders, so that their ideas and concerns are heard and discussed. The outcomes of these sessions would serve as the basis for future development of appropriate messages to effectively reach specific target audiences.

Improvement in scientific literacy

- Development of science outreach programs for K–12, and science workshops for K–12 teachers to educate them about biotechnology and a biobased economy.
- Design and implement biotechnology curricula at all educational levels.
- Conduct extension activities to communicate with particular target audiences through printed media, web-based media, and workshops.

Facilitation of information transfer between scientists and the news media

- Train scientists in how to effectively communicate with non-scientists on science-related issues.
- All sectors should make “expert” spokespersons available to the media.
- Media should be invited to campuses, research centers, etc. for demonstrations, tours and seminars.

Maintenance of Research Credibility/Objectivity

Although increased partnering between academia and industry would generally be desirable in furthering a biobased economy, it does carry some risks. In particular, questions may be raised about the credibility and objectivity of academic research since funding would be provided by industry directly to academia. Any public perception that academic scientists lack credibility would seriously hamper efforts to increase the publicís scientific literacy through effective science communication. Indeed, no one will believe the message if the messenger is not trustworthy. Therefore, it is imperative that research objectivity be preserved in order for credibility to be maintained. Without this credibility/objectivity, a biobased economy may never reach its potential.

Recommendations

Maintenance and improvement of funding structure

- Ensure that there is core funding (public universities, public centers) for operating costs and to conduct essential research according to agendas set by scientists and administrators within academic institutions.
- Some industry funds should be placed in a general or ìescrowî account to finance research by academia into safety or efficacy of industry products. Decisions regarding the distribution of these funds to specific individuals/ projects should not be determined by the industry, but again, by those in the academic institution.
- Academic freedom and independent peer-review of research results never should be compromised by the funding source.

Create a "disconnect" between industry and Extension.

- Those, whose positions include communicating about biotechnology and the biobased economy, such as Extension faculty, should be independent of particular industry support and should not be in any position to benefit from research results.
- A complete discussion encompassing all sides of a biotechnology issue, including ethical, environmental, social, and legal aspects, should be brought out by those communicating the impact of this research.

There is little doubt that we are moving toward a biobased economy. However, in order for this transition to be efficient, sustainable, and, ultimately, in the service of the greater public good, new and creative ways will be needed, in which public institutions and private enterprises can structure, fund, and monitor research and development of biobased processes and products. Moreover, there must be a spirit of openness on the part of individuals and institutions involved in the move to a biobased economy, in order to ensure public trust in science, and ultimately to guarantee, as far as possible, that real benefits associated with biobased processes and products are obtained. Participants in this workshop area articulated the need to move forward toward the biobased economy, though with a constant eye on potential risks as well as benefits.

Appendix

Contributions from workshop participants that may not be directly covered in the three areas described above, were as follows:

- Congress should pass legislation to support industrial biobased research centers at the university level.
- The federal government needs to aid in the development of markets for biobased products by providing the necessary incentives and minimizing investment barriers.

- USDA must be more aggressive/successful in obtaining funds for competitive grant programs; NIH, for example, does a much better job.
- The federal government needs to articulate the need for biobased research and fund it as it has done for NASA.
- Peer-review for safety and efficacy testing should be demanded of the industry and the findings should be in the public record.
- Industry should provide graduate-level internships.
- Intellectual property guidelines need to be in place to promote commercialization while protecting society.
- Patents and intellectual property issues are having a paralyzing effect on developing commercial products from academia.
- Ways must be found to redirect faculty to conduct research on biobased product development.
- Universities need to provide a better context for entrepreneurship.
- Biobased research at universities often does not support the needs of the industry because there is no dialogue between the two when fundamental decisions about research first take place. This situation needs to be changed so that initial decisions are made together.
- A small group of leaders is needed from all sectors to champion the biobased vision.

Workshop B

Producer-Industry Relationships in a Biobased Economy

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Our group was assigned the task of exploring how the transition to a biobased economy will affect relationships between producers and the industries that process and market food, fiber and fuel.

THE ISSUES IDENTIFIED

In our first session, we identified twenty-two issues concerning the development of new relationships between producers of agricultural products and the industries that process and market them. Points were assigned to each, and five key issues emerged:

- How can farmers achieve alternative modes of organization so as to capture markets and control the end (final, processed) products in order to reduce the volatility of those markets? How can these alternative modes of organization be financed?
- The transition to a biobased economy will put farmers in an environment of changing technology and markets. How can producers anticipate and embrace change in order to reap its benefits rather than suffer its negative consequences?
- How can producers acquire the skills and attitudes needed to survive in a much changed business environment? Alliances will become more important and individual entrepreneurship will decrease. In an environment that is technologically sophisticated, the ability to take advantage of value-added opportunities will be critical.
- How can farmers deal with the liability that results from increased involvement in processing and marketing?

- New processing facilities will need to be located near resource bases to reduce initial capital outlay and maintain product supply. What socio-economic impacts will these facilities have on rural communities?

DISCUSSIONS

The most important issue was the question of how producers can best organize themselves and acquire the capital needed to be effective players in this new economic environment. Traditional commodity production will likely continue, although reliance on the traditional approach to moving the product to market may mean that such producers will retain price premiums for new crops for only a short time. A division within the producer community may occur, where those farmers who elect to use the traditional commodity markets would be the economic losers in a biobased economy. Contracts that reflect demand and supply have advantages and disadvantages, particularly if they are long-term. A five-year contract, for example, may protect the grower from downturns in market price, or it may preclude reaping the benefits of periodic upturns in demand and price. New, more flexible, contract arrangements may be needed, but such arrangements may well increase grower exposure to market volatility as well as offer opportunities to profit from new technologies and crops.

Much of the discussion dealt with new structural forms that could better position producers to capture economic benefits in a biobased economy. One example is that of the 21st Century Alliance, who shared their entrepreneurial strategy at the conference. Their focus is farmer-participation in processing and marketing, an approach that will help growers capture more of the added-value component of biobased products. This option will range from full ownership and vertical integration of producers, to developing synergistic relationships with industry. One example of the latter would be that of a group of producers becoming essentially the sole suppliers of certain agricultural products, thereby ensuring a supply to the processor and protecting the intellectual property rights of the company that develops new knowledge. Other approaches involve restructuring agricultural businesses to capture niche markets or to use new technology to capture a greater share of the market value of transformed agricultural products.

Implementing many of these approaches, especially producer ownership of processing and distribution, will require large capital investments. This may be difficult to obtain, particularly at this time, when farmer resources — especially cash resources — are very limited. Offering land as guarantee for venture capital is risky. Furthermore, moving upward in the processing and marketing hierarchy will probably not be a panacea, because these sectors of the food, fiber and fuel industries are very competitive. Some large distributors have gone into direct purchasing or contract production, thereby eliminating several traditional middlemen (wholesalers, etc.).

Another major issue can be summed up in one word: change. The transition to a biobased economy will be technology- and market-driven, and the educational and skill needs of farmers will change concomitantly. Traditional attitudes and expertise may no longer serve farmers well. Embracing and taking advantage of rapid change will require problem-solving ability and analytical thinking. The traditional approach of lengthy research to verify recommendations that pass through a review process to Extension and finally reach the farmer will not be effective in a world of fast-paced change. Any given set of data or new production practices may be outdated before they reach the farmer.

Related to the previous issue, our third focus was specifically on the skills and attitudes that farmers will need in order to survive in a technologically sophisticated environment, where traditional individual entrepreneurship may not be the most appropriate way of making the most of economic opportunities. Attitudes that traditionally served farmers well may be ill-suited to this new environment. Strong individualism, for example, may need to give way to building alliances and partnerships. Similarly, farmers and the institutions that assist them may need to re-think their roles. Farmers will need to become researchers and teachers, as well as businessmen, and university researchers will need to learn entrepreneurship to assist farmers in reaping maximum economic benefits. In short, the attitudes, skills, and knowledge of farmers and other agricultural professionals must change if farmers are to take full advantage of a biobased economy.

Regarding the fourth issue — increased liability as farmers move more into processed products and marketing — one advantage of the traditional approach to marketing is that farmersí liability for product damage has been limited. In most cases, the processor and marketer of a product is held liable for any damage to consumers. Also, farmers have not been held accountable for some of the environmental costs associated with producing food, fuel and fiber, because their liability has essentially ended at the farm gate. This, however, has changed in recent years. And as farmers move into new products, processing, and marketing, the potential liability — particularly consumer liability — will increase.

Finally, our group focused on the question of how processing facilities that are tied to new biobased products will affect the communities in which they are located. These factories will need to be located near to the sites of production of the raw material, the agricultural product, but will have many requirements, including power, infrastructure, transportation, labor, and human capital. Therefore, as they develop, it is clear that there will be major socio-economic implications for rural communities. Labor is a good example; getting enough of it is already a problem for many farmers. Processing industries will demand not only labor, but also new skills and knowledge. How will influxes of such labor affect rural communities? Similar issues arise for the other components essential for building and operating large-scale processing facilities.

In our final session, we chose not to address the issue of increased liability. For the other four priority issues, we analyzed the inherent challenges, problems, opportunities and promises, and then looked for ways to overcome the challenges to take advantage of the opportunities. Several recommendations resulted.

Structure and Financing: Three opportunities exist, associated with the need for new forms of organization and financing.

- The potential for improving the economics of farming is high, since, in a biobased economy, the opportunities for farmers to participate in all aspects of product development and sales will increase.
- Similarly, a strong role for biobased products in the economy offers the producer opportunities for longer-term, more stable, market relationships, and synergistic associations in which farmers and processors benefit.
- The technological sophistication of new biobased products will offer opportunities for shared interests on the part of producers and processors, and the possibility of proprietary production methods extending from farm to market. On the other hand, these new structural and financial arrangements also pose challenges, e.g. decreased independence of the producer. As a farmers develops alliances either with other farmers or with businesses in other sectors of the food, fuel, fiber, and chemicals industry, his traditional independence is lessened. The other challenge is that the potential for losing the fundamental farm resource — the land — is high, if is is used as the capital to finance new organizational and production arrangements.

Recommendations To finance the structural changes needed, we recommend the formation of joint ventures between farmers and industry to share risk, as well as both formal and non-formal alliances among farmers and between producers and other segments of the food, fuel, fiber, and chemicals industry. Farmers have not traditionally been involved in raising the venture capital that may be a key to success in the future. Two conference presentations discussed useful new approaches to finding venture capital.

A Rapidly Changing Environment: Farmers will have opportunities to use biotechnologies of many types to broaden marketing mechanisms open to them, and to increase the kinds of products that they sell and their share of the consumer dollar. Dependence on highly volatile markets will decrease commensurately. The alliances discussed above may help farmers anticipate and take advantage of change. By working closely with other segments of the business community — from suppliers of inputs to marketers — farmers will gain access to information of all types and will probably have a more robust set of tools for analyzing that information. On the other hand, there are considerable risks associated with rapid change. One is that the public research and Extension system is simply too slow to respond effectively to a rapidly changing technological and economic environment. Another related concern is the quality of the data available for decision-making. Clearly, all decisions are made based on imperfect or incomplete knowledge. However, as change accelerates, the need to make decisions even more rapidly may force farmers into decision-making based on less — and potentially less accurate — information. Added to this is the fact that the technology and its related economics are still largely unknown. Such unknowns add significant risk to decision-making. Finally, even the most skilled and knowledgeable decision-maker, even if backed by adequate capital, may not be able to meet the challenges of the highly volatile, rapidly evolving marketing environment.

Recommendations There is need to enhance the flow of information to the producer. We recommend that this may be achieved by developing an institutional framework that is more entrepreneurial and product-focused than the current research and Extension system. Researchers in the chain must focus on end-product development. This will require changing institutional rewards to encourage entrepreneurial thinking, and training researchers and Extension personnel to think beyond simply developing knowledge to developing a marketable product.

Attitudes, Skills and Knowledge: The biobased economy offers producers the promise of more-stable, higher farm-based income. Smaller producers may develop skills and expertise in producing goods with low volume but high value, and larger producers can take advantage of larger markets for new biobased products. A producer with the appropriate skills, attitude, and knowledge will have opportunities to move beyond merely growing food and feed to participating in business ventures in which there are higher demands for, and profitability of, value-added crops. Exploiting these opportunities will require new ways of thinking: in many cases there will be less emphasis on production and more on business skills, less emphasis on individualism and more on building partnerships and alliances.

Recommendations The key to taking advantage of these opportunities lies in developing analytical and problem-solving skills. We recommend training programs both for producers and for agricultural professionals that will emphasize how to find information efficiently and how to evaluate its quality. In a rapidly changing technological and economic environment, knowing where to get information, how to evaluate it, and how to use it, will be keys to success for all agricultural professionals, including farmers.

Socio-Economic Impacts on Communities: No clear recommendations for action emerged. Many questions arose. Will the school systems in rural areas be able to prepare the work force demanded by these industries? Will local labor supply be sufficient to meet the needs of processors? Will processing have negative impacts on the quality of life many people value in rural areas? Will the infrastructure support the development and operation of such crop-processing facilities? In short, are we aware of the profound effects that locating major processing facilities in rural areas would have on local communities? Given the current status of rural communities, it is not clear that they are capable of supporting and meeting the needs of robust processing industries. This factor may slow the development of a biobased economy.

SUMMARY

The development of a biobased economy offers great potential and great challenges. While the potential economic benefits of these changes to producers and their communities are great, reaping these benefits will require new ways of doing business, new forms of organization, new avenues for transferring knowledge to producers, and new attitudes, skills, and expertise for all involved. We believe that one phrase describes the future of producers and rural communities: it will be different. The ability to cope with change is, clearly, the key to success.

Workshop C

Food and Environmental Issues Associated with the Biobased Economy of the Twenty-First Century

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Workshop participants were asked to address the following issues regarding the influence of the expansion of agriculture for a biobased economy on food production and the environment:

- What will be the impact of an expanded biobased economy on food quantity and price?
- Is there enough agricultural land, including that now underutilized, for food and the production of biobased industrial products?
- What will be the local, regional, national, and global environmental impacts of the biobased economy, including those on global climate change, local and regional air pollution, and local pollution resulting from processing crop residues?

A remarkably diverse collection of professionals debated these issues, ranging from directors of university-based biotechnology centers, scientists, philosophers, sociologists, corporate managers, communications specialists and writers, reporters, and environmental planners. Given this diversity, it was relatively easy to identify major theme areas of consensus. That it was possible to reach a consensus speaks as a strong endorsement of the importance of the main theme areas identified by the participants.

DEVELOPMENT OF FIVE THEME AREAS

During the first session, seventy-one issue statements or issue-related questions were identified (see Appendix). Individual statements or questions were grouped under one of five major theme areas that emerged: assessment, communication, global food security, process, and sustainability, of which, assessment, sustainability, and communication had the greatest concurrence.

ASSESSMENT

The policy discussions and public debates now active would benefit significantly from the dissemination of substantive peer-reviewed quantitative analyses of the impact of biobased products on the environment, human health and safety, and the economy. For example, the report *Biobased Industrial Products* by the National Academies of Science (NRC 2000) concluded that production of plant biomass for biobased industries could pose a hazard to the environment. If possible, it would be best to know the disadvantages, risks, and potential economic costs of new biobased industrial production ahead of time instead of after the fact. Knowing the potential long-term consequences and costs can help guide the development of the most environmentally friendly and safe biobased economy possible.

Biobased products have the potential to significantly affect consumers and society. In order to evaluate these effects, the products should be subject to the same critical safety criteria as their conventional counterparts. Included among the risks that should be assessed are: food safety, allergenicity (introduction of non-human proteins to biobased products), gene flow and disease resistance to non-target plants. At the same time, the benefits of biobased products should be substantiated not only standing alone, but in comparison with displaced conventional agricultural and non-agricultural products. Expected benefits include: increased productivity; utilization of otherwise useless by-products and residues; lower costs; quality improvement of nutrition, flavor, and texture; reduced environmental footprint(s) or impact; renewable raw materials; economic security for farmers; and improved balance of trade.

In order to stimulate the comprehensive assessments of an emerging biobased-industry, the federal government should promulgate competitive solicitations and make grants on a peer-reviewed basis. Converting to a biobased production will also have significant impact on the economies of rural communities and of developing countries. In addition to the basic scientific research called for by the NRC report, the development of new industries, and the evaluation of environmental impacts and issues of social and economic justice should also be substantively analyzed.

SUSTAINABILITY

The first step was to define sustainability. The group concluded that it is the ability to produce adequate food and materials for the human population in a manner that is continuously ecologically, socially, and economically sustainable, and in terms of the promise of a biobased economy. In addition, sustainability is also long-term survival with a high standard of living (good quality of life and environmental health), self-sufficiency in food/energy/materials in developing as well as developed counties, globalization of sustainable technology, and retention of wilderness.

Some of the problems and concerns about sustainability include what is the carrying capacity of the earth (is it higher or lower than at present?) while providing a reasonable standard of living. Presently, there is an inadequate knowledge base, and sources of funding are lacking with which to develop the prerequisite information. In addition, a concern is how to provide incentives for adoption of practices that sustain land, water, and other limited resources.

Several policy statements regarding the development of a biobased agriculture were formulated to help guide decision-making:

- Large-scale conversion of agriculture to a biobased economy will require a thorough analysis of sustainability.
- Stable public-sector investments will be required to establish a knowledge base to develop appropriate technologies.
- All constituent groups must work toward the development of policies that incorporate consideration of ecological costs into products and goods destined for the marketplace.
- A global dialogue is necessary on these issues using partnership structures, with participation of federal, state, academic, industry, non-governmental organizations, and citizen groups.

One aspect of biobased production of biomass for fuels — such as alcohol — is that biomass is a renewable resource, that, unlike petroleum-based fuels, would not necessarily contribute additional carbon dioxide to the atmosphere (NRC 2000). Plant material used for biobased fuel fixes essentially the same amount of carbon dioxide as that released by combustion, and thus is more sustainable than petroleum-based fuels. It would be especially beneficial if biobased fuels could meet the growing energy needs of the developing world. Additionally, plants used for other biobased industrial purposes will act as a sink for additional carbon dioxide and help to mitigate the production of greenhouse gases that contribute to global warming. Another potential benefit of biobased industrial production includes the opportunity to use systems that require less input of agrochemicals and energy, improve soil structure, and increase water quality and soil organic matter.

COMMUNICATION

Due to the complex nature of biotechnology/biobased industries, increased educational and communication efforts are needed for people to better understand the science and the products that originate therefrom. The NRC report on biobased industrial products states, “The public as well as policy-makers should be educated regarding the rationale and benefits of biobased production” (NRC 2000). In this process of communication, the risks and benefits of the science must be presented to the public. Sensational aspects of the topic have been reported by the media, thus communication efforts are now needed to show the complete picture. This must be accomplished in partnership with the media. In particular, examples of currently utilized products should be highlighted.

Based on studies showing that the public trusts universities as sources of information, these institutions can be charged with at least some of these communication efforts. Consumer focus groups should be actively pursued to identify major obstacles to acceptance for the public, and areas of concern. Out of this process, specific communication tools can be developed that reflect both the concerns and understanding of the public.

Process Involvement

A biobased economy is inevitable, and is already being promoted by the federal government under Executive Order 13101 requiring federal agencies to implement cost-effective procurement preference programs for the purchase of recycled products and environmentally friendly products and services. However, the right process must be in place to ensure that biobased agriculture, as a source of fuel, materials, and chemicals is sustainable in terms of ecosystems, health, equity growth and economic viability. Further, the growth and transition to a biobased economy must be based on consensus among researchers, consumers, producers and processors, investors, and technology developers. For this to occur smoothly, good-quality science must focus on priorities set by the public as a result of widespread discussion. If there is public involvement from the beginning, general well-being can be protected. We need to continue with the systematic consideration of renewable non-petroleum alternative fuels, materials and chemicals. However, finding consensus is perhaps a most difficult task, especially when reasonable people disagree on basic premises. Concerns raised by the discussion regarding process and involvement include:

- What is the impact of current implementation of intellectual property rights on innovation and accessibility?
- Intellectual property rights hold up the transfer of technologies through licensing and non-exclusive licensing.
- Research priorities supported by public funds should be designed to serve the greatest public good.
- Risks and benefits must be shared so that farmers are dynamic partners in the value chains, rather than contractors or low-cost providers. Public involvement will help to build a political environment that will hasten a just and equitable transition.

Recommendations We recommend broad public involvement in discussions of the different ways a biobased economy could be achieved. There is opportunity for farmers and rural communities to benefit from new employment and businesses that develop from biobased industries. These opportunities can arise, in part, from the fact that biobased industries will likely be located near production areas. Therefore, it is critical that rural communities be equal participants in the development of new biobased production and industrial commodities.

Food security

If world population continues to increase and at current production rates, we could face shortfalls in food production if large tracts of arable land are shifted to biobased non-food uses. Ideally, population growth would be restrained to limit pressure on the need for growth in the food-production system. Otherwise, there will clearly be impacts on food security, distribution of wealth, political stability and world peace. In 1998, the United States had about 2.2 million farms, with a total of more than 950 million acres and an average size of 435 acres (National Agricultural Statistics Service, http://www.nass.usda.gov:81/ipedb/). In 1990, 12 percent less land was devoted to crop production than in 1929 (USDA 1999). Coupled with continued losses of land under cultivation (which occurred at about one percent per year in the 1990s), large shifts of arable land to non-crop uses could result in food-price increases. Also possible are declines in global food stocks, price and supply fluctuations as producers shift back and forth between food-crop and non-food-crop production in response to changing government policies, the marketplace, corporate consolidation, spin-off and technological advancements. Global conflicts may be provoked by food shortages and inequitable distribution. On the other hand, productivity per acre has significantly increased over the past 60 years. For example barley yields remained constant between 19 and 25 bushels/acre from 1866 to 1949, then doubled over the subsequent fifty years (Table 1). Productivity gains for corn have been even more dramatic (Table 2). If biotechnology can lead to additional gains in yields similar to those of the past fifty years, then the shift of some arable land to non-food biobased industrial production may have little impact on food production or world food security.

	Yield (bu/acre)
1866–1940	19–25
1950–1959	27–32
1960–1969	30–45
1970–1979	40–50
1980–1989	49–57
1990–1998	55–62

Table 1. U.S. barley yields (USDA National Agricultural Statistics Service, 1999).

	Yield (bu/acre)
1920–1929	22–30
1930–1939	19–30
1940–1949	29–43
1950–1959	37–53
1960–1969	55–86
1970–1979	72–110
1980–1989	81–120
1990–1998	101–139

Table 2. U.S. corn yields (USDA National Agricultural Statistics Service, 1999).

Conclusion

In the workshop's final session, additional important points about the five major theme areas were discussed.

Sustainability

When sustainability is discussed, there is a critical need to address specific terms, e.g. water, competition for resources, long-term vs. short-term considerations. Equally important is the need to consider the "true cost" of biobased industries and specifically how do we determine what elements contribute to it. It was again emphasized that there is a need for stable funding of research relative to the development and impacts of a biobased economy and that it is the obligation of federal/state/international partnerships to ensure that adequate information is available to capture the benefits and minimize the risks.

Assessment

Assessment must include system impacts: what is grown and where. This must include all levels of human and environmental contact.

Global Food Security

In terms of global food security, there must be a balance between equitable food production and distribution and agricultural production of value-added specialty commodities.

Communication

Communication must go both ways. Information flow and dialog must occur in all directions among government, the public and industry. Communication must be sincere, thoughtful and substantive.

Recommendations

- Comprehensive socio-economic assessments will be necessary of the influences of the biobased economy on food supply/prices particularly in importing countries of the developing world focusing on ability to pay, increased use of marginal or fragile land, and producers' desire to shift to higher-value biobased crops from food crops. Implicit to these issues is who will have access to technology and the distribution of its benefits?
- A national policy should be adopted that global food security shall not be compromised to meet the needs of a biobased economy. Food security is the underpinning of global political stability, which ultimately serves the national security and economic interests of the United States.

- Stakeholders (national and regional representatives, scientists, farmers' organizations) from the developing world should be included in policy formulations and decision-making regarding development and deployment of biobased non-food technologies. Opportunities for global forums on the subject should be encouraged and supported.

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Appendix

Important issues that were identified and issue-related questions that were raised.

Global Food Security

1. Would there be a shift from food to biobased production?
2. What are the local versus global perspectives?
3. Would limited or diminished food resources increase chances of war?

Assessment

1. A holistic examination of biobased agriculture is needed.
2. What will be impacts of raw-material transport to processing plants?
3. What will be the economic impact/price of products and farm income?
4. Life-cycle analysis is needed for individual products/crops, industry.
5. Environmental assessment of biobased conversion is needed.
6. What will be the long-term indirect effects (e.g., population growth rate) of biobased production?
7. We need to understand change on the large scale.
8. What will be the societal and consumer benefits and risks? Benefits: in health, productivity, quality. Risks: food safety, allergenicity, price, genetic pollution, disease resistance in non-target plants.
9. Will vertical integration of farmers and companies occur?
10. How can we integrate visions of a biobased agriculture with realities?
11. Where will funding come from to pay for assessment?
12. Will biobased agriculture advance consumption and/or conservation?

Sustainability

1. Can biobased production be maintained with increased food production?
2. Can we maintain an adequate supply of biobased raw materials?
3. Land stewardship: how to improve it with biobased agriculture?
4. Will biobased agriculture stimulate an ecological economy? How to move forward?
5. Can we further intensify food and fiber production? Will there be conflict between new crops and old crops?
6. Will there be adequate resources e.g., water availability to support biobased agriculture?
7. Will limited resources increase likelihood for war?
8. If not sustainable, who pays? Who should?
9. Will water availability limit biobased agriculture?
10. A consumer-benefit list is needed.
11. A consumer-risk list is needed.
12. Will institutional innovation accompany technological innovation?
13. Substantive analyses of life-cycle assessment and equity assessment are needed.
14. What long-term indirect effects of biobased agriculture on population growth could arise?
15. Will a long-term stable funding source be available?
16. An open regulatory process/evaluation is needed to maintain community trust.
17. Risk/benefit assessment needs to involve the developing world in the debate.
18. Will high-risk GMOs arise from biobased applications?
19. There is a need for a holistic examination of biobased agriculture.
20. Can decentralized agricultural networks be maintained?
21. How will biobased agriculture affect raw-material transportation?
22. What will be the economic impact on food production?
23. Presently there are major acceptance obstacles.
24. How will a biobased economy impact land stewardship?
25. Clearly there will be a need to understand change on a large scale.
26. How can we effectively inform/communicate the risks/benefits of biobased agriculture to the public?
27. Further intensification in forestry is desirable.
28. How can a biobased agriculture help us to move to an ecological economy?

Communication

1. How do we allay concerns about high-risk genetically modified organisms (GMOs)?
2. How can we effectively inform the public?
3. Public education must be a priority. Must improve public's knowledge of science.
4. Can there be a perception of DNA as a pollutant?
5. Can plant pharmaceuticals be as beneficial as pharmaceuticals derived from other sources?
6. Presently we have major acceptance obstacles.
7. Can there be sustainability with increased food production and increased biobased production?
8. Biomass cultivation could be useful to increase biodiversity of agriculture.
9. Can agriculture and input resources supply enough biobased raw materials?

Process Involvement

1. Who will control and benefit from the intellectual property rights?
2. We need to make the public true participants in developing a biobased economy.
3. Who decides and who will decide what research priorities are necessary for sound assessment of benefits/risks
4. We need to ensure that farmers have an opportunity to participate as partners/contractors.
5. What is the current political/policy environment?
6. Communication/education of public is essential.
7. What are the health ramifications of a biobased agriculture?
8. Will the public embrace plant-based pharmaceuticals?
9. Some may see DNA may as a pollutant.
10. How do we go about creating a positive political space for biotech?
11. Should regulation be science based or politically based?
12. Intellectual property seems to exclude involvement of the public and farmers.
13. Can we increase the utilization of waste from existing crops to create new specialty crops without requiring more land or input resources?
14. It is important that farmers do not become contract providers to vertically integrated multinational corporations.

15. Will a biobased economy affect food safety?
16. Who decides what needs to be researched?
17. How can we make the public true participants in the debate on value-added applications of agriculture for the biobased economy?
18. Process involvement must include local and global perspectives.
19. How will the shift from food production to biobased products affect food security?

PART III

KEYNOTE SESSION

THE EXPANDING ROLE FOR AGRICULTURE IN THE TWENTY-FIRST CENTURY

Hydrocarbons to Carbohydrates, The Strategic Dimension

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I was quite honored to be asked to speak to you, particularly to be a warm-up act to Ralph Nader. But to tell you the truth, since, one, I am a lawyer, two, from Washington DC, and three, I have spent some time with the CIA, I am pretty well honored to be invited into any polite company for any purpose whatsoever.

I think that it is perhaps surprising to some of you to hear a presentation on the use of biomass as an alternative to petroleum by someone whose most recent government credential is head of the CIA. I spent twelve of the last thirty-two years in Washington in government, twenty of them in private law practice. The twelve years in government have been at the State Department, the Defense Department, the National Security Council, Congressional Staff, and the CIA — all in areas of national security of one type or another. Five years ago, Senator Richard Lugar invited me to testify before Congress on national security issues related to energy security and energy independence.

Over the past five years, as I have written and spoken on this issue, and a few small companies have asked me for advice and help. I have learned more about this subject. And the more I learn, the more I am convinced that the issue that has brought you here for this conference is right at the heart of many aspects of American security as we move into the twenty-first century.

Why do I say that? First of all, we are a society of networks. Some of them work, most of them work very well, e.g. electricity grids, transportation networks, fuel distribution networks, and the Internet. None of these was designed to be resistant to intentional interference. The Internet provides a recent example: the extraordinarily destructive “love-bug” virus may well have been either a prank by a young Filipino student or an accident. Think of the consequences of an adversary deciding to create problems, disruption, and destruction within that network. The same is true of the other networks upon which we depend for our economy and society. They are interrelated in unexpected ways. In 1966, there was an electricity blackout in New York City that lasted just over a day. At the end of that period, people were surprised to realize that all of the emergency vehicles were out of fuel— ambulances, police cars, and fire engines. Police, many hospitals and fire companies had been forced to curtail their activities because the fuel pumps were electrically powered and no one had considered the need for back-up generators. People in New York City hope that that particular problem has been fixed.

In modern society, with its great degree of interdependency, these networks can be disrupted by accidents and by nature. However, we have no strategies to deal with intentionally planned disruptions. Most of these networks are designed for ease of maintenance, ease of access, and to be user-friendly — not to be resistant to outside interference. Einstein said, "God may be sophisticated, but he's not plain mean," by which I think he meant that if you are trying to develop a theorem in physics, if you are playing against nature, or in a sense, God, you are not going up against someone who is trying to outwit you and make the problem harder. You are not up against someone who is just plain mean.

The interconnected, extremely elaborate and fragile nature of the networks we depend on poses a serious national security problem, as we try to maintain a modern society in the face of potential terrorist operations, or even serious pranks. To the degree that we can decentralize some or any of them, manage them locally, take local responsibility for what is produced, produce what we use locally, produce what we need in an economically sound and useful way without depending upon the intricate and fragile complexities of interconnections, to that degree, I think, we enhance our security. Obviously we cannot go overboard with this — we cannot all become family farmers growing everything we need, which would reject all that modern society stands for. But we can begin to focus on the networks that are the most fragile, the most difficult, and that create the most serious dependencies.

The network I will address briefly is the reliance on hydrocarbons, particularly petroleum, because it creates at least four sets of difficulties. First of all, there is the long-term problem of emissions that cause global warming. By burning petroleum and releasing CO_2 that was photosynthetically fixed by plants hundreds of millions of years ago, we contribute to long-term global climate change. Petroleum, of course, absolutely dominates the transportation industry, and burning it causes close to 40 percent of the world's contribution to man-made global warming emissions.

A study by five laboratories of the Department of Energy (DOE) a year and a half ago examined the global-warming implications of using, for example, gasoline in an automobile engine versus using ethanol that had been produced from biomass, i.e. cellulosic biomass (cellulose and hemicellulose), which includes about two-thirds of urban garbage, agricultural residues, grasses, and much of what grows except lignin, the woody, structural component of plants. If, on a scale of 0 to 200, the amount of global warming gasses emitted by a gasoline-burning car is set at around 200 — from pumping the petroleum, refining it and running the equipment — a gasoline and ethanol mixture, or even pure ethanol if made from corn, is at 140, 150, and 160 on that scale. The figure is high because petroleum products are consumed to produce the corn crop, i.e. to synthesize chemical fertilizers, for plowing, cultivating, harvesting, transporting, and processing.

It is interesting that electric cars on that scale are somewhere between 130 and 180, depending on whether natural gas or coal is burned to produce the electricity. Although an electric vehicle has nothing coming out of the tailpipe in the Los Angeles basin, out there in the Four Corners Power Plant in New Mexico, they are burning coal or gas in order to produce that electricity, and so CO_2 is still going into the atmosphere. Of course, this does not apply to electricity from renewable fuels, or, for that matter, from nuclear power plants, but global warming emissions from coal- and gas-fired plants are substantial.

If that same car burns ethanol produced from agricultural residues, there is a debate on whether it is 2 or 3 on the 0 to 200 scale, or -2 or -3. There is no net increase in global warming emissions since the CO_2 that is released in the production and burning of the ethanol had been recently fixed by the plants during photosynthesis. Therefore, from the point of view of global warming emissions, which are of concern to increasing numbers of objective scientists around the world, gasoline and other petroleum products, and mining fossil fuels to produce electricity for automobiles, is ill advised. The substitution of ethanol from biomass has much to recommend it.

Second, from the point of view of air pollution, to the degree that one mixes biomass ethanol with gasoline — let us say it is 50 percent ethanol and 50 percent gasoline — about 50 percent fewer pollutants comes out the tailpipe. At ratios of ethanol to gasoline below 22 percent ethanol, there is a slightly higher vapor pressure. So, although there is less pollution, there may be more evaporation of the pollutants that are in gasoline, particularly during the hot summer months. Thus, Brazil sells only E22, a fuel that contains 22 percent or higher ethanol. On average, vehicles in Brazil run on a 40/60 ethyl/gasoline mixture. This is relatively expensive because the ethanol is produced from sugar cane. If they made it from agricultural residues and other wastes, their costs would be considerably less. But, even so, Brazilians feel it is worthwhile to have independence from the global oil market and less air pollution as a result of using ethanol from sugar cane

There are ways of solving the problem of low percentage ethanol mixtures with gasoline, such as refining out butane and pentane from the gasoline for use in aviation fuels. Also credits may be traded between urban areas, where, in the hot summer months, the use of low ethanol mixtures is disadvantageous, and other parts of the country. These issues are being considered in the Congress in Senator Thomas Daschle's bill that is before the Senate Agriculture Committee.

The bottom line is that, in terms of air pollution and global warming, we have a serious problem with hydrocarbons. The methyl tertiary butyl ether (MTBE) used in reformulated gasoline to make it burn more cleanly has been found to pollute ground water. Therefore, many states, including California, are declining its use. Hydrocarbons are, and always will be, serious pollutants of the air and ground. Products from biomass offer the promise of an alternative to our dependence on hydrocarbons.

Third, there is an issue on which few people focus — hydrocarbons create a very serious economic problem for a number of developing countries and to a lesser extent for the US. Petroleum constitutes an extraordinarily high share of our imports: tens of billions of dollars a year. The US now borrows about $1 billion every working day from the rest of the world to finance our consumption — roughly the size of our trade deficit.

Developing countries have an even bigger problem. They tend to rely on what are today very low-priced agricultural commodities for their exports. Yet they have to import petroleum, for which the price is dollar-dominated. They can afford this even less than we can, and they continue to go deeper and deeper into debt as a result of their need for petroleum imports. If, for example, sub-Saharan African countries could produce their own transportation fuel, they would substantially change their balance of trade and the degree to which they must be indebted to the developed world. I might add, so would we.

Today, our booming economy can probably deal with a $200 to $250 billion dollar a year trade deficit. But the time may come, and I hope the stock market is not giving us an early indication of it, in which the world will tire of continuing to lend us $1 billion or more every working day to finance our consumption. To the degree that we can produce our own transportation fuel in this country and forgo many tens of billions of dollars in imports, our own international economic situation will be more stable. And, for the likes of Chad, Malawi, Bangladesh, etc., there is the opportunity to go from absolute poverty to a chance for self-sufficiency. They must break, or at least begin to break, the imported oil habit.

The fourth area we need to focus on — in which hydrocarbons create problems for the rest of us — is in overall strategy and national independence. Now, why do I say that? Is oil not always going to be around? And even if Saddam Hussein controls a fair amount of it, he cannot eat it. He has to do something with it. He is going to sell it to somebody. Maybe he will charge a bit more, but we will be able to buy it, right? Well, perhaps, but this is a question of wealth transfer.

Back during the 1973 and 1979 Middle East crises, there was much hand wringing in this country with talk of the price of oil going up to $100 a barrel!

There were many wild and crazy schemes for what the country ought to do in order to avoid having to rely on petroleum, and there was a lot of talk about how the world is running out of oil. Well, the world probably will never run out of oil. It is a matter of cost. The question is, "At what point does cost get to be a serious problem for us?"

Back in the early 1950s a man named King Hubbert, a geologist for Shell Oil, invented the King Hubbert Model, which is essentially a way of forecasting when oil fields are depleted to their halfway point. Once a field gets down to its halfway point in reserves, it begins to decline in total production, and the cost simultaneously begins to increase. As far as I know, Hubbert is the only individual to have successfully made major long-range predictions about oil exhaustion. He predicted that, in the lower forty-eight states of the US, production would peak around 1969. You have to remember that, in the 1950s, the US dominated much of the world's oil market. Hubbert hit it virtually on the nose — the peak came in 1970. Throughout much of the world of petroleum forecasting, Hubbert's model is used and relied upon.

The real question is, "At what point is it likely that the world production outside of the Middle East — Nigeria, Alaska, Venezuela, and other regions — will start to decrease?" At that point, not only will the costs go up, but we will also start to rely much more heavily on the very volatile and dangerous Middle East than is the case today.

The International Energy Agency of the Organization of Economic Cooperation and Development (OECD) in Paris is the major international group that looks at these matters. It predicts that, this year, net world production will decline outside the OPEC nations of the Middle East, and it predicts that OPEC production will start to decrease around 2010.

There are more-positive assessments, the most optimistic of which come either from oil companies or from oil-producing countries. But the most optimistic objective assessments indicate that total oil production, including that in the Middle East, will take a downturn no later than 2020.

I am aware of only one major institution that is neither an oil company nor an oil producing country that says that world production will not start a downturn until after 2020: the DOE. In my opinion, they do not rely on King Hubbert's or any other recognized models for predicting oil supplies. They rely on the Julie Andrews Model as in, "I'm just a cockeyed optimist."

Therefore, we may well see global oil production begin to decline — somewhat later in the Middle East than elsewhere — in the timeframe of 2010 to 2020. That is the year, by the way, when a child born this year enters fourth grade versus the year (s)he becomes a junior in college. So, we are not talking about the distant future. This means that world production starts to decrease a decade from now, or, if you are an optimist, just two decades from now. At the same time, populous Asia is growing economically, and the Chinese can actually afford to drive some of the Buicks that General Motors is building for them in China. If Asia starts to rise economically, increasing the demand for oil, and at the same time world production starts to decrease, then there is a very strong likelihood of substantial oil-price increases a decade or two from now. The most rational approach for the countries of the world dealing with declining oil production — and in some cases cut-offs from the Middle East — is to begin production of substitute fuels from what can be grown locally.

We have an opportunity to do so now as a result of improvements in genetic engineering. Some of the most important research has been done here at the University of Florida. Lonnie Ingram, as some of you know, does superb work in this area. The design and genetic modification of biocatalysts allows the break-down of biomass by fermenting the pentose components of hemicellulose and hydrolyzing cellulose. Those two steps are essentially the philosopher's stone that allows the conversion of agricultural residues, waste, grasses, kudzu, urban garbage, whatever grows, into ethanol, simply and cheaply. The pentose biocatalyst was developed by Ingram; substantial work is in progress to develop the other.

Once that second biocatalyst is developed, our dependence on imported oil will be greatly reduced. These biocatalysts will reduce the production costs of ethanol from today's approximately $1.10 per gallon to approximately $.45 or $.50 per gallon. Since ethanol has about 70 percent of the energy of gasoline, that is equivalent to about $.65 or $.70 per gallon wholesale gasoline, which is something over a $1.00 per gallon retail. But it is not wildly different from the price of gasoline, as long as oil costs $20 to 30 per barrel.

In short, biocatalysts hold out the possibility of making ethanol from cellulosic biomass — approximately 80 percent of all plant material, which is plentiful everywhere in the world — roughly competitive in cost with refining gasoline from oil at current world oil prices. That is a strategic change of the first order. It means that, in years to come, young men and women in the US and other countries would less likely be sent to fight to protect the flow of oil.

Before I close, I want to mention briefly two other technologies that hold a great deal of promise for future use of organic materials, including wastes to allow us to use the farm products to replace substantial amounts of petroleum-based energy and materials. One is the ability to use all sorts of organic waste products and biomass to produce electricity, useful organic chemicals, and fertilizers. Some small companies and several university research projects have embarked on this path and some that are moving aggressively will begin to show commercial promise within the next few months and, at the very most, in the next year or two.

The other is the subject that Ralph Nader and I first met to discuss: industrial hemp. Hemp is an extraordinarily useful plant with a long fiber that can be used to make paper, cloth, carpets, and many other products. In northern Minnesota, where farmers are netting $20 or so an acre from wheat, they look across the border at Canada where the cultivation of industrial hemp varieties with very, very low THC levels is legal. Canadian farmers are netting about $200 an acre from hemp because hemp has so many industrial uses.

The cultivation of industrial hemp is banned in the US for all practical purposes because it is the same species (*Cannabis sativa*) as high-THC marijuana. Industrial hemp may now be legally grown in Canada, Britain, and all of Western Europe. A number of countries have seen its utility and find it easy to distinguish it from marijuana both in appearance and with simple on-the-spot testing.

Yet, unlike Britain and Canada, the US government at this point has no inspection system in place that would permit the cultivation of a new cash crop for industrial uses that would be a great boon to American farmers. Industrial hemp would make it possible to replace substantial amounts of petrochemical products and even be used, as it is in Europe, to fabricate materials for car-body manufacture, for example. It may also replace trees as a source for paper.

Research into all three of these areas, of the sort that many here assembled are engaged in — ethanol from biomass, useful energy and chemicals from various organic waste products, and a wide range of useful products, particularly fiber, from industrial hemp — hold the following promises: improvement in the economic health of rural America, higher productivity for American farms, and a fundamental change in American and world security.

Changing the Nature of Nature: Corporate, Legal, and Ethical Fundamentals (Description of the Presentation by Ralph Nader)

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Mr. Nader discussed NABC's *Vision Statement*, characterizing it as tremendously optimistic. He found the theme of that statement — of what "will" happen in the future — to be troubling in that, in the 1920s, a radical change in technology, with similarities to biotechnology, was championed by luminaries such as Thomas Edison and Henry Ford: to replace hydrocarbons with carbohydrates. Despite broad support, including deans of MIT and Harvard, for the concept of manufactured products from plants as raw materials rather than minerals, it did not come to fruition. Why not? Was the science faulty or the technology inadequate?

In fact, major industries, e.g. petrochemical, paper and auto, resisted the change to carbohydrates. The petrochemical industry expanded enormously in size, and products therefrom came to occupy all major market niches. Carbohydrate-based products could not compete, and the global repercussions include hazards in the workplace, environmental pollution, and waste-disposal costs.

How much is learned from history's lessons? Industrial hemp, for example, preceded petrochemicals by thousands of years, yet, despite this long lead time, it fell out of favor in the 1920s along with many other carbohydrate-based materials. The role of power in deciding directions — corporate power and the governmental power it reflects — should be probed at conferences such as this and not avoided as is usual. For example, over the past seven decades, little of USDA's research budget has been invested in carbohydrate development, whereas subsidies for the oil, gas, nuclear power and forest industries have been enormous. In the 1960s and 1970s, discussions of auto safety, albeit few, camouflaged the fact that executives in Detroit emphasized style while progress in engineering stagnated and never surfaced as a topic of debate. And we must learn history's lessons in terms of the corporate personality. The Greek sculptor and architect Polyclitus (fifth century BC) said, "Character is destiny," to which should be added, "but personality is decisive."

In the early days of this country, corporations were tightly controlled and were granted sometimes only a 10-year state charter, renewable on the basis of good conduct. Products were restricted and expected to fulfill "a public purpose." Public perception has since become blurred that there are obvious differences between corporations and human beings. People cannot be internationally ubiquitous, cannot dodge responsibilities or be temporarily bankrupt, and cannot pocket generous remunerations while avoiding full payment of creditors. The many differences between the corporate personality and the individual will affect whether the priorities of a biobased economy in the twenty-first century will be driven by corporate for-profit structure, or by government and university research with open exchange of information.

The corporate science of today contrasts with the traditional *modus operandi* chiefly in terms of:

- Proprietary and confidentiality agreements. When industrial priorities intersect with research at universities and public institutions, free exchange of scientific information and the peer-review process are compromised.
- Priorities. In general, corporate priorities differ from those normally perceived as being in the public interest. Pharmaceutical companies are marketing drugs for baldness, obesity, and potency, while neglecting research to tackle infectious diseases of enormous global relevance, such as malaria, tuberculosis, and AIDS. As reported recently by the New York Times, these same companies enjoy billion-dollar governmental subsidies.
- Power. Corporations hold political power by which to garner federal tax credits and subsidies. This power extrapolates to the presence of genetically engineered foods on supermarket shelves without being so labeled, whereas many consumers would welcome such information for reasons of religion, personal preference, or public policy.

So, on the one hand, corporations hold proprietary information, different priorities, and power, and, on the other, traditional science is dedicated to the free pursuit of knowledge for its own sake and for the common good. The playing field is not level, which should form the basis of discussions with concrete examples, citing Monsanto, ADM, etc.

In the area of bioengineered food, policy-making is fraught with unknowns. Part of the problem is that the technology has developed ahead of the scientific understanding that must underpin its regulation. Industry representatives have failed to address critical aspects of agricultural biotechnology:

- ecology,
- nutrition and disease dynamics, and
- basic molecular genetics.

The consequences of genetically engineering organisms across species barriers remain poorly understood. Technology outstripping science has led to trouble in the past; for example, decades of smog plagued Los Angeles before it was discovered that motor-vehicle exhaust was causal. And nuclear power plants were built to produce energy inexpensively, yet the resultant radioactive waste still cannot be stored safely for the long term. The distinctions between corporate science and its traditional university-based counterpart need emphasis.

Who will make the key decisions? Will it be a random process influenced by who has the funding to do the research, who has the political power, or who makes the discoveries that lead to implementation? Or will our supposedly democratically representative government have a say? The public has the right to know, in principle at least, and to participate in the deliberations. We should ask the question, "What do genetically engineered corn and soybean really do for the farmer and for the consumer, compared to the costs and the unknowns?" At a recent meeting between Monsanto representatives and citizen environmental groups, an Iowa farmer growing 3,000 acres of genetically engineered corn stated that his crop did not taste or yield better, but he was able to spend more time with his family because he spent less time weeding. His response should be measured against the misgivings about such crops and against the questions raised above regarding inadequate research.

It is important that the question of who decides, tough as it is, should be answered by the many rather than by the few, with consideration given to the needs of overworked family farmers, of whom so many are in dire straits even after nine years of national economic growth. Will family farmers and their producer cooperatives survive and retain independence, or will they go the way of chicken farmers who, indentured to Tyson, Perdue, etc., make a profit of just a nickel per broiler (240,000 per year = $12,000). Some call this poultry peonage.

If the increasingly integrated technology patterns of multi-national companies result in further losses of family-farms, then rural America, with its traditional independence and its cultural and political creativity, will be sacrificed. Is that an acceptable risk without clear-minded projections and thorough debate?

In contrast with the statement by English philosopher Alfred North Whitehead (1861–1947) that science has to keep its options open for revision, much corporate science fails in this regard because of entrenchment of investments and technologies. The infernal internal combustion engine is one such entrenched technology: it has changed little in 110 years with its high incomes from sales and service and its built-in obsolescence.

Revision options are key, and this leads to a consideration of the *NABC Statement 2000 on Agricultural Biotechnology: Promise, Process, Regulation and Dialogue*, which, in Mr. Nader's opinion, is so self-assured that it fails to address adequately what may go wrong. For example, the *Statement* suggests that "what is" should be given more weight than the never-ending and untestable "what if?". Would scientists at the Council for Responsible Genetics (more on the CRG later) concur with the concept that the most important risk from a product is inherent to that product not to the process by which it is made, i.e. that identical products, however they are made, pose identical risk? And would scientists at the CRG concur that the genetic roulette is less predictable in organismal than in molecular genetic improvement?

There are other issues that should be considered at this and future conferences. When huge sums of money are invested in industrial-scale production of crops, there are global consequences in terms of land control. Is it possible that reform acts in the developing world will result in new ownership patterns with land-control by large corporations? Apparently aware of this point, over a million farmers in India six years ago protested the restrictions that patenting of seed by Cargill and other agribusiness companies would impose on them culturally and economically; that demonstration received no press coverage in the United States.

With good planning, many exciting opportunities — unrelated to genetic engineering — would exist for small-holding farmers, such as industrial hemp. Industrial hemp must become a political issue, and a media issue, to be released from the medieval yoke enforced by the DEA. It should be held up as an object lesson on how the most versatile plant on earth, in terms of its multiplicity of uses, has been suppressed and that suppression ignored. Certainly in environmental terms, industrial hemp is superior to the alternatives that are used in its place.

Current emphasis on biotechnology as a means of alleviating hunger denies the central fact that malnourishment results chiefly from unequal distribution of food, lack of access, and from poverty. As an analogy, two million people die yearly from tuberculosis, most of them in the developing world, even though the cure is available, as are resources for delivery. Power structure is the chief determinant of whether a technology is delivered.

It should be stressed that many innovations in agricultural biotechnology are driven by profit rather than by need, e.g. soybean has been genetically modified to sell more of a particular herbicide. This sequence of events will become more common as seed patents increasingly affect farm practices.

According to Mr. Nader, the integration of the seed and chemical industries accelerates per-acre expenditures, which will affect patterns of agricultural credit. Consolidations into larger, fewer farms will parallel the vertical integration of biotech companies. The editorial of an agribusiness newsletter recently stated: "Get real, farmers! We are not far away from having fifty integrated production units in this country delivering food and fiber." Consolidations in the beef, pork and poultry industries are already occurring; with only fifty production systems, farmers would be integrated into contract units with little bargaining power, as has been the misfortune of chicken farmers.

The promise of increased yields from genetically engineered seed is yet to be realized. Other, traditional, approaches exist to improve crop yields and to alleviate post-harvest losses from rodents, fungi, etc., that plague developing countries. It is arrogant to presume that exogenous untested technologies that have neither cultural nor historical context do not jeopardize long-standing practices and customs. The spiritual aspect of economic activity in agrarian societies is often underestimated. For example, in northeast Brazil, the many available varieties of corn play specific roles in the local diet and in customs and festivals.

On one hand, deliveries of clean water, immunization against devastating diseases, extension advice to foster traditional practices, land reform and agricultural credits remain beyond reach for many, yet biotechnology is viewed as a cure for what ails the developing world. A Nobel Prize awaits the person who achieves that integration.

The FDA is about six years behind in its promise to develop standards to address the possibility that genetically modified foods may contain new allergens or toxins, and their recent pronouncements do nothing to alleviate concerns. Likewise, the EPA, rather than imposing regulations, continues to promise guidelines.

The old "one pest, one chemical" model has been superseded by "one pest, one gene." Although the number of genes is almost infinite, very little is known of their relation to resistance or how they may be exploited to address the problem of development of resistance by pests.

The USDA spends an inadequate sum on risk assessment, only one to two million dollars per year of the biotech research budget. This illustrates the pressures that influence the USDA's research priorities. Significant federal funds are spent on biotechnology, and there is need for assessment of accompanying effects of the Bayh-Dole Act (by which universities are encouraged to collaborate with commercial concerns to promote patenting and the utilization of inventions arising from federal funding). Some are of the opinion that passage of the Bayh-Dole Act into law has poisoned relationships among university researchers, with its encouragement to draw proprietary distinctions and to wheel and deal. This raises the question of whether non-profit institutions can remain sufficiently independent of corporate entanglements for the benefit of society and for the maintenance of free initiative and scientific exchange — a topic worthy of inclusion on a future agenda.

In the recently published book *Natural Capitalism: Creating the Next Industrial Revolution*, Paul Hawkin, Amory Lovins and L. Hunter Lovins discuss opportunities to improve resource productivity, to get more from less of a raw material. This approach is being put into practice by Interface, Atlanta, GA, the largest manufacturer of carpet tile in the world, which is moving towards zero pollution; if part of a process or product does not add value, it is eliminated. Hawkin, a practical businessman, cites many similar examples in his book.

Also, he cites a professor who has drawn up a cost budget for one pound of hamburger meat: one hundred pounds of mid-west soil and a thousand gallons of ice-age water from the aquifer. Other examples in the book include, the manufacture of a semi-conductor chip produces one hundred thousand times its own weight in waste; a lap-top computer generates close to four thousand times its own weight in waste; two quarts of gasoline and a thousand quarts of water are needed to produce a quart of Florida orange juice; and one ton of paper requires ninety-eight tons of various inputs. Mr. Hawkin has suggested the objective of ten-fold increases in productivity and efficiency, with all the attendant benefits.

The Council for Responsible Genetics, founded in 1983 by scientists at Harvard and MIT, monitors developments in new technologies as they relate to human genetics and commercial biotech and the environment. The CRG encourages informed public debate on the social, ethical, and environmental issues. Their recently published *Genetic Bill of Rights* for consumers covers policy issues, privacy rights, and questions of disclosure; it should be required reading for all stakeholders.

Mr. Nader emphasized that these comments and observations should not be viewed as negative on biomaterials, which hold promise for small-holding farmers, for the environment and for poor people abroad. However, any technology that is driven by a distorted power system can be misused and become a monster. It can fail to deliver on its promise, like pharmaceutical research, and it can help concentrate power, which, in the wrong hands may be very anti-democratic and invade privacy. It is important to bear in mind all these aspects, which is why there is need for a more deeply deliberative democracy with increasingly more citizens engaged in discussions of the serious problems society faces.

We are entertaining ourselves to death. No longer a weekly Saturday afternoon outing to the Bijou theatre for twelve- and thirteen-year olds, entertainment is accessible twenty-four hours a day and is the focus of much of the media, which no longer deal with sensible issues. This conference should be on C-Span, and in newspaper headlines instead of the continuous fodder of Elian Gonzalez, O.J. Simpson, reprobate celebrities, etc. For functional and normative reasons, there is need to encourage understanding, commitment, and skepticism in the citizenry. The jurist Learned Hand (1872–1961) said, “Whatever our constitutions, whatever our laws may be, the only basic hope for a democratic society lies in the public sentiments of its people, namely its civic culture.” This holds true for the emergence of biotechnology, which is likely to be enormously, fundamentally, and irretrievably transforming for the planet as a whole; we must tread very carefully indeed.

“A free society made up of free people” brings to mind the definition of freedom expressed by the Roman orator Marcus Cicero (106–43 BC): “Freedom is participation in power.” Many centuries ago, an anonymous Chinese sage commented, “To know and not act is not to know.” Inhibition and self-censorship that are concomitant with excessive concentration of power must not encumber free sharing of information by those who are informed.

Most of Mr. Nader’s comments were related to food and applications of biotechnology, rather than to agriculture’s expanding role in the twenty-first century, the theme of the Keynote Session. However, as noted, he did express support for the development of biobased industrial products.

PART IV

PLENARY SESSION I

EVOLVING ROLES FOR SCIENCE, TECHNOLOGY, BUSINESS, GOVERNMENT, AND EDUCATION IN A BIOBASED ECONOMY

Biobased Industrial Products: Back to the Future for Agriculture

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In 2000, the National Research Council published a report on the potential impact of biobased industrial products in the twenty-first century. The priorities for research and commercialization were described in terms of agriculture expanding into health, energy, chemicals and materials. Agriculture is now armed with new biotechnology and bioprocessing tools, and is going back to reclaim the markets it lost to the petrochemical industry after the 1930s. This paper will discuss new markets and research and development priorities, and provide examples of new biobased industrial products that are entering commercialization. These include transgenic plants, pharmaceuticals, biochemicals, fuels, agri-chemicals, bioplastics, and higher-value polymers and materials. As an example, the role of MBI International in the scale-up and demonstration of these new biobased industrial product technologies will be highlighted.

INTRODUCTION

The NRC report, *Biobased Industrial Products*, assumes that "biological sciences will have the same impact on the formation of new industries in the next century as physical and chemical sciences have had on industrial development in this century" (NRC 2000). This prediction is supported in part by four dominant themes. First, US agriculture's history of making industrial products from agricultural feedstock before the advent of the petrochemical industry, and the realization that agricultural carbohydrates are a lower-cost resource than petroleum-based hydrocarbons (Figure 1). Before 1940, medicines, synthetic fibers, plastics, paints and inks were made from agricultural feedstock. For

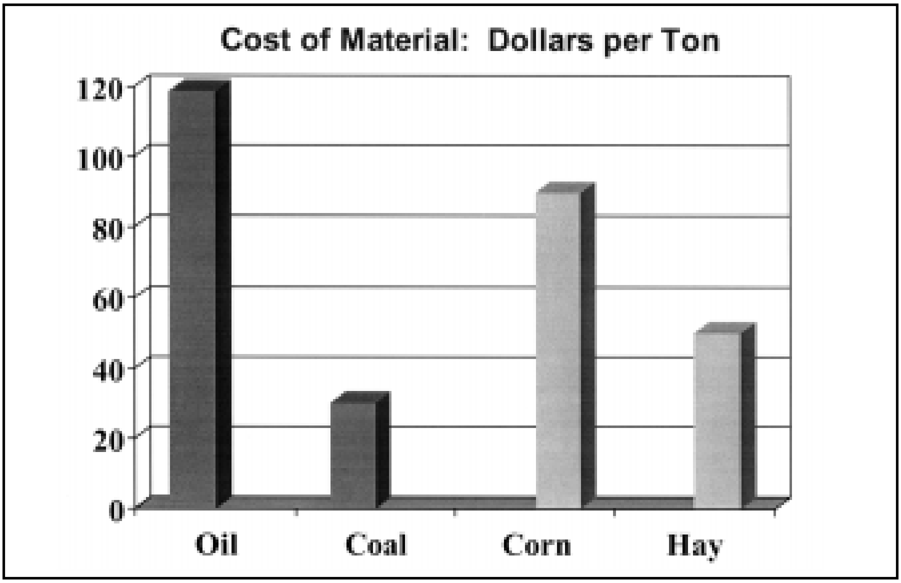

Figure 1. Cost of raw materials: fossil vs. renewable plant materials (NRC 2000).

example, in 1935, each Ford car contained components manufactured from two pounds of soybeans. Second, the new tools of genetic and bioprocess engineering now enable economic improvements in feedstock utility and manufacturing systems. They produce a wider diversity of higher-value products than is feasible by petrochemical processing. Third, significant environmental problems, including pollution and global warming, are associated with industrial processing of fossil fuels. Finally, it is common sense that petroleum, a non-renewable chemical and energy resource needs to be replaced by renewable agricultural carbohydrates to drive the economy of the new millennium.

These factors invite the question, "Are biobased industries America's next frontier?" If so, there is need for a national awareness far greater than that used to launch the space program that put the first man on the moon. Both our future economic and our planetary well being are at stake in developing the "Biobased Industrial Products Society." In the rest of this discourse, I will address market-pull and technology-push issues, the NRC report, research and commercialization priorities, and the role of universities, federal laboratories, MBI International and others in making this vision of the future a reality.

Market Pull–Technology Push

A wide variety of industrial products, including biomaterials, fuels, and biochemicals are already manufactured from biobased raw materials (Figure 2).

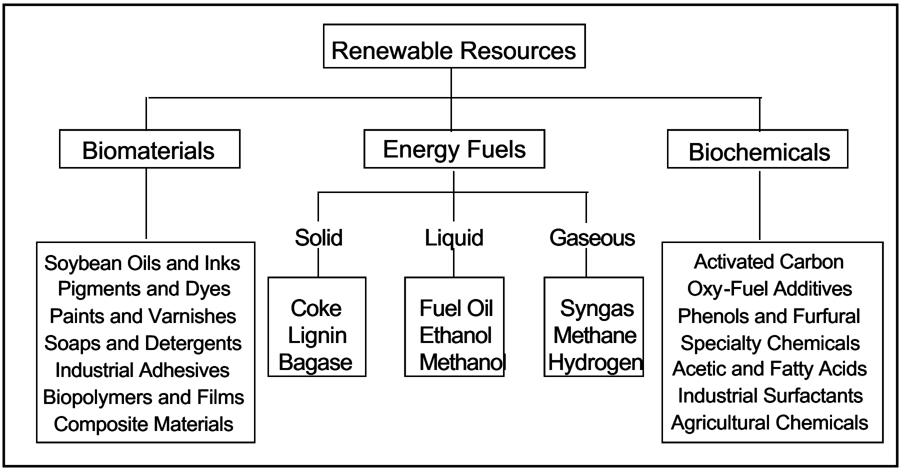

Figure 2. Biobased products manufactured today (NRC 2000).

The current emphasis placed on production of liquid fuels (i.e. ethanol) is a difficult challenge because it competes with a petroleum product, gasoline, which requires minimal refining. Oxychemicals, on the other hand, offer the possibility to produce higher value organic molecules via biobased processes, because costs to introduce oxygen into hydrocarbons are higher for oil refining. The NRC report targets for increasing biobased industrial products manufactured in the US over current levels for liquid fuels, organic chemicals and materials are 50 percent, 90 percent and 99 percent, respectively, of total industrial production by 2090 (Table 1).

TABLE 1. TARGETS FOR A NATIONAL BIOBASED INDUSTRY (NRC 2000)

	Biobased production levels (percent derived from biobased feedstocks)		
Biobased product	Current level	Future target: intermediate (2020)	Future target: ultimate (2090)
Liquid fuels	1–2%	10%	Up to 50%
Organic chemicals	10%	25%	90+%
Materials	90%	95%	99%

Industrial products are already made in large amounts from processed agricultural carbohydrates (Zeikus 1990). Sales of these products increased from $5,400 million in 1983 to $11,000 million in 1994 (Table 2). Sales of specialty biochemical products (phytoceuticals, nutraceuticals, biocontrol agents, vitamins, food-ingredient agents, etc.) are growing at greater than 15 percent annually. Crop processing has many added economic benefits for the US when compared to petroleum processing (Table 3), including decreased oil imports, enhanced balance of trade, decreased environmental pollution, and the development of renewable sources of chemicals, fuels and materials.

TABLE 2. WORLDWIDE SALES OF BIOTECHNOLOGY PRODUCTS, 1983 AND 1994 (NRC 2000)

	1983 ($ millions)	1994 ($ millions)
Fuel and industrial ethanol	800	1,500
High-fructose syrups	1,600	3,100
Citric acid	500	900
Monosodium glutamate	600	800
Lysine	200	700
Enzymes	400	1,000
Specialty chemicals	1,300	3,000
Total	5,400	11,000

TABLE 3. BENEFITS OF CROP PROCESSING TO INDUSTRIAL PRODUCTS

Better use of agricultural resources
Revitalize rural communities
Functionally superior products
Reduced dependence on foreign oil
Export more value-added industrial products vs. crop commodities
Potential greenhouse gas benefits

Today, many new kinds of genetically engineered crops are entering the marketplace. They lack approval in foreign markets and from the US public because they are being viewed as “altered and unsafe.” This false perception is not currently a problem in the marketplace for biobased industrial products. For example, enzyme products from genetic engineering are already used in making cheese and high-fructose corn syrup. Genetically engineered plants for pharmaceutical synthesis are viewed as positive for lowering costs of drug production. It is anticipated that genetic engineering of plants and microbes will lower costs for both the feedstock and the manufacturing process for biobased industrial products.

Research Priorities

Decades of agronomic research have shown us how to inexpensively grow crop commodities. Now, investment is needed to learn how to inexpensively convert value-added crop commodities to industrial products. The NRC report established research priorities for systems, biology, engineering, and research.

Research priorities for systems include:

- evaluate sustainability/environmental issues
- integrate biological and engineering research
- emphasize risk reduction/proof of concept
- develop infrastructure of trained people, databases, demonstration facilities, etc.
- consider incentives/preferences.

Research priorities for biology include:

- the genetics of plants and bacteria that will improve understanding of cellular processes and plant traits
- the physiology and biochemistry of plants and microorganisms directed toward modification of plant metabolism and improved bioconversion processes
- protein engineering methods to allow the design of new biocatalysts and novel materials for the biobased industry
- maximization of biomass production.

Research priorities for engineering include:

- principles and processing equipment to handle solid feedstock
- fermentation technology to improve the rate of fermentation yield and concentration of biobased products
- downstream technologies to separate and purify products in dilute aqueous streams.

MBI International

MBI is an entrepreneurial center that develops new industrial products made from agricultural resources. MBI's sole focus is on the risk reduction/proof of concept stages of research and development. We call this "Death Valley" because many new discoveries do not meet the objectives that are required for commercialization. Negligible funds are available from industry and investors to develop products from discoveries unless technical and economic validations are presented (Figure 3). Since 1992, MBI has launched eleven technologies into new biobased companies via our business pipeline model (Figure 4). MBI (a non-profit 501c3 corporation) researches technologies and markets for new inventions, and performs scale-up and economic demonstrations. The commercial-ready technology is then transferred to Grand River Technologies, Inc. (MBI's wholly owned for-profit subsidiary), for commercialization via a start-up company, joint venture or warranted out-license.

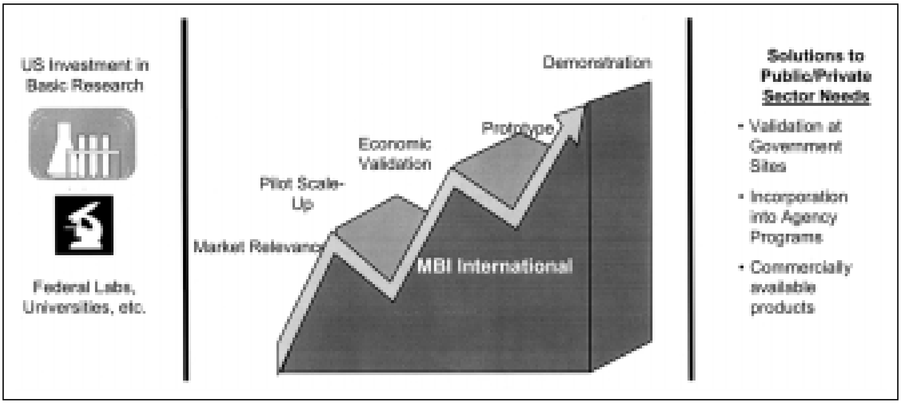

Figure 3. Death Valley

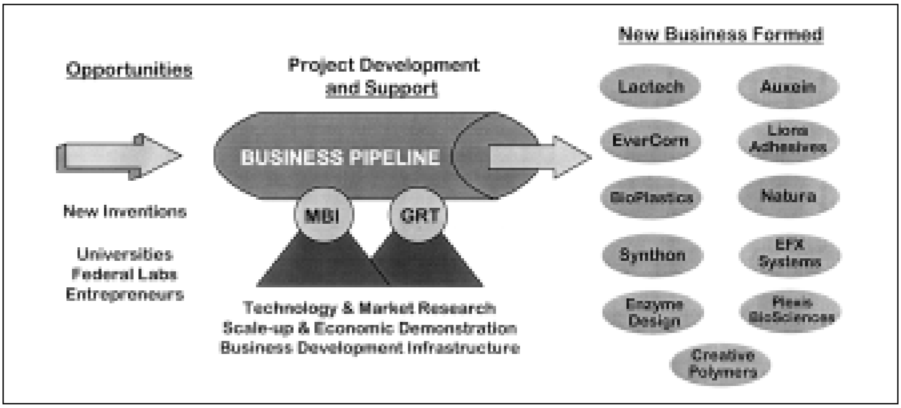

Figure 4. MBI International

Lactech, Inc. was a joint venture with Cargill to develop low-cost polymer-grade lactic acid by fermentation of corn glucose. At the completion of the scale-up/demonstration phase, Lactech was fully acquired by Cargill, who then formed a joint venture with Dow Chemical, Cargill Dow Polymers, LLC. This new joint venture has invested $300 million in the first of three plants. Cargill Dow plans to sell 3 billion pounds of polylactic acid in industrial fibers and 1.5 billion pounds in packaging plastic films, coatings and containers. The first plant in Blair, Nebraska will use 40,000 bushels of corn per day.

Synthon Corporation of Princeton, NJ, is a second company launched by MBI/GRT. It makes chiral intermediates from optically pure sugars, for drug manufacture. The first technology used lactose, a by-product of cheese making, to synthesize hydroxygamma butyl lactone, a compound used in $5 billion worth of drugs including cholesterol depressants, analgesics, broad-spectrum antibiotics and HIV protease inhibitors.

Auxein Corporation of Lansing, MI, is a third company launched by MBI/GRT. It produces natural “plant metabolic primers” (i.e. γ-amino butyrate, succinic acid, and glutamate) that enhance plant growth and decrease pesticide usage under environmentally stressed growing conditions. This product increases the yield of all crops, but most noticeably increases flowering, the size of potatoes, Brix content of grapes and the solids content of tomatoes.

MBI has a full pipeline of biobased industrial product technologies currently at various stages of proof-of-concept, scale-up and economic demonstration (Table 4). One platform technology under development is succinic acid, which promises to be a large-volume product (Zeikus et al. 1999). The reason ethanol production from biomass is not economical without a subsidy is the loss of carbon in current corn-processing systems. Notably, 2 moles of CO_2 are lost per mole of glucose fermented into two moles of ethanol. In the dry milling process, non-fermented fiber is used as an even lower-value animal feed

TABLE 4. MBI'S CURRENT BIOBASED INDUSTRIAL PRODUCT R&D PROJECTS

Coatings for medical devices
Coatings to prevent biofouling
Coatings for use in electronic devices
Low-cost, premium animal feeds
Oral vaccine production and delivery systems
Phytoceuticals
Biorepellents / biocontrol agents
Bioabrasives
High-value co-products from ethanol production (including succinate and derivatives)

byproduct in lieu of direct conversion to ethanol or higher-value products. Succinic acid can be made by fermentation of a variety of carbohydrates, including starch, cellulose, glucose and xylose. The succinic acid fermentation fixes CO_2, hence it can be integrated into ethanol fermentation to convert both CO_2 and cellulose fiber wastes into ethanol, thus improving the overall product value and economics. Succinic acid can be utilized as an intermediary carbon feedstock to make nylon, polyesters, engineered plastics and other commercial solvents and chemicals (Figure 5).

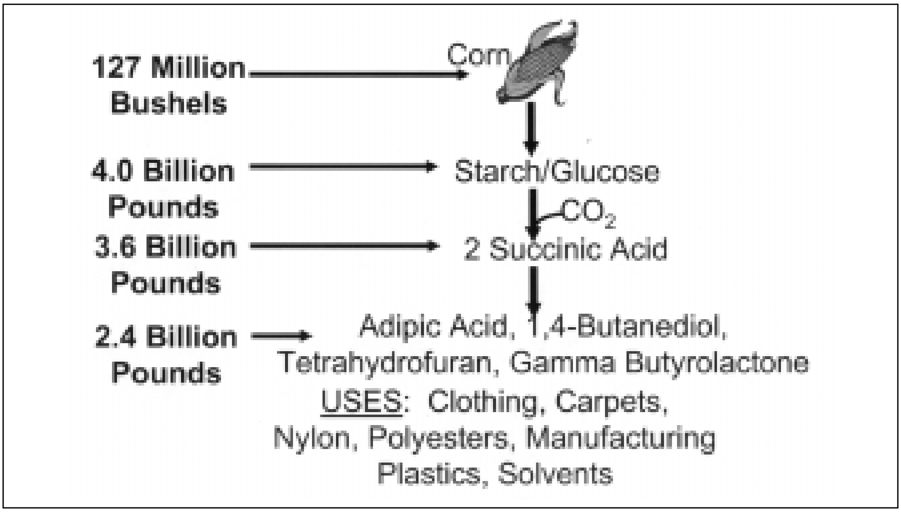

Figure 5. Industrial use opportunity for corn to succinic acid derivatives in U.S. markets.

CONCLUSION

The NRC report on biobased industrial products provides a roadmap for research and commercialization policy needed for agriculture to go back to the future and reclaim its higher-value industrial product markets. The market-pull and technology-push dynamics are poised for this, and the US desperately needs to reclaim control of its agricultural, chemical and energy economies as well as enhance overall environmental quality for the future.

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Sustainable Materials and Chemicals for the Next Generation

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I will describe a specific example of a large-scale chemical company's approach to, and progression towards, the development of sustainable chemicals and materials. At this point, it is hypothetical, but, I will sprinkle through it highlights of our work on bioprocess synthesis of 1,3-propanediol, to suggest that this is feasible, that it is being done and that it will be commercialized.

How might biotechnology interact with the chemical industry? The global economy today is a $50 trillion enterprise; biotechnology is having major impact on at least two sectors. In health care, it is revolutionizing the development of new drugs and therapies, and in agriculture it is affecting crop choices and farming practices. While these effects sometimes cause verbal and intellectual fireworks, no one can doubt that actual change is going on.

IMPACT OF BIOTECHNOLOGY ON CHEMICALS AND MATERIALS:

- Biotechnology is an alternative chemistry
- Biotechnology is complementary to traditional sciences

The chemical industry is divided into four sectors: organics, inorganics, industrial gases, and fertilizers. The higher performance segments, organics and inorganics, are dominant. The organics sector, built on the transformation of carbon, is where biotechnology is likely to have greatest impact by generating new knowledge, new molecules and new functions, leading from new products to new businesses. When that cycle functions effectively, change takes place, almost driven by itself.

Chemistry touches most aspects of human endeavor. Without its benefits, this meeting room would look very different. It would be a structure of bare wood and an inferior form of concrete, and you would be sitting on the floor, probably only half clothed. In modern life, we use the results of chemistry essentially all day, every day.

The chemical industry has much in common with agriculture. They are mature industries, largely commoditized, facing similar issues. How will the chemical industry change and what will be the economic and scientific forces that impact it? One aspect seems clear, the chemistry of biology is a means toward new knowledge and new business opportunities.

Global "Drivers"

- Needs for food, shelter, and health
- Demographics / developing countries
- Technology: information / biotechnology
- Environmental necessities: local / global
- Business competiveness

Society wants: "more, better, cheaper and cleaner"

Humanity's basic needs are constant: food, shelter, health. The relative expression of those needs changes with demographics. Fortunately, the global population growth rate is beginning to decline. But the standard of living of 75 percent of humanity still does not approach that of the other quarter. There is a tremendous, unmet need for advantages that we enjoy.

What drives change? Technology has a major impact, both from the information side and the biotechnology side. Environmental necessities are changing. Fifteen or thirty years ago, these were almost always considered to be geographically isolated, local problems: e.g. a chemical plant, food-processing factory, public utility, or a defense facility that had not operated properly. Over the past twenty years, however, environmental issues have become viewed on a broader, even global, scale. Perhaps, the first of these was the CFC/ozone-depletion problem that has been instructive in terms of climate models.

Business competitiveness has a major influence on public thinking. What do people want? People want more and better goods, which they wish were less expensive in order to increase access. And they would like those goods to be produced with less environmental impact than is currently the case.

Biotechnology is highly complex, almost impenetrable for the layman. But from the perspective of chemist, it can be reduced to a simple thought: the primary impact of biotechnology on the chemicals and materials industry will lie in presenting alternative chemical methods based on new knowledge.

This biotechnology-based chemistry must be complementary to traditional chemistry. To polarize the argument in terms of chemistry having to be either "all carbohydrate" or "all petroleum" does the dialogue a major disservice. We have to progress from where we are today to a renewable future, a transition that will combine both raw-material bases.

SUSTAINABILITY: Built on Three Legs

- In markets: greater functionality
- In business: lower costs and investment
- In the world: smaller environmental footprint

In using the word “sustainable” in the title, I meant three things relative to sustainability in the marketplace. (1) People will have new products that make their lives better and that are more attractive to business. (2) Costs and investment will be lower and attractive to business. (3) The environmental consequences will be fewer. If we find opportunities for all three, even if not completely in balance, strong pull will be coupled with strong push, a situation that generally leads to movement and progress.

The next few thoughts describe an example of how biotechnology affects these three elements of sustainability. Since sustainability starts with greater functionality and higher performance, let us begin there.

Recently, DuPont introduced a new polymer, trademarked Sorona® (Figure 1). It is a new form of polyester with many attractive advantages and it is the newest member of a series of synthetic polymers, developed at DuPont, that are in common use: Nylon, Dacron®, Teflon® and Lycra®.

SORONA™ 3GT
HIGH PERFORMANCE “POLYESTER”

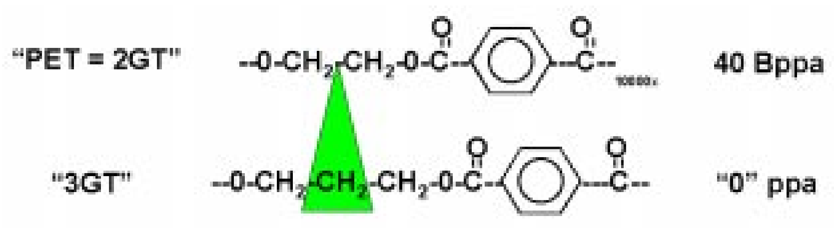

Figure 1.

Polyester is one of the most widely used polymers in the world. About forty billion pounds of polyethylene terepthalate (PET) are produced every year. Today you may drink bottled water from a plastic container, thus using this common form of polyester. PET has remarkable properties: strength, clarity, flexibility, etc. It is easy to recycle by degradation to its virgin chemical components and resynthesis into new, fully performing materials. But it has some shortcomings: fabrics from PET are not terribly comfortable, but rather stiff and scratchy. Therefore, we are making a new polyester by simply adding one extra CH_2, which presents a whole new opportunity and I will show you why you would want this material.

Traditional polyester, PET, is a long linear structure. The other polyester, PBT, that has some volume in the marketplace, is also relatively long and linear. In contrast, the Sorona® form has a kink in it (Figure 2), which allows the molecules, as organized in polymer, to act like a coiled spring. Instead of being a stiff piece of wire, the coils let the material stretch and recover; so they are softer and return to their original shape.

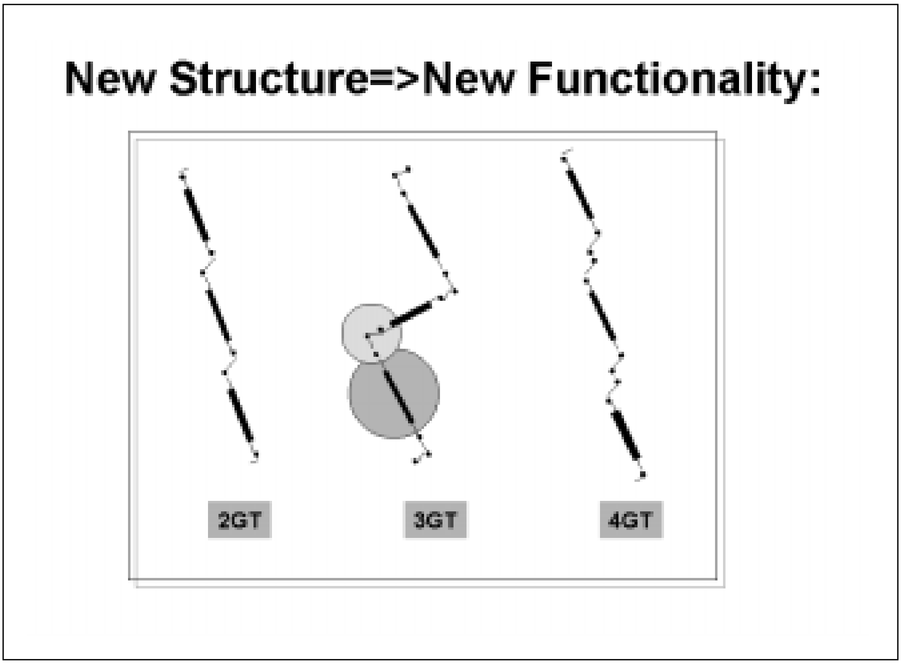

Figure 2

When you flex your elbow while wearing a long-sleeved blouse or shirt, or sit in a car, or put a heavy weight on a carpet: you are stretching or crushing the textile materials. Of course, you want those materials to return to their original size and shape when you remove the strain. Sorona® can be stretched up to 20 percent and return to its original shape, whereas conventional polyesters and nylon can be stretched only to 3, 7, or 10 percent and return to the original length (Figure 3).

Sorona® brings with it additional properties. It takes on dyes easily in an environmentally friendly way, is stain resistant, etc. — properties you are glad to have in materials you use.

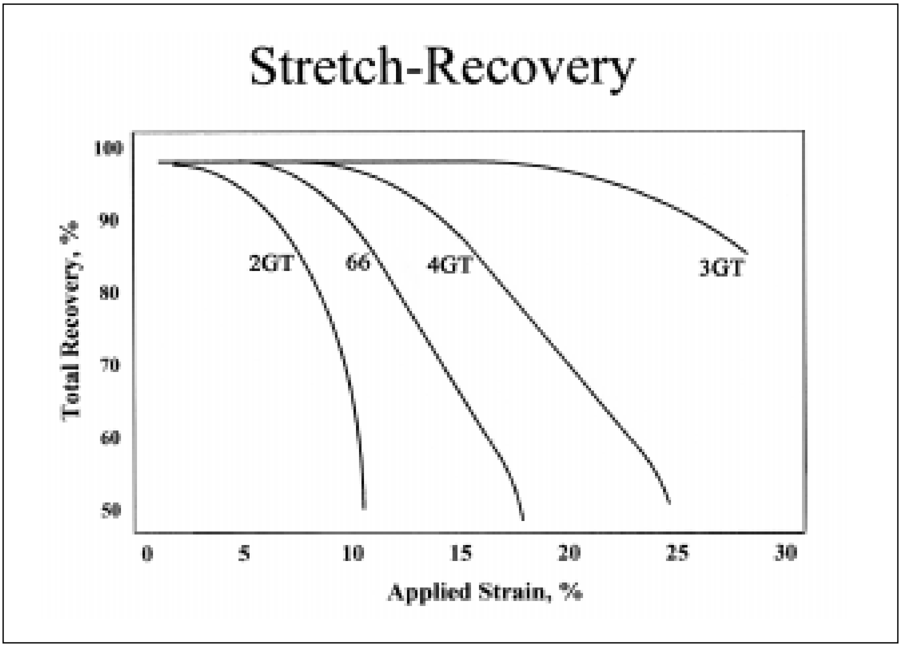

Figure 3

The second leg of sustainability is reduced cost and investment. The new biotech applications utilize alternative feedstocks, and multiple chemical reactions are possible literally in a single reactor. That reactor is a microbe, enabling process simplification and operation-cost reductions.

We are building one half of the Sorona® molecule from corn and the other half from petroleum. The petrochemical is terepthalic acid, which we combine with the new corn-based fermentation product, the oxy-chemical 1,3-propanediol. Thus, Sorona® utilizes the best of both worlds: a low-cost material from petrochemical feedstocks and a low-cost oxy-chemical from corn-derived glucose: a combining paradigm rather than a competing paradigm.

An effective biocatalyst was designed. By combining some genes from yeast, for conversion of glucose to glycerol, with genes from a bacterium, for conversion glycerol to 1,3 propanediol, we built a new microorganism (Figure 4). This is a complex, but highly specific process. Returning to the broader view, these biocatalysts let us go beyond traditional chemical catalysts and their hydrocarbon feedstocks to a whole new set of catalysts, providing the chemist and the chemical engineer with a much broader range of processes and starting materials.

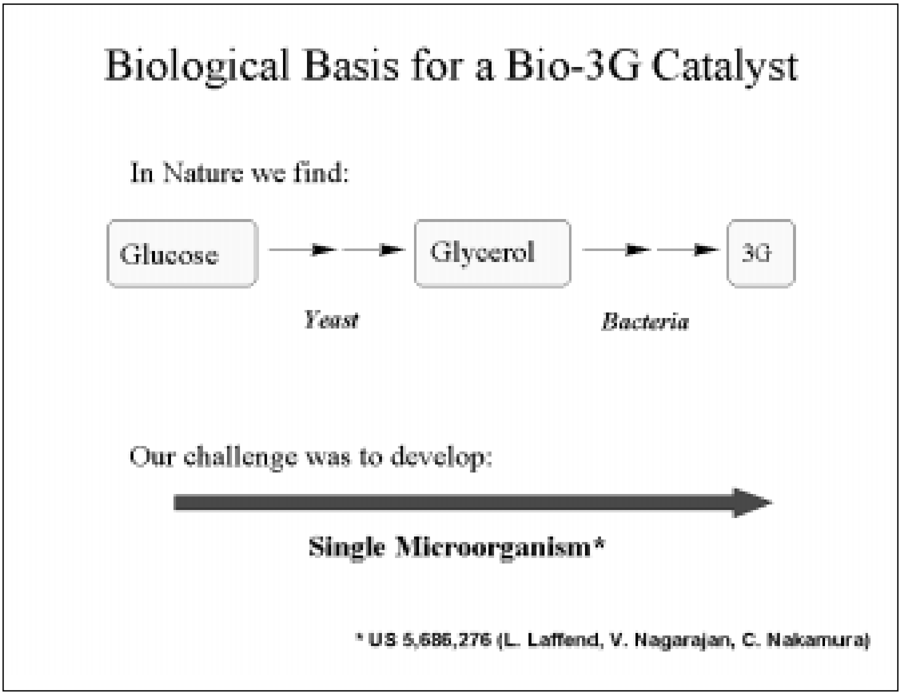

Figure 4

We can make biological catalysts, multiply them through fermentation processes, and separate pure products to derive new sets of chemicals, polymers and fibers largely unknown in the world today.

As an example, in our collaborative work with Genencor International, we have constructed a microorganism that makes levels of 1,3-propanediol even higher than for ethanol in current fermentation processes.

The last aspect of sustainability is environmental impact. Two hundred and fifty years of industrialization have forced the atmosphere out of equilibrium, clearly necessitating careful consideration of the consequences. Agriculture and forestry provide perhaps the only opportunities to fix CO_2, capture nearly free energy from sunlight, and produce plant matter to feed fermentations for new commercial products.

To summarize, we need (1) products of greater functionality to give greater value, (2) processes that operate at lower costs with lower investments, and (3) combinations of products and their processes that achieve a smaller environmental footprint that insures our future.

The Department of Energy's Contribution to the President's Bioproduct and Bioenergy Initiative

DANIEL W. REICHER
Department of Energy
Washington, DC

I bring greetings from Bill Richardson, Secretary of Energy, who is a strong supporter of the development and utilization of bioenergy.

There are four key messages that I want to deliver:

- This is an opportune time for the development and utilization of biobased products and energy.
- Success will require a more integrated approach than hitherto.
- Our nation's colleges and universities have a very large role to play.
- Government/industry/academic partnerships will ultimately be the key to success.

The development of clean-energy resources in this country, including bioenergy, has the following driving forces: (1) energy security, (2) electric utility restructuring, (3) environmental quality, (4) climate change, and (5) economic competitiveness.

ENERGY SECURITY

This is the traditional driving force for work by government, industry and academia relative to energy, with the emphasis on reducing our dependence on foreign oil. Table 1 shows that it is a mounting challenge. Domestic production of oil is declining, whereas requirements are increasing, particularly in the transportation sector and especially as a result of rapid growth in the use of light and heavy trucks. Filling the gap between domestic oil production and domestic transportation requirements, in many respects, represents our biggest energy-security challenge.

TABLE 1. DOMESTIC OIL PRODUCTION AND TOTAL USE

Year	Domestic production	Oil use by Autos	Autos + light trucks	Autos + light & heavy trucks
	(millions of barrels per day)			
1970	9.25	6.25	6.50	7.50
1980	8.50	6.25	8.25	10.2
1990	7.50	6.25	8.25	10.2
2000	7.00	6.00	9.50	12.2
2010	5.25	5.00	12.0	14.5
2020	5.50	5.00	13.7	17.0

ELECTRIC UTILITY RESTRUCTURING

Currently, about twenty-seven states have introduced competition and choice in some form to their electricity markets. This means that new energy technologies will have increasingly greater opportunities for success in the marketplace. And consumers, whether they are commercial or residential, will have choices in terms of supplier and technology.

ENVIRONMENTAL QUALITY

It is noteworthy that, in the United States, an extraordinarily high fraction of pollutant emissions result from the production and use of fossil-based energy. Of the total emissions nationally, 97 percent of the NO_x, 85 percent of CO, 91 percent of SO_2 and 98 percent of the CO_2 result from the use of fossil fuels; this is emerging as a significant environmental challenge. Clearly, the use of renewable resources, including biomass, represents an important new approach to improving environmental quality.

CLIMATE CHANGE

The substantial growth in carbon emissions that is projected for the next few decades may contribute to global warming. Biofuels have the major advantage of being relatively carbon-neutral.

ECONOMIC COMPETITIVENESS

In the world today, power production of about three million megawatts is installed. Over the next 20 years, it is projected that in excess of two million megawatts more will be required — almost double.

While these driving forces suggest a bright future for bioenergy, there are serious challenges also. An important point to consider is the need to improve integration across the various focus areas of bioenergy. In other words, the people in chemicals, power, fuels and bioproducts are not working together. The fundamental commonality is that they all work with biomass and see a future for it. In our view, we must increasingly integrate our efforts across those focus areas.

The oil-refining industry is an excellent example of integration. Depending upon technologies, policy influences and market signals, a barrel of oil can be used to make fuels, power, chemicals, and a whole array of products. A similar integrated approach must be developed if biomass is to see the growth that we think it needs. Therefore, an integrated bioenergy industry must look across all these focus areas, advance the technologies, put the right policies in place, and stimulate the appropriate markets.

An integrated bioenergy industry would evaluate and consider all possible resources for biofuel production: trees, grasses, crops, residues, animal wastes, municipal solid wastes. It would evaluate a broad array of conversion processes for the widest spectrum of products. The fact that the product possibilities are far broader than from petrochemicals is a very exciting opportunity that has stimulated people in Washington, DC, to focus in a way that we have not seen before.

Fortunately, "the stars have aligned" in pursuit of this goal, as shown by some of the activities of the past couple of years. Your organization (NABC) issued a very compelling *Vision for Agricultural Research and Development in the 21st Century*. A major National Research Council report on renewable bioproducts was released. And President Clinton's executive order in August 1999 is a major development in our joint work to move biomass forward. We are seeing an unprecedented level of legislative interest and legislative support. It is rare these days in Washington when the Congress agrees with the White House, the Senate agrees with the House, and the Democrats agree with the Republicans, but when it comes to biomass we have seen very strong legislative support from both ends of Pennsylvania Avenue and across the two parties.

This cooperation has focused on Senator Lugar's bill, which has been adopted by the full Senate. We expect House passage of a bill shortly, and then resolution in a conference leading to a major new piece of legislation that would authorize new work by the federal government on biomass, and hopefully result also in increased appropriations. We are striving not only to obtain authorization to move forward in a more integrated fashion but also to receive appropriations that would support work in industry, universities and government. We have also seen a modest increase in the current budget in support of work on biomass. And the Department of Energy along with other federal agencies are working on a biobased products and bioenergy vision and roadmap that will link the approach to technologies, policies and markets in a very fundamental way.

President Clinton's goal is to triple use of biobased products and bioenergy (power, fuels, chemicals, materials) within 10 years. We think it is realistic to go from our current use of bioenergy, which is approximately 3 percent of United States primary energy, and triple that by 2010.

Many offices of the federal government are working cooperatively to achieve this: the Department of Agriculture, Department of Energy and a number of related entities, including the National Science Foundation, Environmental Protection Agency, Department of the Interior, and the Department of Commerce. As an example of these activities, an interagency council on biobased products and bioenergy has been established, jointly chaired by the Department of Energy and the Department of Agriculture. I chair it from the DOE side and Miley Gonzales, the Under Secretary for Technology, chairs it from the USDA side. In addition, a new advisory committee is being formed that will have university representation, to advise the government on its approach to bioenergy and biobased products. Also, an office to coordinate the federal government's various functions has been established and is under way. These activities represent a large strategic planning effort addressing questions such as: Are we spending money in the right ways? Are we coordinating in the right ways? Have we placed the right level emphasis on our work with industry and universities?

The development and widespread use of bioproducts face a number of challenges from the technological side, such as securing reliable feedstock sources, developing new delivery systems, and, perhaps most important, reducing conversion and downstream processing costs. The cost curves for these issues must be reduced, no matter what the technology is, if bioproducts are to compete with the petrochemical-based processes already in existence

Also, many market challenges exist. Reliable biomass supplies must be established. Securing capital for new technologies can be difficult, especially when the "dot coms" are wooing Wall Street. Factors such as the price, quality, and availability of alternative sources of power and fuels, e.g. fossil-derived fuels, in addition to the replacement costs of facilities, will also determine the development of biobased industries. Practical aspects must be considered such as sales, distribution and service networks, trade opportunities and foreign-market access; some of the biggest opportunities will lie overseas.

And there are key policy challenges. How will the tax code affect the development and utilization of biobased products? What decisions will be made on a state-by-state basis regarding electric utility restructuring, and ultimately at the federal level when legislation is finally adopted? How will these resources be treated under environmental regulations, particularly clean-air regulations? Where does this fit in our response to global climate change, rural economic development policies, and government procurement. As a matter of interest, the federal government is the largest user of energy in the world, representing 2 percent of all energy consumed in the United States.

Several ongoing projects across the country are jointly financed by the federal government and industry. In New York State and Vermont, hybrid willow is being used in a co-firing process with fossil fuels. Alabama Power is also involved in a co-firing project. Switchgrass is being grown in a number of states, also for co-firing. New gasification technologies are being developed that, instead of direct burning, are able to gasify biomass material or black liquor waste from the forest-products industry to make a medium-BTU gas that will turn a turbine to make electricity.

We are excited also about the prospects for cellulosic ethanol. Production plants are under development in Louisiana, New York State, California, North Carolina, Idaho and North Dakota, some of which are supported by DOE.

The data below represent a realistic projection of the total ethanol production over the next 20 years in the United States. With cost declines, improved technologies, and current biotechnological advances, we believe there is a bright future for cellulosic ethanol.

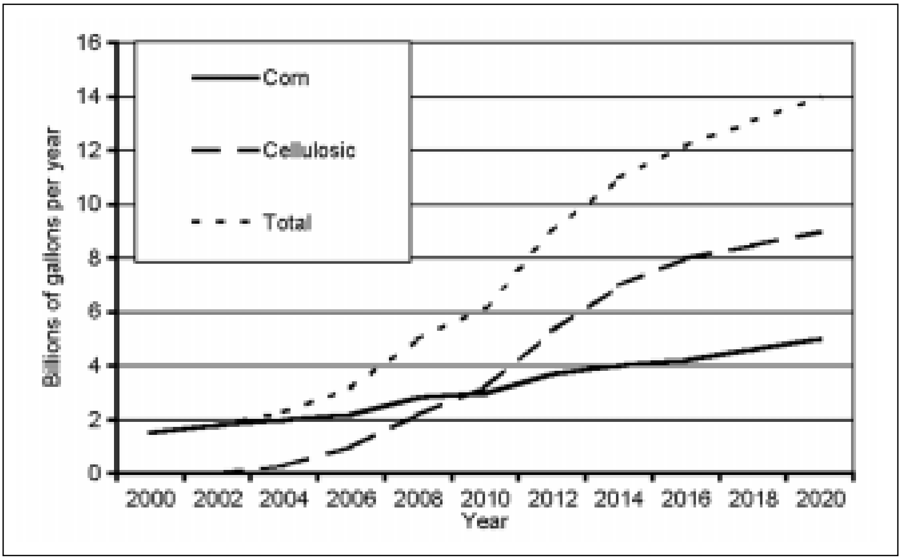

Figure 1. Projected production of ethanol, 2000–2020.

There are also some interesting relationships to other emerging energy technologies. Some companies are looking at biofuels as a source of hydrogen to power fuel cells. In late 2001, General Electric is planning to market residential fuel cells.

Opportunities exist also in rural areas for wind power, which is the fastest growing source of electricity in the world. Major advances in this technology in a Minnesota project recently have driven the price down from 40 cents per kilowatt hour in 1979 to 4 cents per kilowatt hour (unsubsidized). In farm country from the Dakotas to Texas, in Kansas, Nebraska, Minnesota and Iowa, there is huge wind-power potential and we are seeing major developments.

Recently, there have been major advances also in the technology of harnessing solar energy. Systems are well developed and costs are decreasing.

A broad array of funding opportunities from various federal agencies is available to universities and industry. Currently, there are active solicitations for work on biobased products, co-firing research, analytical tools, and biorefineries. These solicitations have enjoyed huge responses across fuels, power and chemicals to generate the best ideas in industry and academia on how to progress with a more integrated approach. Furthermore, we are increasingly interested in working with the state universities and land-grant colleges in this area of endeavor, and are hopeful that such partnerships will be fruitful.

To conclude, a wonderful opportunity exists for bioenergy and biobased products. The stars truly have aligned from a policy prospective, the technologies are developing well, there is increasing market interest and, over the next decade, we look forward to working with you to move this vision forward.

The USDA's Contribution to the President's Bioproduct and Bioenergy Initiative

Roger Conway
Office of Energy Policy and New Uses
Office of the Chief Economist at the United States Department of Agriculture
Washington, DC

My topic is the role of the United States Department of Agriculture (USDA) in enhancing the development and use of biobased products and bioenergy. In August 1999, President Clinton announced Executive Order 13134 at the USDA along with Secretary Dan Glickman, Secretary Bill Richardson, Administrator Carole Browner, and Senator Richard Lugar.

The very ambitious goal of this Executive Order is to triple the nation's use of biobased products and bioenergy by 2010. Why are we interested in this? From the perspective of the USDA, first and foremost, we want to help improve the rural economy, the farm economy, and the forest economy. This past fiscal year, we spent $23 billion in direct payments to farmers, the highest amount ever. There is need to find a market-based solution to support agricultural commodity prices. Over the past 20 years, exports for agricultural products have been fairly stable, and we will continue to look at that market as an opportunity. In addition, the market for bioenergy and biobased products has the potential to help raise farm income and strengthen the rural economy. Also, biobased products are environmentally friendly. They have low toxicity, are biodegradable, and have a high flash point relative to petroleum products.

In addition, there is the goal of enhanced national energy security. The high gasoline and oil prices in the spring and summer of 2000 remind us that we are beholden to other countries for much of our energy, and that there in need to increase our domestic supplies. Even though we are more energy-efficient than we have been in the past 20 years, the United States still has an issue with energy security. Bioenergy and bioproducts may not be the whole answer, but they are part of a solution.

In what markets may biobased products compete? There is a $5.1-billion market in lubricant sales, $14.6 billion in composites, $43 billion in paint, and $77 billion in plastics. These are substantial markets. If the agricultural sector could gain 5 or 10 percent of each of these, additional demands for farm products would be major contributions to farm income and rural development.

What is the current use of biobased products? Currently 98.15 quadrillion (quads) Btu are being consumed per year by the United States. Although ethanol is the great success story in liquid fuels, contributing about one percent of the transportation fuel, this is only 0.14 quads Btu. Except for the Agricultural Research Service (ARS), there is very little use of biodiesel fuel; it remains in the early developmental stage, especially the 20-percent blends. Biomass in the form of solid fuels is a significant source of energy. The total consumption for the year 2000 is estimated at 2 quads Btu, most of which is direct combustion of forestry residues; in addition, residential use consumes about 0.6 quads. To meet the goal of tripling the nation's use of biobased products, including bioenergy, by 2010, there is much to be done in terms of science, development, and commercialization.

The USDA, with more than a hundred years of experience in developing new products, can contribute to meeting the goal in several ways. In particular, through the 1938 Agricultural Adjustment Act, the ARS created four utilization laboratories at which there has been a great deal of work on bioproducts. Examples include the superslurper and soy ink; a number of products have been commercialized and are marketed. In addition, the Forest Service has seven field-research stations. Tom Jeffries's research, at the Forest Products Laboratory at the University of Wisconsin, is on cellulosic ethanol. Of course, we are proud of the linkages that USDA has with land-grant universities for leveraging research, education and outreach, principally through the Cooperative State Research, Education, and Extension Service (CSREES) by formula funding, competitive grants and special grants programs.

The USDA is ready to meet the challenge to assist the president. We have an effective network for reaching farmers and landowners with education outreach efforts. Not only through the Extension Service, but also with the Farm Services Agency, and the National Resource and Conservation Service (NRCS) through their Resource Conservation and Development Councils (RC&Ds). The NRCS has been helpful in supporting many activities with the Department of Energy (DOE). In addition, we have some effective programs for strengthening rural communities through our Rural Development Mission Area. For example, in conjunction with the Rural Business Service, the Business and Industry Loan Program, and the Cooperatives Program, our cooperatives have assisted in the development of ethanol plants in Minnesota, South Dakota, and Nebraska. In addition, the USDA has an active network through the Foreign Agricultural Service for building future export markets for biobased products.

We have also been developing what we at the USDA think is a good system for coordinating policy for energy and new uses of farm and forest products, *viz*. through the Interagency Bioproducts and Bioenergy Counsel, which President Clinton created. We have within the USDA the Bioproducts and

Bioenergy Coordination Council, led by Richard Holcombe from the Office of Administration, to ensure that we are communicating and not duplicating effort within the Department. In addition, we now have a formal joint Coordination Office with the DOE, in which there are two representatives of the USDA.

The USDA has participated with the DOE in many activities related to biobased products and bioenergy. The Biomass Power for Rural Development Project is an example, with two joint USDA-DOE projects. One DOE-funded project is in the Chariton Valley, IA, where 40,000 acres of Conservation Reserve Program (CRP) land is being experimentally used to grow switchgrass for co-firing and for small-scale gasification, in cooperation with an Iowa utility. In another DOE project, in conjunction with the State University of New York College of Environmental Science and Forestry, Syracuse, NY, the Forest Service and RC&Ds are exploring the use of willows as a feedstock, also for co-firing and gasification.

We have cooperated extensively with the DOE also on conversion technologies for cellulosic ethanol. The USDA and the DOE have funded Lonnie Ingram's research at the University of Florida on cellulosic ethanol, and we are proud of that association. You may know that he was awarded the five millionth patent for that technology (the four millionth was for a microchip). We have hopes that his technology will soon be commercialized at the BC International, Jennings, LA, plant with some funding support from the DOE.

We have worked also in product lifecycle analysis. This is an important issue, since we have to dramatize the net environmental and energy benefits of bioproducts and bioenergy to garner public attention. We have worked with the DOE on biodiesel as well as ethanol and have shown that, in terms of adverse greenhouse-gas emissions there is much less with corn and cellulosic ethanol than with petroleum-based gasoline. Biodiesel emits 70 percent less CO_2 per unit of energy than does its petroleum-based counterpart. Such information is important to the argument to Congress and others that net environmental benefits accrue from these products. At the USDA we believe we can deliver scientific breakthroughs in the area of properties of biomaterials, both for new crops and for new technologies for separation fermentation. The DOE is particularly interested in working with the USDA to accelerate the development and demonstration of biobased products and bioenergy. Through our Rural Development Mission Area, NRCS, and other program agencies, we plan to tailor programs with help from the DOE to facilitate their pre-commercialization projects. The USDA can help identify bioproduct opportunities with high economic potential. We want to be good stewards of taxpayers' money and ensure that our resources are directed toward the biggest return for the investment and a definable market payoff. Economists working with scientists can help find opportunities to marshal USDA's resources productively. Product promotion and education are also important elements for success of the initiative.

The CSREES is proposing an increase in funding for this biobased initiative. In conjunction with land grant institutions three comprehensive projects will encompass research and development, demonstration, and test evaluation of biobased products. The focus will be on lubricants, paints, coatings, and solvents, with performance validation and cost-effectiveness appraisal. Another issue for CSREES in conjunction with the Office of Administration and others is to use the purchasing power of the USDA and the federal government to create markets and find opportunities to demonstrate these products. From these government markets the objective is to develop private-sector commerce.

The Office of Energy Policy and New Uses will identify market opportunities for developing new biobased and bioenergy products. There is an economic procedure for ranking programs. Julian Austin, at the University of California-Davis, has devised methods for ranking scientific programs based on a discounted net-benefit model. My office will appraise these methods in working with the ARS and others, and will look at estimating costs and environmental lifecycles of bioenergy and biobased products. One method is lifecycle cost analysis, with which a procurement manager would compare a biobased product with some other product in terms of the total cost over its lifecycle. Another approach is to look over the entire production and use cycle — e.g. in the case of biodiesel, from soil to tailpipe — to obtain a comprehensive energy and environmental analysis. We have used both types of analysis with some success.

In conclusion, we hope that the new funding we seek will help meet the president's goal of tripling the use of biobased products and bioenergy by 2010, and, most importantly, will create new market demands for agricultural and forestry commodities to increase farm income and strengthen rural communities.

The Role of Land Grant Universities: Responsible Innovation

Patricia B. Swan
Iowa State University
Ames, IA

Land grant institutions share many aspects of their role in society with other public research universities. Unlike those others, however, the land grant universities also have responsibilities assigned to them by congressional legislation.

Beginning with the Morrill Act, signed by President Abraham Lincoln in 1862, federally enacted legislation has specified several roles and responsibilities for land grant universities. When asking what these universities should be doing with regard to the developing biobased economy, it is important to review current societal expectations as well as the evolution of their responsibilities under federal law. It is necessary also to consider how they receive financial support for carrying out their responsibilities, and how well they have met expectations in the past. Finally, it is important to examine the nature of the present challenge, that of assuming a role in fostering the biobased economy, and ways in which these universities might meet this challenge in the future.

FEDERAL LEGISLATION

In 1862, with the absence of dissenting southern members, Congress was able to pass legislation granting public lands to each state as an endowment for a public university. President Lincoln signed the Morrill Act on July 2, 1862[1] and the General Assembly of the State of Iowa was the first to accept its terms, in a special session called for other purposes on September 11, 1862 (Ross 1958). In the Morrill Act, the universities were instructed to carry out their work under state direction "in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life."

Congress recognized the importance of research in support of the land grant universities' mission in the Hatch Act of 1887. This legislation authorized funds for establishing an agricultural experiment station as a “department” within each university. The stations were charged with a series of specific investigations that would bear “directly on the agricultural industry of the United States . . . having due regard to the varying conditions and needs of the respective States or Territories.” In the Adams Act of 1906, Congress authorized additional funds for the stations and repeated this charge.

In 1925, Congress specifically broadened the charge to the stations through the Purnell Act, which authorized additional funding to support:

> “ . . . conducting investigations or making experiments bearing directly on the production, manufacture, preparation, use, distribution, and marketing of agricultural products and including such scientific researches as have for their purpose the establishment and maintenance of a permanent and efficient agricultural industry, and such economic and sociological investigations as have for their purpose the development and improvement of the rural home and rural life . . .”

Ten years later, the Bankhead-Jones Act clearly assigned responsibilities related to new uses for agricultural products to the land grant universities. This legislation authorized additional funding to the universities and asked that both they and the United States Department of Agriculture (USDA) conduct research relating to “ . . . new and extended uses and markets for agricultural commodities and byproducts and manufactures thereof…” An amendment to this legislation, passed in 1946, was even more explicit; among other charges, it called for:

> “ . . . research relating to the development of present, new and extended uses and markets for agricultural commodities and byproducts as food or in commerce, manufacture, or trade both at home and abroad . . . research to encourage the discovery, introduction, and breeding of new and useful agricultural crops, plants, and animals, both foreign and native, particularly for those crops and plants which may be adapted to utilization in chemical and manufacturing industries.”

Beginning in the mid-1950s, legislation authorizing various programs of the USDA was consolidated into one large bill — the Farm Bill, in which the programs of the land grant universities formed one section. The effect of this consolidation was to generalize the previously stated responsibilities for the land grant universities, and also to add some specific programs of interest to members of Congress. Funds for marketing research were still managed separately, but, over time, that research focused more on markets for existing uses of commodities rather than on new uses. Interest in new uses for agricultural commodities declined.

The energy crises of the 1970s refocused Congress's attention on the potential for using biomass for fuel, and a special program was authorized within the Farm Bill. When the Department of Energy (DOE) was formed in the late 1970s, it was given responsibility for research on alternative energy sources, including solar energy and biomass. Cooperative programs with the USDA focused some of this work through special grants to researchers in the experiment stations. Unfortunately, funding for these efforts was not adequate to the task, and, under these programs, the work has not been carried out in a coordinated or comprehensive fashion.

Interest waned as petroleum-based fuel sources once again became plentiful. Agricultural commodities as fuel sources remained of interest primarily to certain states, as did new uses of specific alternative crops. Programs aimed at the use of a particular crop to produce fuel (such as ethanol from corn) or the development of an alternative crop for industrial use (such as kenaf for paper) were authorized from time to time. Land grant universities have participated in these programs, focusing on crops and uses of particular local interest, but there has been no comprehensive program to develop biobased materials to replace petrochemicals in industrial uses.

Until recently the Alternative Agricultural Research and Commercialization Corporation (AARC), a wholly government-owned corporation established by Congress with reporting responsibilities to the Secretary of Agriculture, promoted development research and commercialization aimed at introducing biobased industrial products into the marketplace. It was authorized as a means to promote rural development through commercialization of new uses for existing and alternative crops. In my opinion as a former AARC member, the Corporation's efforts were limited by insufficient funding, lack of knowledgeable management within the companies commercializing new products, and, to some extent, by lack of innovations worthy of investment. Land grant universities have participated only to a very limited extent in these efforts, which are focused on the marketplace rather than on more fundamental research. AARC funding was discontinued in 2000.

The Federal Agriculture Improvement and Reform Act of 1996 and the Agricultural Research, Extension and Education Reform Act of 1998 continue to authorize work on "new and alternative uses and production of agricultural commodities and products." The former also talks about "priority mission areas" that include "new uses and new crops" and the need to "protect the environment and maintain an adequate, nutritious and safe supply of food."

Legislation Needed for the Future

Throughout the past century, the land grant universities have had a federal mandate to work on new uses for agricultural commodities, and this mandate continues. The mandate has been clearer in some decades than in others, and funding has waxed and waned with the public interest, reflecting only the circumstances of the moment. The interest of the states, which fund greater portions of the work of these universities than does the federal government, has been fragmentary due to diverse local priorities. There has been no attempt to build a comprehensive program toward the development of the biobased economy.

Although there is widespread recognition that sources of petroleum are finite, there is disagreement as to when they will be exhausted. There is no general sense of crisis due to limitation of sources, although, from time to time, concern is expressed over immediate access to supplies of petroleum due to changing political and economic conditions. Sometimes, emphasis is placed on the environmental pollutants arising from use of petroleum-based fuels, and both federal and local legislation has sought to limit these pollutants.

Usually, however, the need for a biobased economy is seen as being far in the future and, perhaps, only of limited value to the environment. Moreover, public-interest groups, focused on aspects of the environment, have not made a coordinated effort to emphasize the needs for alternatives to industrial uses of petroleum, including as a fuel. Thus, if there is to be a comprehensive program in which the land grant universities participate, aimed toward development of the biobased economy, there must be a concerted effort to impress upon the public and, ultimately, Congress and state legislatures, the need for such a seemingly futuristic endeavor. Traditionally, the federal government has taken the lead in establishing programs aimed at developing new industries. It seems reasonable, therefore, that it should take leadership in programs for developing the biobased economy, which has the potential for spawning many new industries. Full participation of the land grant universities in fostering a biobased economy will require that they have both a clear, forceful mandate, and adequate funding for the task.

Responses of the Land Grant Universities to Past Mandates

Federal legislation has made it clear that land grant universities have certain specific responsibilities that are not so directed to other universities. The universities have responded to these directives with varying degrees of enthusiasm, but their capability to address issues successfully when requested to do so by the public and when they have the necessary funding, has been clearly demonstrated.

The history of the land grant universities' responses to their various assigned responsibilities is somewhat checkered. There are clear success stories where the mandate was explicit and funds were provided. Some of these are: improvement of seeds, evaluation and standardization of fertilizers, development of hybrid crops, improved farm-management practices, determination of nutrient requirements for farm animals and humans, determination of the nutrient composition of foods, and development of food preservation and food-safety technologies.

There have also been failures, both temporary and long term. An example of a temporary failure that was quickly corrected in one state is provided by the story of the development of a method to extract the oil from soybeans. In the 1940s, the pressure method for oil-extraction was not entirely satisfactory. Therefore, the chemical engineering department at Iowa State College developed a chemical process and the necessary commercial-scale equipment. Three patents for these processes were licensed and put into practice in the early 1950s. When the resulting meal was fed to cattle, however, they died. It was found that the solvent used, trichoroethylene, formed toxic adducts with the protein in the meal. Prior to commercialization, no one had adequately tested the meal to confirm its feed value because the focus had been on complete extraction of the oil. A cursory evaluation had seemed to show that the meal was safe. Research at Iowa State, Minnesota and elsewhere quickly confirmed that the problem was with the solvent. At Iowa State, chemical engineers screened other solvents and determined that hexane worked equally well and did not harm the feed value of the meal.

In this case, financial losses were experienced first by the cattle farmers, who recovered these losses through legal action against the manufacturers. Payments to the farmers diminished company resources and required contributions by Iowa State, which, in turn, diminished resources for other purposes at the university. It was a costly mistake to have disregarded potential consequences and to have insufficiently evaluated the product beforehand. Although the problem was quickly corrected and the harm was not long term, the story provides lessons that are important to our present considerations.

An example of a long-term failure is provided by a more recent occurrence. Over the past 25 years or more, the land grant universities have failed to actively evaluate the applications of new biotechnologies in agricultural production and, especially, in new food products. Those with medical schools have not focused on applications in the human-health industry. There were at least two reasons for this failure: there was little or no funding designated for this purpose and no mechanism for thinking comprehensively about the potential consequences of these innovations for the environment, the economy, and the consumer. Moreover, as a first approximation, they seemed safe enough. There was no obvious reason to consider them potentially harmful.

There are problems today, however, because the land grant universities have not actively evaluated the applications of biotechnology. Although no major adverse consequences of agricultural biotechnologies have been experienced in the environment or by animals or humans consuming resultant products, the failure lies in the fact that the universities are unable to provide data to assuage the increasing fears of a lay public. Concerned groups have raised the specter of potential harm to the environment and to human health, and universities do not have adequate data to address these misgivings. True, most of the innovations have come from industry, but legally required evaluations by companies do not cover many of the concerns now being raised. Moreover, the public does not always trust possibly self-interested evaluations by companies. Why have the universities not demanded the resources and assembled informed multi-disciplinary teams to broadly consider consequences? Why has the public not insisted that they do so? Does the public believe them to be unable or unwilling to undertake objective evaluations? This has been a long-term failure of almost three decades duration. The current situation provides valuable lessons for our present considerations related to the biobased economy.

Responsibilities for the Biobased Economy

These lessons provide land grant institutions with a basis from which to discharge their responsibilities with respect to the biobased economy. First, there is opportunity, if the universities will seize it, for research that will result in important innovations. Second, there is the responsibility for broadly based evaluation of consequences of implementing these innovations. Third, there is a need to capture the minds of the students who will be the innovators, evaluators and implementers in the biobased economy in the future. Finally, additional resources must be made available.

Researchers at the land grant universities have been innovators when they have had the necessary resources. The recognition of opportunities for innovation and the acquisition of resources to support that innovation require both scientific and administrative leadership. Failure in leadership on either count would be fatal to the effort; presently, leadership is lacking on both counts. The rate of innovation towards developing agricultural materials for industrial and pharmaceutical products and fuels must increase for continued progress toward the biobased economy, if the potential benefits of that economy are to be realized globally.

Experience shows that innovation alone is not enough. Thoughtful and broadly based evaluation of innovations must take place, involving effective across-discipline communication with mutual sharing of understanding and of within-discipline perspectives of potential consequences. Only with informed multidisciplinary evaluation is it possible to foresee consequences of implementing a particular innovation. The required disciplines exist within the universities, but the researchers lack experience in working together. Moreover, these researchers are frequently distrustful and depreciative of contributions from other disciplines. Such barriers will be overcome only if there is effective leadership, both from scientists and from administrators.

Students represent the best hope that the land grant universities will make their needed contributions to the biobased economy. Again, leadership is required, from faculty and administration alike. Students have a natural interest in the world of the future, much more so than do most middle-aged faculty members and administrators. They are excited by the potential to find solutions to current problems that will contribute to long-term improvements in the environment and to preservation of natural resources.

What effort is being made to turn the attention of students to the potential benefits and risks of the biobased economy? Are the land grant universities using the challenges of the biobased economy to provide stimulation for the collective student imagination? Are they providing opportunities for students to come together from many disciplines to consider these challenges? Do their various curricula require thinking about these matters? This subject provides opportunities to give students needed experience in thinking and talking across disciplines, but will the universities take advantage of them? So far, in most universities, the answers to these questions are in the negative.

Conclusions and Questions

The challenge to the land grant universities relative to their role in the biobased economy is abundantly apparent. It is to provide the innovation, evaluation, and education that will help ensure that society will reap the potential benefits of the biobased economy with minimal exposure to the possible risks. It fits their legislated responsibilities. To be sure, this is a grand challenge that will require additional resources. Will the public partner with these universities to meet the challenge? Will the land grant universities be asked by the public to make a concerted effort to meet this challenge and, if asked, will the universities do so? It is sobering to ask, "If not these universities, then who?"

Each member university of the NABC has the opportunity to provide leadership, individually and collectively, toward these goals. Each voting member of the public and each public action group has the opportunity to press for a clear mandate and funds for these universities to carry out their role. Is there sufficient will to do so?

Reference

E.D. Ross, *The Land-Grant Idea at Iowa State College* (Ames: Iowa State College Press, 1958).

[1]Legislation reviewed in this paper can be found in several sources, including the web. For legislation through 1955, consult: H.C Knoblauch, E.M. Law, and W.P. Meyer, *State Agricultural Experiment Stations: A History of Research Policy and Procedure*, *US Department of Agriculture Misc. Publ. No. 904*. (Washington: US Government Printing Office, 1962). For legislation through 1985, consult: N.A. Kerr, *The Legacy: A Centennial History of the State Agricultural Experiment Stations*. (Columbia, MO: University of Missouri-Columbia Agricultural Experiment Station, 1987). More recent legislation may be accessed through the US Department of Agriculture's web site.

The Producer's Role — Serf or Partner in the Biobased Economy?

LYNN RUNDLE
21st Century Alliance
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The vision of the structure of the biobased economy of twenty-first century agriculture is, at best, a fuzzy picture of how genetics, production, processing, distribution, and marketing to consumers will integrate. Several important political and social implications must be addressed before specific roles of the players in the biobased agriculture game will become clear.

As the CEO of a new-generation farmer alliance, I believe I have a good understanding of the way in which the commercial family farmer thinks about the future. Commercial family farmers understand the need to get closer to the consumers of food and non-food products if they are to be successful.

The questions I want to address today deal with the role of commercial farmers.

- Who are twenty-first century farmers?
- What is the their position in twenty-first century agriculture?
- How are they surviving today?
- What does an alliance of farmers look like?
- What do farmers want out of agriculture?
- What role do farmers want to play in the biobased economy?

Producers and agribusiness people must address the question, "Will farmers be serfs or partners in the new biobased economy?" The 21st Century Alliance of farmers, developed in the Central Plains over the past four years, is a possible prototype for other committed farmer groups. They want to be partners, and they want to be vertically integrated in the production of biobased agricultural products.

When the alliance was founded in 1996, the vision was simple: to form an organization of farmers — a business of farmers — that would provide profitable commercial opportunities. Today that business is made up of 750 farmers from ten states. We have started five new-generation cooperatives, raised $7 million in farmer equity, developed identity-preserved crop systems for our businesses, and created a vision of what can happen if farmers look at the market place for income instead of relying on government payments.

Historically, returns on investment in production agriculture have averaged 1 to 3 percent. In contrast, food processing as an industry has averaged a return on investment greater than 15 percent since 1980, according to *Business Week* magazine. In 1997, US per-farm earnings averaged $52,350, of which $46, 360 was non-farm income and only $5,990 came directly from the farm. With such statistics underpinning agriculture, we need to be aware that a significant portion of net commercial-farm income is in the form of government payments.

In Kansas, the Farm Management Association annually collects data from about 2,000 family farms. In crop year 1998, the farmers in the association received, on average, a staggering 60 percent of their gross income from government payments. The government put $23 billion directly into the pockets of farmers in 1999, and in an election year with a booming economy it looks like the government is poised to do that again. Is this a sustainable system? Granted, in order to ensure that we keep farmers farming in times of low prices, government payments are necessary. But, in the long run, I do not believe that the American consumer will be willing to pump $20+ billion per year into farm payments.

These trends have driven the farmers I work for to explore novel means of obtaining more dollars from the marketplace. With the new technology of biobased agriculture just beginning to take off, there is a tremendous opportunity to do it right. To be full partners in new production systems will take capital investment, but visionary farmers will be willing to make such investments if it ensures their long-term survival.

To provide a better understanding of what this means, there follow a few examples of what we have been doing in the Central Plains. In 1997, the first “opportunity to invest” presented to Alliance farmers was a flourmill in New Mexico. We raised $3.2 million in equity from 375 farmers for the purchase. In 1998, a pinto-bean processing facility was bought with new equity from sixty farmers in Colorado, Nebraska, and Kansas. Alliance members have also raised $3.3 million in equity for two start-up green-field commercial dairies with milking capacity for 4,300 cows.

These investments are geared towards adding value to commodities that our members are already producing. Each farmer must deliver a specified number of bushels of corn, sorghum, wheat, or beans to the processing facility per share of owned stock. This guarantees that the facility has the needed raw material, and incentives are in place — because of ownership — that reward farmers for delivering their best quality commodities, identity preserved, to "their" processing facilities.

Critical to the success of the new biobased agricultural economy are guaranteed supplies of quality raw biomass products. Traditional methods of inducing farmers to produce for specific end-uses, i.e. contracting for acres, bidding up the market to get premium quality, etc., are not nearly as effective as partnering with stakeholders who also are producers of the most important manufacturing resource: the raw product.

In observing some biobased business startups, I have seen all kinds of approaches to the "farmer." In most cases there is an adversarial relationship. In the case of Isobord Enterprises, Inc., a company manufacturing particleboard from wheat straw, located in Elie, Manitoba, local farmers signed five-year contracts to allow their wheat straw to be harvested for the new production plant. The gross return to the farmer is approximately $5 per acre. The plant next door holds no financial incentive for the farmer who has nothing invested; the concept of local employment and improved stability for the rural community of Elie is of only limited relevance to the participating farmer. With expiry of the initial contracts in five years, there is a possibility that, lacking sufficient motivation, the local farmers will no longer participate. The Canadian government invested $140 million in a plant that is guaranteed a supply of straw for only five years. Isobord will go out of business if it cannot obtain straw sufficiently close to the plant to compete with the wood-based particleboard industry. The flaw in the current system is evident: the farmers are not committed. The short-term goal of the business, "to make the most money possible," caused the creation of winners and losers instead of partners who, together, could produce a viable agricultural biobased alternative within the highly competitive wood-based market.

To the question of whether farmers will be serfs or partners in the new biobased economy, the answer is, "It depends on the farmers." Those with vision want to progress and retain ownership of their commodities longer.

Partnerships are better long-term options, both for farmers and for agribusiness, than contract production. "Win-win" relationships are possible if agribusiness adopts the long-term view of profitability in new biobased production and marketing systems. Biobased raw materials (crops) will likely need to be grown close to the plants processing them, giving rural communities an important role in these new relationships.

Questions that need to be addressed relating to these developing industries, are as follows:

- Who really benefits from an increasing reliance on biobased economies?
- Will the farmer play a key role in providing the various commodities for the new systems of bioprocessing, or…
- Will contract-driven agriculture replace the current system of free market, open supply/demand, independent family-farm agriculture?

- Will the conglomerates own the land and control the production?
- Will we ensure that the producer is compensated fairly for his effort, or will farmers sell out for a nickel premium on everything for eternity?
- Will the American farmer become the second choice for feeding the world because he is no longer cost-competitive?
- Would today's naysayers of biotechnology change opinion if they went hungry?
- Will public-policy decisions regarding biotechnology be driven by the developed world, which is fat and happy, or by the empty stomachs of the developing world?
- Will the 60 percent of gross income provided by government (1998–99) to traditional farmers (a $22 billion direct payment to prop up farm income in the US) continue in a period of economic downturn?
- Will the "non-farm" public be willing to subsidize farmers in the future? Does the public still believe farmers are "being paid not to produce" as the supply management policies of the 1980s seemed to suggest?

I have more questions than answers, but one thing is not in doubt: many variables will influence the future acceptance of biobased agriculture.

Financing the Development of Biobased Products

ROGER WYSE
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San Francisco, CA

It is indeed a privilege to be invited back to an organization of which I was proud to be a part when I was in academic administration. Now that I have been out of academia in the private sector for a few years, I believe I can offer you a slightly different perspective on the agricultural biotechnology industry — a perspective that may help you attract new sources of financing. My presentation will play off some of the earlier talks, in the context of how we turn great science into great business. My major theme is that we must position this initiative to be a successful business, for it to be considered a success. As a context for my presentation, I will discuss some of the restructuring that has occurred in the traditional agricultural research and development complex, and some new funding paradigms that have developed to support new industry. I will also emphasize the importance of partnerships and alliances as technology moves from universities through these new paradigms to be commercialized by the larger companies. This perspective, I believe, is germane not only to developing a biobased industry, but also to how our academic institutions commercialize technology.

IT'S ALL IN THE TIMING

As Ralph Nader said, we have been here before. Indeed, we have been here many times before and, in most cases, colossal failures resulted. Renewed interest in biobased materials has resulted from recent high prices of crude oil. Oil at $30 a barrel, rather than $10 to $15 a barrel, is a major economic factor.

Timing is everything in business, and the time seems to be right for the transition to more biobased products. During the past year, President Clinton issued an Executive Order and we have seen increased funding from the United States Department of Agriculture (USDA) and the US Department of Energy

(DOE) for research in bioproducts and biomass. In addition, the National Research Council of the National Academy of Sciences issued a comprehensive report laying out scientific opportunities that underpin the development of this industry. The importance of the NABC 2000 *Vision Statement* should not be overlooked, because it lays out a vision that has stimulated debate. However, I believe among the most important developments over the past year were the actions of some of the large chemical companies. For example, DuPont's CEO Chad Holiday stated, "By 2010, 25 percent of DuPont's revenues will come from the biomaterials bioprocessing sector." This declaration was followed by a major new biobased initiative in the development of precursors for a new line of polymers. Likewise, Cargill-Dow created a joint venture, also to develop biobased precursors for the polymer industry. These were seminal events because, if the biobased industry is to be successful, it will require major initiatives by the large chemical companies to develop markets for the new materials. A biobased initiative cannot be driven only by universities or public policy.

It is essential to understand also that environmental issues and public concern over them are important, but not sufficient to drive this development. We can talk about protecting the environment, but unless it helps corporations improve their bottom line, the economic incentive to improve protection of the environment will be absent. The Kyoto Agreement may be the first step in putting an economic incentive in place for protecting the environment. For example, in Canada, they are considering rebuilding an industry that will foster compliance with the Kyoto Agreement. Such agreements are powerful economic incentives.

I do not think we can over-emphasize the importance of market development when timing a new initiative. For example, there is always pressure for lower cost, and faster, better and cheaper ways to develop products; but unless there is a confluence of forces — public policy, economic incentives, and customer demand — new technologies will languish and new companies will fail. Some of the most important initiatives over the past year were the movement of the major chemical companies into this space, and international trade agreements.

Shifting Paradigms and the Technological Opportunity

The development of biobased materials will require a number of new and enabling technologies, some of them coming out of the biotech industry. Fortunately, many of these new technologies have been paid for by the pharmaceutical industry, were tested and tried in agricultural biotechnology, and are now at a point where we can begin to efficiently use them in a new biobased industrial chemicals arena. But, biotechnology is only one aspect. Future success will require the integration of programs across the physical and biological sciences, and the development of effective technology-transfer out of our universities into innovative start-up companies.

To demonstrate the importance of early-stage technology transfer and the formation of new companies, it is important to understand the paradigm shift that has occurred in agricultural research and development over the past five years. This paradigm has been adopted from the pharmaceutical industry, which went through that change some ten to fifteen years ago.

The paradigm shift is exemplified by the emergence of life sciences companies, built on the premise that core genomics technologies will be used to develop new products in both the pharmaceutical and agricultural industries. The adoption of this strategy has driven some $18 billion worth of mergers and acquisitions in agriculture over the past four years. Companies like DuPont and Monsanto “partnered-in” the technologies that they needed, and then began to partner up and down the value chain to not only integrate new technology and build value in the product, but also to position themselves to capture some of the value created. These companies (which were largely chemical) recognized that if they were to move in this arena they did not have the internal skill-set to do it in the traditional manner, but saw they could — in a cost-effective way — partner it in with small, innovative companies.

That is exactly what the pharmaceutical industry has done in the past. Companies like Merck now access over 60 percent of the products in their pipeline through alliances and partnering activities.

And just when we were beginning to see agricultural research and development pursue that same model, the life sciences model was called into question. During 1999, several large pharmaceutical companies, which had previously supported the life science strategy, began to re-evaluate their commitment. While technology synergies occurred early as the new products began to move through the development and marketing pipelines, the differences between agriculture and pharmaceuticals became significant. In late 1999 and continuing through 2000, we saw some life sciences companies disaggregate into pure-play agricultural units. Despite this disaggregation, the paradigm shift remained intact: large corporations will increasingly depend on small companies as a source of new products and enabling technologies. Strategic alliances are a critical part of the new paradigm, and those alliances must include relationships to access technology, to source and market new products and, in the future, will include farmers, producers, technology suppliers, and companies that can carry the new products to the consumer.

As we re-think agricultural research and development, or research and development in support of a biobased industry, it is important to understand the new structure, under which we will rely on small companies that are spinoffs of university research to take the technology, move it through proof-of-concept, and begin to put it into practice. These innovative start-up companies will go through a series of transitions to optimize their positions for initial public offerings (IPOs) or to be acquired by a large multinational corporation. But, in all cases, developing partnerships both among themselves, and with the multinationals, is critical to their success.

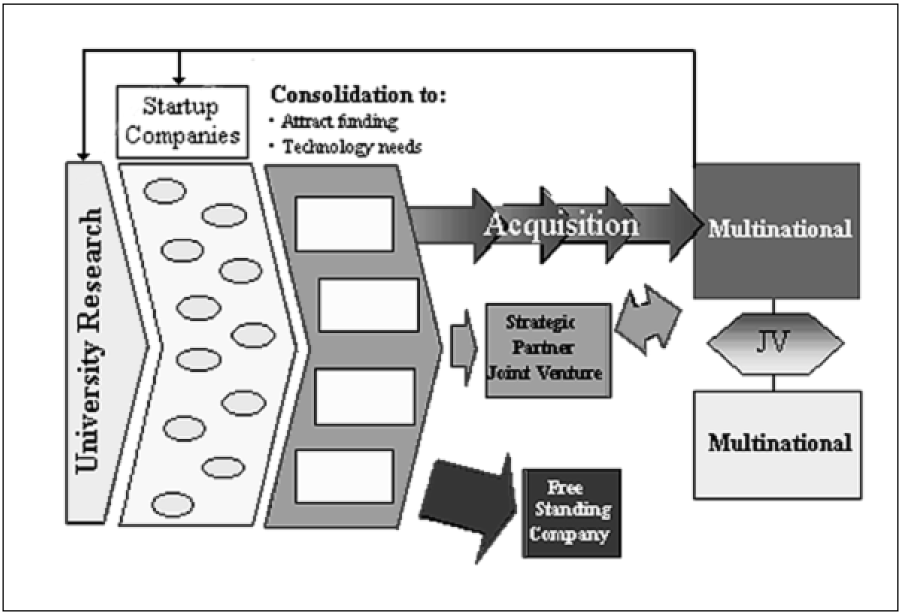

Figure 1. Evolving Biobased Industrial R&D

FINANCING: THE FUEL OF CHANGE

Also of vital importance is the ability of these start-ups to attract private equity financing, and there lies one of the important attributes of the new paradigm: accessing a new source of capital to fund agricultural research and development — the private equity market.

To give you a sense of the size and availability of this new money, over $11 billion of private equity was raised during the first quarter of 2000. Obviously, this was driven by a very positive capital market and interest in biotech companies positioned within the life sciences. Only in the last few years has agriculture begun to take advantage of this financial opportunity, and if the new biobased research effort is to be successful, it also must attract this new source of financing, and thus an important part of that strategy must be the formation of new companies.

Although we exist in a new paradigm, some things remain the same. The foundation of any successful activity is a need for robust fundamental research programs. The industry cannot move forward unless we have major public funding at our universities and federal laboratories for the development of new knowledge and enabling technologies The new challenge is not to leave the results of that research in the laboratory, but rather to move that technology

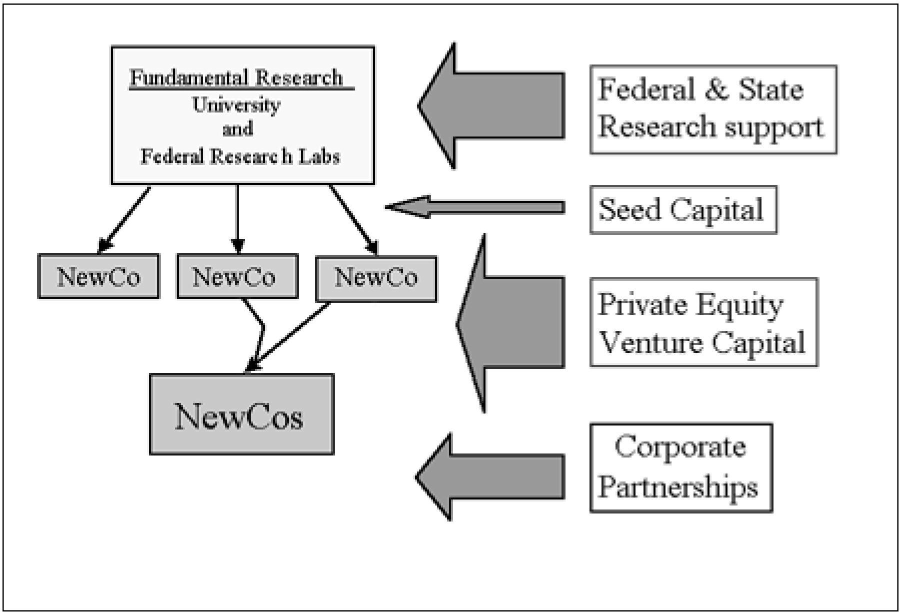

Figure 2. The Biobased Industrial R&D Pipeline: Funding and Financing

into the commercial world as quickly as possible. That transition requires sophisticated technology-transfer offices at our universities and access to seed capital, that early-stage financing so important to the formation of new companies. Indeed, the greatest challenges I see are the availability of such seed capital and the tradition of land-grant universities to provide free public access to new information rather than to form new companies.

Once a company is formed and has attracted its early round of seed financing, the next critical step is to access venture capital. In the past, agriculture has been an area in which venture capitalists did not expect a sufficient return on investment. Only in the last three years have venture capitalists become aware of the opportunities in the "new agriculture." If we are to attract venture capital, it requires a business plan that demonstrates how the new technology will be moved into the marketplace, i.e., it must not only be a concept, but also an economically viable business. This reinforces my earlier point about timing and readiness of the market: you can have a great technology and potentially a great little start-up company, but if time-to-market is delayed, the interest of those with venture capital will be lost.

The Mating Dance: the Importance of Partnering

The next stage in financing for a new company is to establish partnerships with large corporations. This is critical to the development of a small company and is equally important to the large corporation. For the small company, it provides access to technology and capital. For the large company, it provides access to innovation and new products.

Such strategic partnerships are an important part of the new paradigm, but so also will be public/private partnerships. It is increasingly important that we encourage public universities to develop relationships with the private sector, large and small companies alike. This is an additional source of revenue for universities and an important source of innovation for the private sector, but we immediately run into the issue of conflict of interest. This age-old problem has been a significant barrier to productive relationships. I believe that *now* is the time to design business models that are consistent with the need for the unfettered pursuit of new knowledge at universities, and for the need of the American economy to expeditiously move that innovation into the private sector.

Some universities — Harvard, MIT, Stanford, Berkeley, UCSF — have developed comfortable ways of managing these relationships, and are still considered to be among the top research institutions in the United States. It is time for productive dialogue between universities and corporate America to understand the importance of these partnerships and how to make them work. This will be critically important, particularly for technologies that support a biobased industry. The large corporations must move into this new arena and must be supported by innovation. This will initially come from universities and later from start-up companies, but the relationship between the university and small and large companies will be a critical and vital part of the success of this initiative. Achieving these partnerships will be a significant hurdle for land-grant universities where the culture of transferring technology into new companies has been lacking.

Many communities look to biotechnology and the start-up of new companies as an important component of economic development. If those communities are to be prosperous, they must offer an attractive package: a complete, supportive, entrepreneurial environment for new companies that includes seed capital and a source of experienced mentors and CEOs who will provide leadership. The new company must be based on good science, but success will come only with good management. Good science is not sufficient. Seed capital and management teams are in short supply in agriculture and biobased companies. We must address these issues for this initiative to succeed. In addition to the management team, a supportive infrastructure — attorneys, accountants, and others — is needed for the small company to grow.

And, perhaps most important is a conducive environment in which it is understood that starting a new company is precarious and requires entrepreneurs willing to take risks. In the event of failure, a support structure is needed to encourage perseverance. Success will be more probable at the second attempt.

Several new companies have been formed in the area of biomaterials and bioprocessing. Most are in the relatively early stages — less than four to five years old. A few examples are noteworthy:

ProdiGene	At Texas A&M; engineering corn to produce enzymes and therapeutic proteins.
Diversa	Went public last year; identifies enzymes from organisms growing in extreme environments and, through a process of gene shuffling, engineers those enzymes to have important commercial characteristics.
Maxigen	In San Francisco; similar technology to Diversa's, i.e. "molecular breeding" to engineer enzymes and biological pathways to produce unique compounds.
Nexia	A Canadian company that has genetically engineered goats to produce spider silk in their milk.

These are only a few of the examples where powerful new biotechnologies are being applied to this new sector.

Once a new company has been formed with a management team in place, and has received its first or second round of financing, continued growth and development are dependent on the formation of partnerships to either access additional technology or to gain access to the marketplace. This model, developed largely in the area of pharmaceuticals, over the last several years has been adopted also in agriculture. Consequently, large companies (Monsanto, Bayer, DuPont, Novartis, etc.) have entered into numerous relationships with small companies. Gradually we will see these partnerships develop in the area of livestock genomics and nutraceuticals, and will be key in the biomaterials/ bioprocesses arena.

The structure of the partnership is critical to both parties. The larger partner needs to access technology and products in a cost-effective manner, while sustaining the growth and development of the smaller partner primarily because the latter provides the future product pipeline. Significant creativity has been exhibited in a number of partnering deals, all of which have a similar structure, i.e., up-front technology access, milestone payments as the technology or product is developed, and downstream royalty payments as the product moves into the marketplace. However, for any such deal, creativity is necessary to assure a sustainable partnership, strong communication for interaction between the research and development efforts of the two units, and to fairly share in the value created so that both companies are successful.

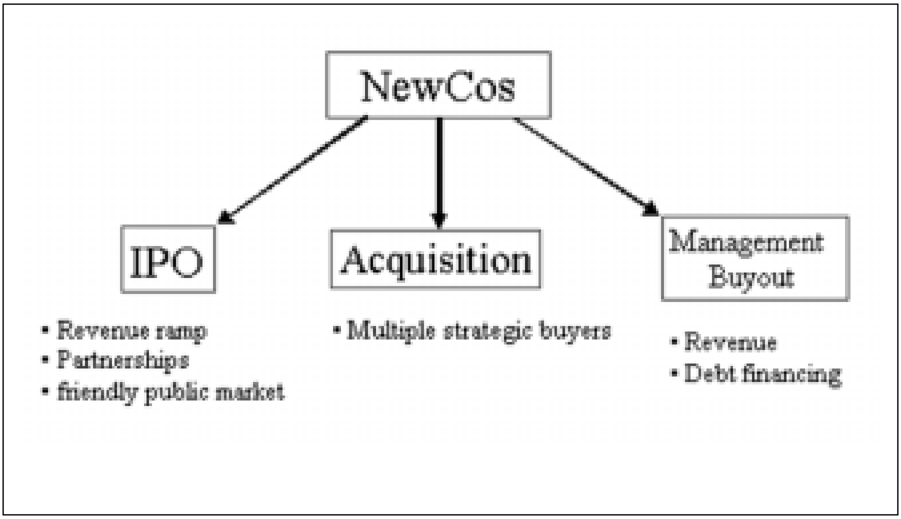

Figure 3. The Biobased Industrial R&D Pipeline: Exit Strategies

Satisfying Investors: Ensuring Return on Investment

Once the small company has developed a number of partnerships, with products moving into the market place, and has a sustained revenue growth, the investors begin to consider how to obtain a return on their investment. These so-called "exit strategies" fall into three categories: the IPO in the public equity markets (normally the NASDAQ,); acquisition by a larger company; financing through debt and a management buyout. Prior to 1999 there had been few, if any, successful public offerings of agriculturally related companies. However, late in 1999 and certainly early in 2000, the IPO window opened and a number of companies successfully went public, giving the venture investors handsome returns on their investments. As the public investor continues to have interest in genomics, there will be tremendous incentive to start new companies. The current investor interest in biotechnology and genomics companies bodes well for the future development of small companies in the area of biomaterials and bioprocessing. However, to date, the market has not yet been tested because no small company from this emerging sector has gone public.

The acquisition of a small company by a large one is an attractive exit strategy. The small company positions itself as a "must-have," and the larger company uses the acquisition as a way to move into a new sector without fully developing the internal capabilities to discover and develop new technology and products.

Finally, the option of a management buyout certainly exists, but requires that the small company have sustained revenue growth to service the debt financing. The small company simply goes to the banks to finance the ongoing development of the company. Few examples of this exit strategy exist in the agricultural biotechnology area.

PITFALLS OF THE NEW PARADIGM

This new paradigm of financing research and development in the agriculture, food, and biomaterials sectors has its vulnerabilities. For example, the public equity market can be fickle. We saw tremendous growth in the value of companies until approximately March 2000, and then there was a tremendous decline as the companies were perceived to be over-valued when President Clinton and Prime Minister Blair made their public statements concerning the patenting of genes.

Of additional concern is the growing public questioning of genetically modified organisms. As these issues remain, so decline the availability of private equity venture capital and the IPO as mechanisms to obtain returns on investment. Even as we access a new treasure trove of financing for agricultural research and development, it becomes a much more fickle source.

Furthermore, we must be aware that we are moving into a new biobased market — one that is largely undeveloped. The first companies to move into this space will not be small; DuPont, Dow, and Cargill have recently made major investments in biomaterials. These major corporations thus provide the wealth of resources to develop markets. This then provides the opportunity for small companies to flourish as they provide the innovation that the large multinationals need to sustain their growth in this market space. Initially these investments by the major corporations must be economically viable and, therefore, the concept of enterprise accounting is an important component of public policy. Enterprise accounting must take into account all of the benefits to moving to a biobased market, for example giving credits for lowering CO_2 emissions and reducing other adverse effects on the environment, or these early products will not be economically viable. This is a serious constraint to the development of biobased products.

It is a major constraint because time-to-market is important for capturing this new paradigm of funding. The market must be ready to pull products into it in a timely fashion or small companies will fail because venture financing will move to more attractive investments — quicker returns on their investment — if they see delays in the conversion of technology into successful businesses.

The development of the market and the maintenance of financing also require a consistent regulatory environment. Again, investment will not be forthcoming if public policy is insufficiently stable for that investment to be turned into a successful business. A useful analogy is the cost of crude oil; when priced in excess of $30 a barrel, there is greater interest in alternative fuel sources. However, when the price drops below $15, interest in alternative fuels declines and many companies go out of business.

The challenge before us is to look at a broad initiative that develops the markets, provides an environment that will attract risk capital, and encourages state universities and federal laboratories to seek creative ways of moving new technologies out of the laboratory into an environment where small start-up companies can be developed and will flourish. This will require additional public financing for fundamental research, and public policies that are consistent with the long-term sustained growth of a biobased materials market. With such incentives, investors will be interested and this new area of biomaterials will capture the necessary funding to be successful.

Let me use Burrill & Company as an example. We are a private merchant bank, focusing entirely in the life sciences. We do three basic things: provide venture capital to small life sciences companies; help small companies partner with large ones (again an important part of the new paradigm in life science research and development); and help large companies spin technologies off that no longer fit their core of business. We are very active in partnering activities. We hold two meetings, at which small companies make presentations to large ones in a two-day format: a “mating dance.” We facilitate the interaction that is necessary for both parties to be successful.

Also, we organize CEO conferences, one in human healthcare and one in agricultural biotechnology. Actually, BIO, the Biotechnology Industry Organization, was spun off from one of these CEO meetings in the early 1980s when the subject for discussion was what needed to be done to make this industry successful. Agricultural biotechnology needed an organization. These meetings are useful for partnering, as well as building a community around the small companies in this area of endeavor.

In our venture-capital activity, we have a series of venture funds: the AgBio Fund is for plant biotechnology and the Biotech Fund is for human healthcare. We have one in nutraceuticals, also a purely financial fund, and we will be raising a biomaterials/bioprocesses fund later this year. We currently have about $250 million dollars under management to invest in the areas we have been talking about. The numbers in the USDA and DOE budgets are paltry compared to what it is going to take to build this industry. Think about new ways of capturing money not only from companies like ours, but other sources of financing, and make that part of your overall strategy.

Thank you very much. I hope that what I have said will encourage you to think more broadly. In addition to going to Congress and initiative funding, think about building the community, not limited to academics, but with policy-makers, small companies and large companies to make this exciting new field a success.

PART V

PLENARY SESSION II

ISSUES SURROUNDING THE BIOBASED INDUSTRY

Ethics, Climate, and Risks

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Washington, DC

I guess one of the first risks being taken in this session is in inviting me to moderate it, and to prove this I will do a quick test of the nerd-level of the audience with a story: Werner Heisenberg was pulled over by a traffic cop who approached him and said, “Do you have any idea how fast you were going?” To which Heisenberg replied, “No. But I know exactly where I am.”

Of course, the question is, “Where are we?” The issue that fascinates me about this session is the examination of public obligations in appraising the risks involved in moving to the radically new paradigm in production represented by bioprocessing. The question of public obligation in situations like this is an old one. The land grant universities that you represent were founded on the idea that public investment in research yields benefits that vastly outweigh the returns possible from any private investment, which is certainly true for broad economic issues. It is specifically true for rural economic issues. And it is certainly true that investments in research at land grants pay enormous benefits in the form of trained students who are not captured by any private entity.

Now, in the twenty-first century, because of these benefits, the obligations of land grants certainly continue to justify federal and state support. But a new class of public benefit, environmental improvement, is now possible through investment in some of the advanced technologies. Public interest in research in bioprocessing, in addition to economic benefits, is motivated by the potential for very significant environmental improvements simultaneously with a growing economy.

However, the risks we are undertaking are obviously very large. You do not need a PhD from a land grant university to figure out that if you double world population and you have three times the economic activity for each human being on the planet, you have a problem that is not going to be solved by 10% fixes. We must have orders-of-magnitude improvements in the relationship between economic activity and environmental impact. The bioprocessing technologies that have been described at this conference clearly provide that opportunity.

In the federal government, we have tried to put together a portfolio of research that meets public obligations broadly in this area. Obviously, the first necessity is to make the processes more efficient. Bioproducts provide that opportunity at the industrial level. Not only are crop plants extremely efficient at producing a variety of chemicals, but they are particularly advantageous from the perspectives of the greenhouse effect and global climate change.

We have put together a budget proposal that we think is robust. We are requesting an additional $44 million for the USDA and $49 million for DOE, and an interagency research partnership has been forged that other speakers have described. Although, there is no guarantee that this money is actually going to appear, there is strong bipartisan support. Given the tough budget year we are in, progress will be impossible without a lot of people working together.

Senator Lugar's bill, authorizing an integrated program, was passed by the Senate. We supported that, but were unhappy to see that the specific authorization for DOE was removed. There are parallel companion bills in the House Science Committee and the House Agricultural Committee, and we hope that a bill will pass both houses and be brought to the president within a month. Again, this has strong bipartisan support, and we would welcome your participation in the deliberations.

A critical component was the issuance of an executive order that fosters integrated research. One of the key elements of that integrated research, contained in the executive order, is the consideration of potentially negative impacts resulting from much greater investment in bioproducts. There is concern about ecology, wildlife, the soil, and genetically modified organisms. We feel that these issues should not be considered as an afterthought, but should be integral to the investment we are making; the research partnerships must include people who share these concerns.

I suggest there are four unique, previously unseen, issues to face. First is the speed of development; the rate of research progress is unprecedented. We are seeing exponential growth in the development of concepts, which, although good, imposes special obligations that society has only years, not decades, to think through. Second, the speed of dispersal: ideas move around the planet, for good or for evil, with extraordinary speed. Third, the scope and subtlety of the impacts are an order of magnitude more complex than, for example, "Do you like nuclear power?"

And, finally, an issue that Bill Joy brought up and which has been attracting a lot of attention lately: the democratization of the development of technologies that have potentially worldwide impact. It is one thing to have someone create a computer virus that spreads worldwide over a 24-hour period. It is another thing to have someone develop a real virus that could do the same thing; if you lower the cost of creating a harmful impact you greatly change the scope of the problem.

In any event, clearly we have an obligation to make public investment in biotechnology and bioprocessing in order to achieve economic advancements and to develop "no-regrets" responses to problems like climate change. Without technology, we simply cannot imagine supporting 6 to 10 billion people in anything like a prosperous world with only a moderate impact on the environment.

Technology is essential. However, in devising ways of minimizing climate change, for example, we must not incur other risks. The land grant colleges are uniquely well suited to take up this challenge, not only with their history of investment in issues of public interest but also because they embody the technical expertise and the ability to anticipate the impact of new technologies.

Bioethics Issues in a Biobased Economy

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There is now a 25-year history of debate over ethical issues associated with recombinant DNA, beginning with the 1975 Asilomar conference to consider the risks and advisability of basic gene-transfer research. Early in that history, issues associated with medicine or the manipulation of human DNA quickly came to be treated as wholly distinct from those associated with every other application of biotechnology. Today, virtually all non-human, non-medical applications of biotechnology are classed as agricultural biotechnology. The only significant exception to this generalization is genetic engineering and cloning for xenotransplantation, which overlaps both medical and agricultural categories.

Controversy over specifically *agricultural* biotechnology really began in about 1984, when Jeremy Rifkin's lawsuit forced the National Institutes of Health's Recombinant DNA Advisory Committee (the RAC) to consider the possible environmental impact of ice-nucleating bacteria proposed to protect crops such as strawberries from frost damage. Social scientists had, by that time, already begun to speculate on the possible impact of a new generation of technologies on the structure of American agriculture, the lot of developing countries, and on the organization and funding of agricultural research worldwide. The National Agricultural Biotechnology Council was founded in 1989 in part as a forum in which to air these controversies. As we gather for the twelfth annual conference to discuss a new generation of technologies not geared to food production, I cannot but sense a hope that these new technologies are so full of prospect that the ethical controversies of the past will now fall by the wayside. As I myself argued in my 1996 remarks to this group (Thompson 1996), there are reasons why that hope need not be vain. But I believe it is best to begin with a look to the past.

Most ethical issues that were tied to agricultural biotechnology over the last fifteen years fall into one of four categories: food safety, environmental impact, animal ethics, and social consequences. I will speak very briefly about each, then will focus the balance of my remarks on a fifth type of issue that spills over from the category of social consequences to encompass the entire debate over agricultural biotechnology. This fifth class concerns how bioethical issues are addressed within advanced industrial democracies, and takes up the question of public trust in science. One could say that comportment with respect to ethical issues is itself the most significant ethical issue facing the scientists, administrators and public servants charged with the development of agricultural biotechnology. However, virtually all of the issues that have been tied to agricultural biotechnology in the last 25 years could have also been raised with respect to other technologies, both within agriculture and for society at large. Debate over agricultural biotechnology is, in this sense, a surrogate for debate over technological progress itself.

Ethical Issues for Agricultural Biotechnology: A Quick Survey

If one's cue were taken from the newspapers or from industry spokespersons, the hottest issue associated with agricultural biotechnology would be food safety. The core issue of ethics associated with the safety of genetic transformation applied to foods (or so-called GMOs) concerns the comparative emphasis on science-based food safety risk assessment as opposed to a policy of informed consumer consent (Thompson 1997). Some argue that individual consumers must not be put in a position where they are unable to apply their own values in choosing whether to eat GMOs. Others argue that the matter of whether genetic transformation has been used is immaterial to the underlying values (such as safety and healthfulness) that are the basis of consumer choice. They argue that the very act of informing consumers about GMO foods would mislead consumers into making choices that are not consistent with the underlying purposes that are sought through the purchase and consumption of food. This is an ethical issue rather than a simple dispute over facts because one viewpoint stresses individual autonomy and consent, while the other stresses rational optimization. The tension between these two ways of stating the most basic norms of decision-making has been endemic to some of the most protracted ethical debates of the last 200 years. Needless to say, it is possible for reasonable people to disagree.

After food safety, the environmental impact of agricultural biotechnology has received a great deal of play in the media. Some critics of agricultural biotechnology argue that we cannot even imagine the possible environmental consequences of genetic transformation. Other critics note some of the specific environmental consequences that have in fact been imagined with respect to products such as herbicide-tolerant or Bt crops, and argue that the risks are unacceptable. Defenders note the procedures for environmental risk assessment that are in place. They argue that these present adequate safeguards for the environment, and note that agricultural biotechnology may well have environmentally beneficial effects that outweigh any risks.

These environmental debates involve far more controversy over factual issues than do debates over food safety, but they still involve ethics. Like debates over food safety, they involve disputes over the validity and wisdom of relying on offsetting cost-risk-benefit optimization to conceptualize the issues. Even among those who accept the risk-benefit approach, the issues involve value judgements about the relative importance of food production as opposed to the preservation of wildlife and genetic diversity. They involve value judgments about how to proceed in the face of uncertainty, and indeed, about the very nature of uncertainty. The issues involve value judgments even about the nature of nature, as some believe that preserving wildlife and a certain aesthetic character on farms is part of nature conservation, whereas others see agriculture as inimical to wild nature. Again, it is possible for reasonable people to disagree.

Perhaps we should class the potential for biotechnology's impact on animal welfare as a sub-heading of environmental effects. It has seemed like a different class of issue to most observers because the focus has been on domesticated rather than wild animals, and because the ethical issues themselves are quite different from those listed above. Here, what is contentious, is the possibility of using gene transfer in a way that eventuates in an increase in suffering for domesticated livestock, *or* ironically, using gene transfer to relieve suffering by creating animals that are more tolerant of conditions that animal advocates currently find intolerable. Animal welfare is an ethical issue because the moral status of animals is itself one of the most fiercely contested ethical issues of the late twentieth century. Reasonable people disagree.

Finally, there are people who have framed the debate over agricultural biotechnology in terms of its social consequences. Indeed, many of the arguments *for* the deployment of agricultural biotechnology note its capacity to feed the poor and benefit farmers while keeping the cost of food low for all. Critics, on the other hand, fear that biotechnology will only turn the crank of the technological treadmill that has caused many farm bankruptcies and depleted the population of rural communities for 100 years. Some critics fear that biotechnology will be the instrument for a similar kind of consolidation of land holdings in the developing world. Others argue that the transformation in the international system of intellectual property rights, which has accompanied the advent of agricultural biotechnology, may not be in the interests of poor farmers in the developing world. Still others have argued that agricultural biotechnology has precipitated a change in the nature of science itself, particularly at public institutions such as universities, resulting in a skewed allocation of resources and corporate control over research priorities. The social consequences of agricultural biotechnology are controversial in part because all of them — those that note biotechnology's putative benefits as well as those that call attention to its social costs — make disputable causal claims about the link between technological innovation and its eventual social impact. With all due respect to my colleagues in the social sciences, the models for social causation in economics, sociology, anthropology, geography, and political science continue to be beset with gaps and ambiguities that render them vulnerable to protracted methodological disputes and ideological influence. For this reason, disputes over social consequences take on a character that is more often political than ethical. Much of what divides disputants over the social consequences of agricultural biotechnology concerns different opinions about the capacity for various forms of social organization, notably private markets and government agencies, to reliably produce desired social outcomes.

Yet, there is still an explicitly ethical dimension to these debates. For example, when someone says that genetic engineering will benefit the poor, they are at least implicitly suggesting that not only is benefiting the poor a good thing, but that it is relatively better than benefiting someone else. There are, thus, ethically grounded notions of fairness and distributive justice lurking in debates over social consequences. Reasonable people disagree about what they and others deserve, what is fair, and how the resources of our society should be distributed. Such disagreements are inherently philosophical, and have been the very stuff of ethics and of social and political philosophy ever since Plato.

So, there are four large issues raised by, or associated with, agricultural biotechnology on which reasonable people disagree. This conference is dedicated to emerging applications of biotechnology that do not involve foods. We may reasonably conclude that issues associated with food safety and individual consent will not be associated with these new agricultural technologies. But this is only one of the four types of issue that have dogged agricultural biotechnology for over 15 years, and it is arguably the simplest and least intrinsically contentious of the four. I must, therefore, conclude that the hopes for a new day and an ethical pass with respect to the biobased economy are probably not in the cards.

Agricultural Bioethics: Public Discourse and Public Trust

So, finally, we come to that fifth comprehensive issue, which we might call the "trust" issue. Does biotechnology — understood not merely as the laboratory techniques or the products themselves but as the consortium of industry and academic researchers, government regulators and research administrators that has shepherded recombinant DNA techniques from basic research through product launch — merit the public's trust? Notice that the question of whether biotechnology merits public trust differs from whether biotechnology is, in fact, trusted. When the matter of trust is framed as a question of merit, of trustworthiness, it becomes an ethical issue in itself.

Even in an explicitly ethical mode, the question of trust inevitably connects with the broader public's attitudes and perceptions of biotechnology. My suggestion today is that the way that researchers, regulators and administrators comport themselves with respect to the ethical issues I have already reviewed, albeit briefly, is the largest single factor in determining whether they are trustworthy. I will make some speculative remarks about public skepticism regarding agricultural biotechnology, but I must stress that I will not try to explain why agricultural biotechnology is mistrusted in fact. Nor do I believe that the relationship between being trustworthy and being trusted in fact is a simple or straightforward one.

First, a simple observation: none of the ethical issues listed above — issues on which reasonable people disagree — depends on active political opposition to biotechnology for their definition or significance. Each would be an ethical issue even if virtually no one was sufficiently concerned about agricultural biotechnology to carry placards, write angry letters or construct web pages that espouse a given analysis of each issue, while recruiting fellow travelers. An issue does not become "ethical" simply by virtue of its popularity, but because deep and systematic differences in values and interpretations open up the possibility for incompatible prescriptions for action. Throughout human history, it has often been the case that a small minority, sometimes a single individual, seizes on a vital difference and opposes a strong majority point of view. These minority viewpoints need not, and historically often have not, represented anything even remotely like widespread public doubt or opposition to the mainstream point of view. So we should not equate a response to ethical issues and a response to public concerns.

In some cases, the proper response to public concerns is a public relations campaign designed to sway citizens in the mainstream to a point of view more consistent with one's own interests. Such a campaign may eschew serious discussion of issues, choosing instead to associate a product or person with favorable images, or to associate opponents with unfavorable images. In such cases, the issue that has given rise to public concern is handled strategically. I shall use the term "strategic discourse" for any form of communication that tries to bolster public support for an objective (or mute public opposition) in an effective and efficient manner. Characteristically, a form of communication is strategic whenever the alteration or manipulation of audience attitudes and behavior is the dominant criterion for success.

I hope it is evident to everyone that strategic discourse is never an appropriate response to an ethical issue. In having too little concern with mutual understanding, strategic discourse disrespects those with differing values and differing points of view. Discourse ethics is a program in philosophy that prescribes a general approach for ethical issues (Habermas 1990). We might summarize it in common-sense terms by saying that ethical issues must not be treated simply as obstacles to be overcome in the pursuit of other goals.

They must instead be addressed seriously and in their own terms. When one is presented with an ethical objection to an opinion or course of action, one has a responsibility to ensure that one has first understood the force of that objection. Second, one must either alter the opinion or course of action to accommodate the objection, or offer a response that explains why the objection has been rejected. This means that those who offer an ethical objection are owed a reply. The reply should restate the objection in terms that the person who offered the objection can accept. If the terms are not accepted, one must conclude that one has not understood the objection, and try again.

If your reply to an objection involves a rejection of it, you owe the person who offered the objection an opportunity to reply to your reply, which, of course may occasion further objections and replies. Obviously, this is a process that can go on at some length, so we must regard this characterization of discourse ethics as an idealization, and we must recognize that time and resource constraints limit the extent to which ideal discourse can be realized in practice. There is the further problem that the back and forth process of objection and reply can itself be deployed not in pursuit of seriousness and mutual respect, but as a delaying tactic. Anyone who has ever attended a public meeting on biotechnology within fifty miles of the Washington beltway knows exactly what I am talking about. Despite these shortcomings, I believe that it is still possible to conduct practical ethical discourse. While falling short of the unrealizable ideal case in which all objections are fully answered, practical discourse does treat ethical issues with the seriousness that they demand.

I believe that serious practical discourse is possible because I believe that I do it all the time myself. It is the standard to which I have aspired in all my research and writing on agricultural biotechnology. I have seen it at the "bioethics workshops" sponsored by Iowa State University, and even on occasion at the annual meetings of the NABC. As further evidence, I would submit that that the Ethical, Legal and Social Implications (ELSI) program of the Human Genome Initiative has supported a great deal of serious practical discourse on the goals and implications of human genetics. I believe that there should be a similar program in agricultural biotechnology, but here I get ahead of my main message.

Strategic and practical discourse are analogous to some criteria we rely upon when we determine whether an individual person is trustworthy. Trustworthy people display thoughtfulness of purpose and a clear capacity to be mindful of the interests of those by whom they are trusted. We do not trust people who seem to be making reference to their own immediate goals and self-interest at every moment. Similarly, I think that we can say that groups or associations of people who always seem to be engaged in strategic discourse, and never in serious practical discourse are manifestly not trustworthy. This is not necessarily a judgment that reflects on the moral character of the individuals involved. People who are fine, upstanding and virtuous citizens in their own right may well be involved in groups or associations that are untrustworthy in virtue of the fact that serious discourse about ethical issues occurs infrequently in these groups and associations. We should not expect groups and associations to avoid strategic discourse on every occasion. That would be like asking someone to be a saint, always putting others' interests before her own. But just as we mistrust the person who seems unable to even contemplate a situation with respect to others' interests, we mistrust the group or association that displays no evident interest in, or experience with, serious practical discourse.

We can bring this observation to the point at hand by considering the three key technologies of the post-war era as described by Martin Bauer: nuclear power, information technology, and biotechnology. According to Bauer (1995), these three are particularly relevant to the problem of public acceptance and trust, because each has been presented to the public as a technology that would revolutionize the way we live. While the scientists, engineers, regulators and power-company officials who developed and promoted nuclear energy displayed seriousness with respect to the safety of their technology, they have never been particularly willing to engage in practical discourse about the social, legal and ethical issues posed by nuclear power generation. In contrast, computer professionals have carried on robust debates about a host of ethical issues from privacy rights to intellectual property and the impact of a wired society on interpersonal relations. Early on, they formed the Computer Professionals for Social Responsibility to promote debate over the risks of inadvertent nuclear war due to computer failure, and this group went on to promote both discussion and activism about access to computers for the poor. Even as the public seemed willing to embrace information technology uncritically, the critical voices emerged from within the culture of the computer industry, and demanded that ethical issues be taken seriously.

How then does biotechnology fare in the comparison? My answer is, better than nuclear power, but worse than IT. On the plus side, molecular biologists got off to an admirable start with Asilomar, and the previously mentioned ELSI program has ensured that medical bio-ethicists are deeply involved in discussions of the future human applications of gene technology. On the agriculture side, there are a few programs here and there, including my own Center for Biotechnology Policy and Ethics, which operated at Texas A&M University from 1991 to 1998. The Executive Council of the National Agricultural Biotechnology Council adopted a comprehensive endorsement of the need for universities to create a climate hospitable to debate and learning about the ethical dimensions of biotechnology in 1997. The National Agricultural Biotechnology Council annual conferences, which began in 1989, are themselves the most visible and substantive vehicle for non-strategic discourse on ethical issues in North America.

On the minus side, I must say that these activities have gone along in fits and starts. Scientists and administrators have been far more interested in talking about ethical issues when agricultural biotechnology was getting negative publicity in the press than when things were going smoothly. Furthermore, many substantive criticisms of biotechnology have not been treated as concerns deserving respect and reply, much less a change in direction. When environmental or social issues are raised, defenders of biotechnology too often shift the subject to food safety or attack the sincerity and motives of their critics. This tendency to change the subject reveals a preoccupation with strategic thinking, and undermines an observer's confidence that serious issues are being treated seriously. I cannot help but draw the same conclusion that a casual observer of the debate would draw. Commitment to serious practical discourse and a critical consciousness among the individuals and organizations who have been involved in the application of molecular biology to agriculture and in the development of new agricultural biotechnologies has not been particularly deep.

Conclusion

Among those who have thought and written about the ethical issues that arise in connection with agricultural biotechnology, I have never been one who thought the use of recombinant techniques posed unique risks or exceptional ethical issues. I do think that the organization and culture of agricultural R&D is insufficiently attentive to a wide range of social, environmental, legal and ethical issues that ride along with any significant technological innovation. I thus think that biotechnology provides an important case study and object lesson for some of the questions that we should be debating with respect to the ecological meaning of agriculture, and the impact of technical change on our social institutions, not to mention the poor. In one sense, I regret that I have not taken this opportunity to address some of those questions directly, but there is only so much that can be done at any given time or place.

It will not suffice to leave these issues to the final stage regulators or adopters of technology. Scientists, educators and administrators must institutionalize continuous critical reflection on their activities, and they must find some way to make that reflection effective in shaping the agenda for research and the deployment of technology. I am not of the opinion that the present status quo is wholly inadequate with respect to its capacity for ethical reflection and serious practical discourse. Indeed, remarkable strides have been made during the last 25 years. Nevertheless, we may not be sanguine about the status quo, either.

There is the distinct prospect that the specific technologies being discussed at this conference will be described and promoted in a manner that will only perpetuate the tendency to avoid seriousness with respect to ethical issues, and will provide even greater opportunity to deploy the strategy of changing the subject. How often I have heard the phrase, "All we need is a product with consumer benefits!" For the life of me, I cannot find a way to interpret such language as anything other than a thoroughly strategic preoccupation with the manipulation of biotechnology's public image. I can appreciate that not everyone involved with biotechnology needs to be engaged in serious discussion of the issues I have raised in my talk. There is room for people who are concerned with its public image, and who are preoccupied with selling a product. I just hope there is room for something else, too.

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Climate Change and Agriculture

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Burning of fossils fuels and eradication of forests have raised the atmospheric concentration of carbon dioxide (CO_2) by some 30 percent since the industrial revolution, and that rise continues at a rate of approximately 0.4 percent per year. Despite its seemingly minute concentration (only 0.035 percent), CO_2 inhibits the escape of longwave (thermal) radiation emitted by the earth throughout the entire atmosphere, a process known as the “greenhouse effect.” The presence of CO_2 and the more abundant water vapor naturally helps to warm our planet from a frigid -18^{o}C to a much more hospitable 15^{o}C. Human-driven increases in CO_2 concentration now appear to be enhancing the natural greenhouse effect, and many scientists believe that these are leading, or will lead, to surface warming and associated feedback effects on the climate system (Houghton et al. 1996).

Other so-called greenhouse gases that are present in even smaller concentrations, but which similarly tend to trap heat, include methane (CH_4), nitrous oxide (N_2O), the chlorofluorocarbons (CFCs), and tropospheric ozone (O_3). The effects of all these gases may be expressed as changes in the planet’s radiation balance in W/m^2/yr. Other changing atmospheric factors that affect climate include ozone, solar irradiance, tropospheric aerosols, and stratospheric aerosols. The increases in greenhouse gases may already be altering the earth’s climate. Global surface temperatures have risen about 0.7^{o}C over the last century, leading the Intergovernmental Panel on Climate Change (IPCC) to conclude (Houghton et al. 1996): “The balance of evidence suggests a discernible human influence on global climate.” If allowed to continue, anthropogenic greenhouse-gas emissions seem bound to result in significant climate change in the coming decades.

The climatic consequences of increasing greenhouse gases are linked to far-reaching changes in agriculture, as well as in natural ecosystems. It is clear that climate change is likely to affect the regional patterns of temperature, precipitation, and evaporation, indeed the entire array of meteorological, hydrological, ecological, and agricultural relationships. Beyond what is clear, however, lie uncertainties: how much warming will occur, at what rate, and according to what geographical and seasonal patterns? And just what will be the consequences to the agricultural productivity of different countries and regions? Will some nations benefit while others suffer, and who might the winners and losers be? Finally, there are practical questions: what can and should be done in timely fashion by individual countries and by the international community as a whole to avert potential damages to life-support systems? And, to the extent that such damages are not completely avoidable, what can be done to minimize or overcome them? Upon our ability to answer such questions may rest the fate of natural and human ecosystems in the twenty-first century.

Physiological Effects of CO_2 Enrichment

The role of CO_2 in agriculture is complex in that it can be positive in some respects and negative in others. Carbon dioxide concentration affects crop production directly by influencing the physiological processes of photosynthesis and transpiration; therefore, it has the potential to stimulate plant growth. The magnitude of that stimulation will vary among species of differing photosynthetic pathway, and will depend on growth stage and on water and nutrient status. The resulting climate effects (including warmer temperatures, changed hydrological regimes, and altered frequencies and intensities of extreme climatic events) may inhibit crop production in some regions. Agricultural pests, overall, are likely to thrive under conditions of increasing atmospheric CO_2 concentrations and rapid climate change. All these changes, in concert, could have major impacts on the prospects for food security — in some cases positive and in other cases negative.

Plant responses to higher concentrations of atmospheric CO_2 may be considered on various scales, ranging from the microscopic cellular level to the macroscopic agro-ecosystem level. The scaling up of plant responses in time and space from one level to another is complicated. Photosynthesis, respiration, and transpiration are the plant processes most directly affected by changing levels of CO_2. A host of interactive changes in crop growth flow from these primary effects, some resulting in positive feed-back and others in negative (Rosenzweig and Hillel 1998).

Effects of Climate Extremes on Crops

When the optimal temperature range for a crop in a particular region is exceeded, it tends to respond negatively, resulting in less yield. The optimal temperature varies with the crop. Temperatures greater than 36°C cause the pollen of corn (*Zea mays*) to lose viability, whereas, in potato (*Solanum tuberosum*), 20°C depresses tuber initiation and bulking (Paulsen 1994).

Most agronomic crops are sensitive to episodes of high temperature. Air temperatures between 45 and 55°C that last for at least 30 minutes directly damage leaves in most environments; even lower temperatures (35 to 40°C) may be detrimental if they persist (Fitter and Hay 1987). Vulnerability of crops to damage by high temperatures varies with developmental stage. During reproductive development they are particularly injurious — for example, to corn at tasseling, to soybean (*Glycine max*) at flowering, and to wheat (*Triticum aestivum*) at grain filling. Soybean has an unusual ability to recover from heat stress, perhaps because most cultivars are indeterminate (i.e. vegetative development continues after flowering) (Shibles et al. 1975).

Precipitation, the primary source of soil moisture, is probably the most important factor determining the productivity of crops. Although climate models predict an overall increase in mean global precipitation, their results also show the potential for changed hydrological regimes (drier or wetter) in most places. A change in climate may affect total seasonal precipitation, its within-season pattern, and its between-season variability. For crop productivity, effects on patterns of precipitation events may be even more important than effects on annual totals. The water regime of a crop is also vulnerable to rises in the daily and seasonal rates of evapotranspiration, brought on by warmer temperature, drier air, or windier conditions.

Drought conditions may also be induced by less precipitation falling as snow and by earlier snowmelt. In arid regions, such as the Sacramento River basin, these effects may reduce subsequent river discharge and irrigation-water supplies during the growing season (Gleick 1987). Episodes of high relative humidity, frost, and hail can also affect yield and quality of fruits and vegetables.

Interannual variability of precipitation is a major cause of variations in yield and quality of crops. During the 1930s, severe droughts in the United States lowered yields of wheat and corn as much as 50 percent in the Great Plains. By reducing vegetative cover, droughts exacerbate erosion by wind and water, thus affecting future crop productivity.

As with high temperature, crop yields are most likely to suffer if dry periods occur during critical developmental stages. In most grain crops, flowering, pollination, and grain filling are especially sensitive to moisture stress. Accordingly, management practices have been devised to maximize crop growth in water-scarce conditions. For example, mid-season drought may be avoided by early planting of rapidly developing cultivars; fallowing and weed control can help to conserve moisture in the soil.

Heat and drought stresses often occur simultaneously, one exacerbating the effects of the other. High solar irradiance may be accompanied by high winds. When crops are subjected to drought stress, their stomata close, reducing transpiration and, consequently, raising plant temperatures.

Excessively wet years, on the other hand, may cause yield declines due to waterlogging, lodging, and increased pest infestations. High soil moisture in humid areas can also hinder field operations. Intense bursts of rainfall may damage younger plants and promote lodging of standing crops with ripening grain, as well as soil erosion. The extent of crop damage depends on the duration of precipitation and flooding, crop developmental stage, and air and soil temperatures. The costs of drying corn are higher under wetter climate regimes.

Potential Impacts on Crop Yields

Figure 1 shows projections of changes in wheat yields in the United States, for two global climate model (GCM) change scenarios; these changes are projected to occur in the 2030s if emissions of greenhouse gases continue to increase in a "business-as-usual" trajectory (~0.5 percent/yr increase). The direct effects of higher levels on crops are taken into account (higher CO_2 increases the rate of photosynthesis and improves water-use efficiency). Results show that there is still considerable uncertainty in the climate projections as described by the

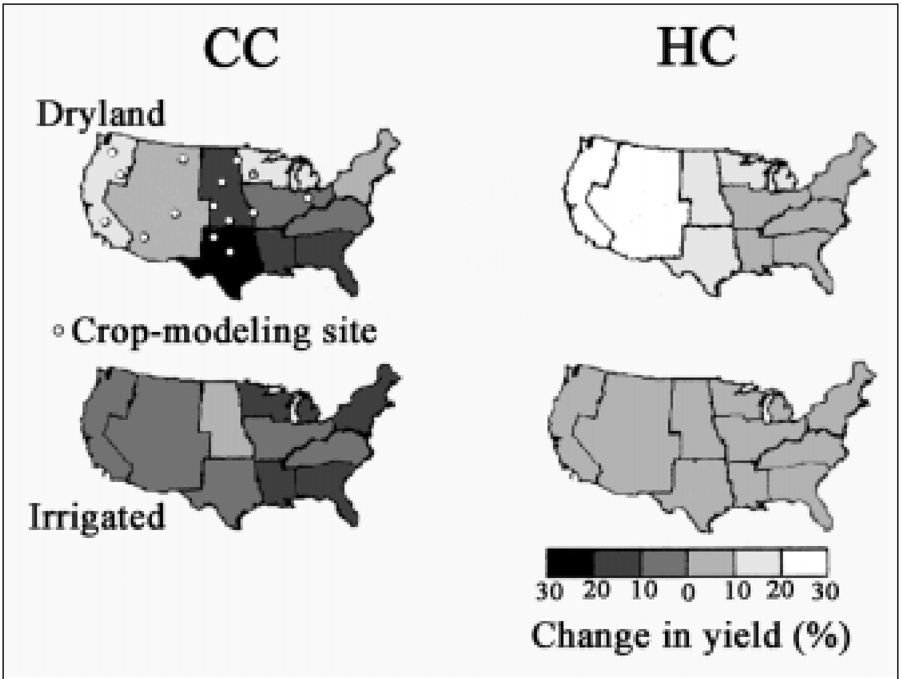

Figure 1. Projections of changes in wheat yields in the United States for the Hadley Centre (HC) and Canadian Climate Centre (CC) climate-change scenarios. Climate projections are for the 2030s and include the effects of greenhouse gases and sulfate aerosols. Crop-yield simulations take the direct physiological effects of higher CO_2 on crop yields and water use into account (Tubiello et al. 2000).

two GCMs; some regions may have improved production, whereas others will suffer yield losses. Irrigated crops may suffer greater yield losses, depending on precipitation projections. Furthermore, different crops will be affected differently. These effects are likely to bring shifts of agricultural production zones around the nation, leading to the need for on-farm adaptation, as well as changes in supporting industries and markets.

Beyond national boundaries, changes in the global patterns of supply and demand may have far-reaching consequences. Figure 2 shows projections of average national crop-yield changes around the world for the Hadley Centre climate-change scenario. At high latitudes, warmer temperature may benefit crops that are currently limited by cold and short growing seasons. In mid-latitudes, however, increased temperatures are likely to exert a negative influence on yields through shortening of crop-development stages. At low latitudes, growing periods for crops are accelerated and heat and water stresses

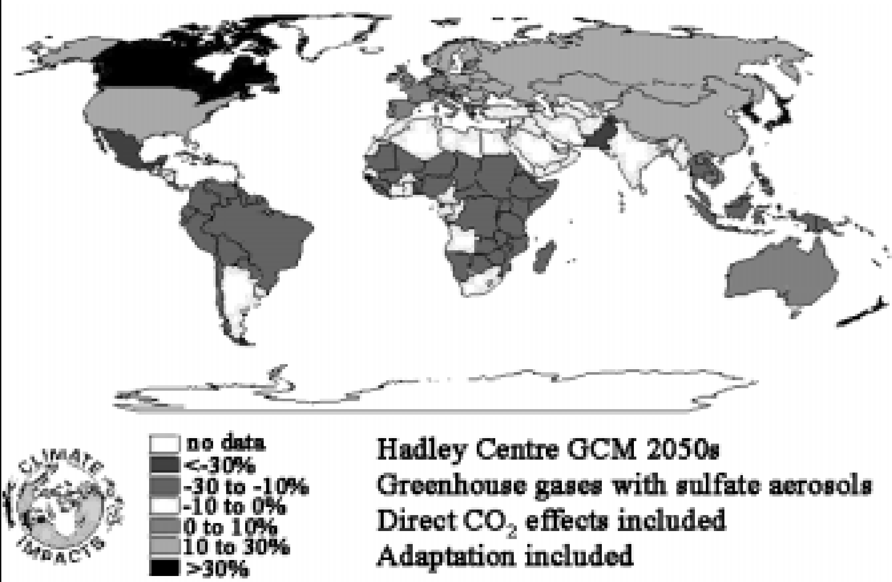

Figure 2. Projections of average national crop yield changes for the Hadley Centre HADCM2 climate change scenario. Climate projections are for the 2050s and include the effects of greenhouse gases and sulfate aerosols. Crop yield simulations take into account the physiological effects of higher CO_2 on crop yields and water use; farmer adaptation to projected climate change is also simulated (Parry et al. 1999).

are exacerbated, resulting in steeper yield decreases than at mid and high latitudes, notwithstanding the beneficial physiological effects of atmospheric CO_2 enrichment.

Changes in Extreme Events

Climate change is likely to alter event patterns as well as affect mean values. If temperature variability increases, crops growing both at low and high mean temperatures may be adversely affected since diurnal and seasonal canopy temperature fluctuations often exceed optimum ranges. If temperature variability diminishes, however, crops growing near their optimum ranges might benefit. Increases in daily temperature variability can reduce wheat yields due to lack of cold hardening and to resultant winter kill. Extremes of precipitation, both droughts and floods, are detrimental to crop productivity under rainfed conditions. Drought stress increases the demand for water in irrigated regions.

To explore the effects of changes in daily climate variability, tests of changes in temperature and precipitation variability on corn have been made using crop growth models at Des Moines, Iowa (Figure 3). If variability in temperature or precipitation is doubled, decreases in corn yields and increases in corn crop

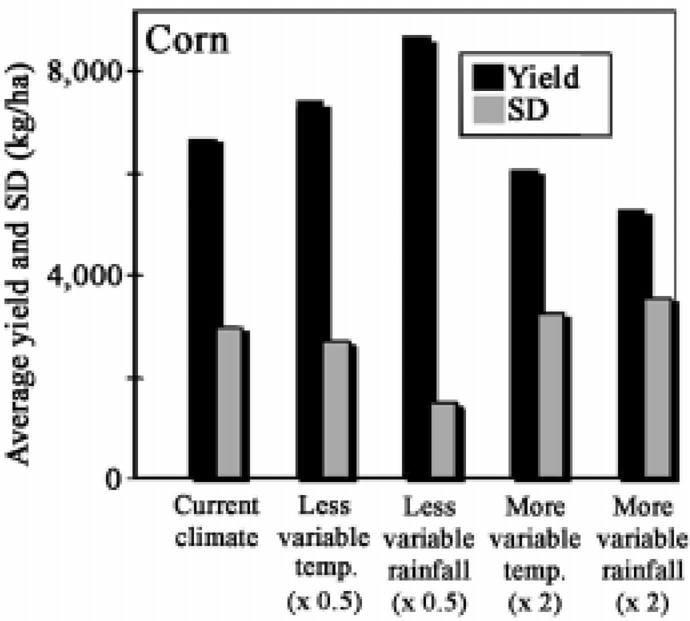

Figure 3. Effects of changes in daily temperature and precipitation variability on corn average yields and yield standard deviation at Des Moines, Iowa (Rosenzweig et al. 2001).

failure result. Such failures for doubled temperature variance are due to slower grain-filling that extended ear development into frost episodes. Doubled precipitation variance causes water-deficit failures in the crop. Halving precipitation variability increases mean yield and strongly decreases variability of the corn yields year-to-year. For soybean, results of changing the variability of temperature and precipitation are similar to those for corn in direction yet greater in magnitude.

Sequential extremes — e.g., prolonged droughts followed by heavy rains — may spawn surprises and have the severest impacts in terms of soil quality, propensity to flooding and the associated impacts for yields and pests. Droughts can reduce populations of beneficial insects (lacewings, lady bugs, etc.), spiders and birds, influencing pollination and pest infestations. The effects of several years of drought (e.g. as occurred with the "double" La Niña of 1998–99 and 1999–2000) can be additive and have longer-lasting impacts on soil quality and groundwater.

Pests and Climate Change

Climate affects not just agricultural crops, but also their associated pests as. The major pests of crops include weeds, insects, and pathogens. The distribution and proliferation of weeds, fungi, and insects are determined to a large extent by climate. Organisms become pests when they compete with, or prey upon, crop plants to an extent that reduces productivity. Not only does climate affect the type of crops grown and the intensity of the pest problems, it affects the pesticides often used to control or prevent outbreaks. The intensity of rainfall and its timing with respect to pesticide application are important factors in pesticide persistence and transport.

Because of the extremely large variation of pest species' responses to meteorological conditions, it is difficult to draw overarching conclusions about the relationships between pests and weather. In general, however, most pest-species proliferation is favored by warm and humid conditions. But crop damages by pests are a consequence of complex ecological dynamics between two or more organisms and, therefore, are very difficult to predict. For example, dry conditions are unfavorable for sporulation of fungi, but are also unfavorable for the crop; a crop weakened by drought is more likely to become infected by fungi than when it is not stressed. Pest infestations often coincide with changes in climatic conditions, such as early or late rains, drought, or increases in humidity, which in themselves can reduce yields. In these circumstances, accurately attributing losses to pests can be difficult.

Weeds. Worldwide, weeds have been estimated to cause annual crop production losses of about 12 percent (Parker and Fryer 1975; Pimentel 1992). In the United States, annual losses due to weeds have been valued at approximately $12 billion, amounting to some 10 percent of potential production (Patterson and Flint 1990). Large efforts are made to limit these damages through a variety of weed-control measures. Around the world, more human labor is expended in hand-weeding than in any other agricultural task, and most cultivation and tillage practices are designed to aid in weed control. The chemical industry manufactures herbicides, which, after fertilizers, account for the largest volume of chemicals applied to crops (Furtick 1978). Over $6 billion/yr are spent on weed control in the United States (Patterson and Flint 1990).

Insects and Diseases. Insect pests in agricultural systems are the second major cause of damage to yield quantity and quality after weeds. Insect habitats and survival strategies are strongly dependent on patterns of climate. Insects are particularly sensitive to temperature because they are cold-blooded. In general, higher temperatures increase rates of development, with less time between generations. Precipitation — whether optimal, excessive, or insufficient — is a key variable that also affects crop-insect interactions. Drought sometimes changes the physiology of perennial vegetation, affecting the insects that feed on them (Mattson and Haack 1987). Abnormally cool, wet conditions can also bring on severe insect infestations, although excessive soil moisture may drown out soil-residing insects. Climate factors that influence the growth, spread, and survival of crop diseases include temperature, precipitation, humidity, dew, radiation, wind speed, air circulation patterns, and the occurrence of extreme events

Changes in Pests. The results of most analyses indicate that, in a changing climate, pests may become even more of a problem than they are currently, thus posing the threat of greater economic losses to farmers (Watson et al. 1996). While the majority of weeds are invasive species from temperate zones, many of the most aggressive species in temperate regions originated in tropical or subtropical regions, and in the current climate their distribution is limited by low temperature. Such geographical constraints will be removed under warm conditions. Warmer temperature regimes have been shown to increase the maximum biomass of three grass weed species significantly (Figure 4).

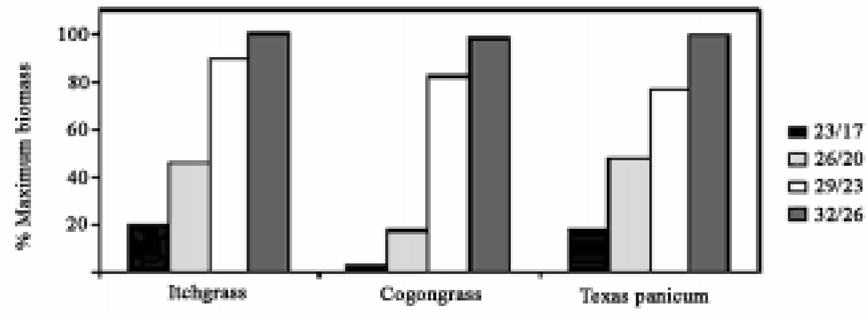

Figure 4. Effect of temperature regime on biomass of three grass weeds (Patterson and Flint 1990).

In crop monocultures, undesirable competition is controlled through a variety of means, including crop rotations, mechanical manipulations (e.g., hoeing), and chemical treatment (e.g., herbicides). The need for such measures is likely to increase in a warming climate.

With temperatures within their viable range, insects respond to warmer conditions with increased rates of development and with less time between generations. (Very high temperatures reduce insect longevity.) Warmer winters will reduce winterkill, and consequently there may be increased insect populations in subsequent growing seasons. With warmer temperatures occurring earlier in the spring, pest populations will become established and thrive during earlier, more vulnerable, crop growth stages. Additional insect generations and larger populations, encouraged by higher temperatures and longer growing seasons, will require greater efforts of pest management.

Warmer winter temperatures will also affect those pests that currently cannot over-winter at high latitudes but do over-winter in lower-latitude regions and then migrate north in the spring and summer. For example, the potato leafhopper (*Empoasca fabae*), a pest of soybean, alfalfa and other crops, may expand its over-wintering range (now limited to a narrow area along the Gulf of Mexico) and be better positioned to spread northward earlier and in greater numbers during the cropping season (Figure 5).

Some species are pests in the southern United States but not in the Midwest, because they do not migrate northward early enough or in significant numbers. Corn earworm (*Heliothus zea*) is an example of a current pest of corn in the South that is not a serious pest in field corn in the Midwest. With climate change, extension of over-wintering range may bring *H. zea* to field corn crops of the Midwest (Stinner et al. 1989).

Damage from the European corn borer (*Ostrinia nubilalis*), a major insect pest of corn in the United States and elsewhere, is limited in many regions due

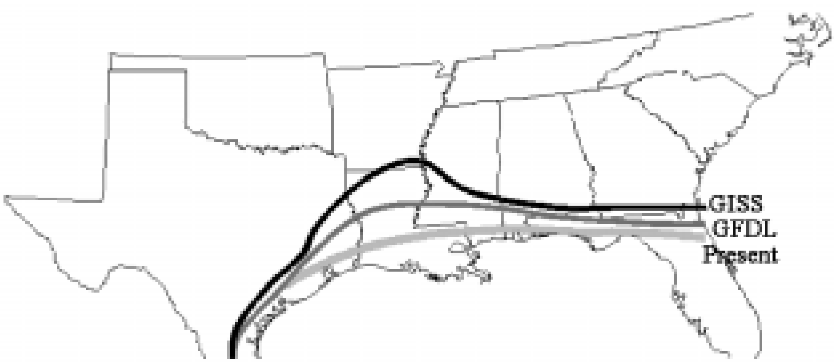

Figure 5. Over-wintering range of potato leafhopper (*Empoasca fabae*) for current climate and two climate-change scenarios (Stinner et al. 1989).

to current climate conditions. For example, in Iowa, the insect has only two generations per corn-growing season because the third generation pupae cannot complete development before winter. Warmer conditions will ensure a third generation of the insect and will significantly increase its over-wintering populations.

The Mexican bean beetle (*Epilachna varivestis*) and bean leaf beetle (*Cerotoma trifurcata*), major pests of soybean, presently have two generations in the Midwest and three in the Southeast. An additional generation may be possible in the Midwest if the growing season there lengthens (Stinner et al. 1989).

Drought stress tends to bring increased outbreaks of pests; therefore, insect damage may increase in regions destined to become more arid. If the climate becomes warmer also, the population growth rates of small, sap-feeding pests may be favored (Stinner et al. 1989). Higher temperature and humidity and greater precipitation, on the other hand, are likely to result in the spread of plant diseases, as wet vegetation promotes the germination of spores and the proliferation of bacteria and fungi, and influences the life-cycle of soil nematodes. In regions that suffer greater aridity, however, disease infestation may lessen, although some diseases (such as the powdery mildews) can thrive even in hot, dry conditions as long as there is dew formation at night.

Adaptation

The responses of individual producers to changes of climate regime will involve adjustments in the selection of crops and in practices of cultivation, irrigation, and pest control. Changes on the farm may, in turn, modify regional energy use, water demand, storage and transportation providers, and food processing. Improved climate forecasts can help farmers prepare for changing seasonal-to-interannual conditions. Ultimately, the ability of farmers to adapt effectively may determine the success or failure of individual farms and, by extension, may affect local, regional, national, and international economies.

Climate change will gradually (and, possibly at some point, even abruptly) affect agriculture on regional, national, and international scales. The range of options available for producers in any given region will change. Since farmers' strategies grow out of experience, they will find that the past will be a less reliable predictor of the future. Accumulated experience will be less useful as a tool for coping with what might eventually be a very different future. Under progressively changing climate conditions, adaptations will need to evolve continuously.

National farm policy is likely to be a critical determinant in the adaptation of the farming sector to changing conditions. In the United States, farm subsidies may either help or hinder necessary adaptation to the eventuality of a changing climate. An important policy consideration is the assessment of risk due to weather anomalies. If flood and drought frequencies increase as projected, the need for emergency allocations will also increase. Anticipating the probability and the potential magnitude of such anomalies may help make timely adjustments, reducing social costs.

With the advantage of extensive research and extension capacity, farmers in the United States may adapt effectively to climate change, at least initially. However, some adaptations — such as development of new irrigation systems — may be costly, while others may cause significant disruption for people in rural areas. Beyond our national boundaries, changes in the global climate may have more negative consequences. Where infrastructure for agricultural research is less effective, as in many developing countries, adaptation may be slower, leading to failure of individual farms and to losses in economies dependent on agricultural production. The vulnerability of food-deficient regions in marginal climates is likely to be exacerbated due to increased climatic extremes, including more severe and prolonged droughts alternating with floods. An overall increase in global food demand may benefit climatically favored regions, such as parts of the United States, though that advantage may be offset by intensified competition from still more favored regions (possibly Canada and Russia).

Costs of production may rise in a changing climate, as producers adjust crop varieties and species, scheduling of operations, and land and water management. Successful adaptations to climate change may imply significant alterations from current agricultural systems, and some of the required changes may be costly. There is likely to be need for investment in new technologies and infrastructure. New irrigation systems may be required where aridity or instability of precipitation ensues. Damages from flooding may increase in many areas. Costs may include greater applications of and/or development of new agricultural chemicals, particularly herbicides and pesticides.

Even without climate change, agriculture faces some serious challenges in the coming decades. Because of the growing interdependence of the world food system, the impact of climate change on agriculture in each country depends more and more on what happens elsewhere. For example, improvements in the climate of key competitive regions, such as Argentina for soybean production, may affect the United States' comparative advantage. On the other hand, the vulnerability of food-deficient regions to heat and drought may work to the advantage of major grain producers such as the United States. International trade policy issues, especially the movement to lower agricultural trade barriers, will be crucial in climate change response strategies.

Agricultural Emissions of Greenhouse Gases

The role of climate as a primary determinant of agriculture has long been recognized. Only in the last decade, however, has agriculture's reciprocal effect on climate change come to light. Clearing forests for fields, burning crop residues, submerging land in rice (*Oryza sativa*) paddies, raising large herds of ruminants, and fertilizing with nitrogen, all release greenhouse gases to the atmosphere (Rosenzweig and Hillel 1998). The main gases emitted are CO_2, CH_4, and N_2O. Emissions from agricultural sources account for about 15 percent of total anthropogenic greenhouse-gas emissions and land-use change (often for agricultural purposes) contributes another 8 percent approximately (Houghton et al. 1996). Agriculture ranks third after energy consumption and chlorofluorocarbon production as a contributor to the enhanced greenhouse effect.

Carbon in various forms (CO_2, carbonates, or organic compounds) is cycled between the atmosphere, oceans, land biota, and marine biota on short time scales and into sediment and rocks on geological time scales. Agricultural practices manipulate the vegetation and soil carbon reservoirs (Jackson 1993). As areas of natural vegetation are transformed into cultivated fields, much of the vegetative biomass originally present is converted to CO_2. Land-use change and biomass burning cause the release of carbon, in the form of CO_2 that had previously been contained in plant biomes and soil organic matter, both of which, in turn, resulted from cumulative prior photosynthesis. The aboveground material is either burned or decomposes rapidly. Declines in organic matter in agricultural soils are largely due to losses from the labile pool, also known as the "light" fraction. In contrast, the resistant pool or "heavy" fraction of organic matter in the soil, while not entirely stable, decomposes at a much slower rate.

When land supporting a natural ecosystem is first converted to agricultural use, the organic matter in the soil is gradually oxidized as the soil is cultivated and cropped. Deforestation, biomass burning, drainage, plowing, cultivation, and overgrazing all promote the decomposition of organic matter and the release of CO_2 to the atmosphere. Soil degrading processes (erosion, crusting and compaction, acidification, salination, etc.) further exacerbate losses of carbon (Lal et al. 1998). As agricultural production continues over time, soil organic matter declines still further (albeit at a slowing rate), resulting in more CO_2 releases, until a steady state is reached or until the field is abandoned (Houghton and Skole 1990). Curtailed tillage practices such as "minimum tillage" or "no-till," efficient crop rotation, strip cropping, and fallowing tend to decrease CO_2 fluxes to the atmosphere and may sequester carbon over a period of time (Rosenzweig and Hillel 1998).

Climate Change and Biotechnology

The prospect of a changing climate, caused by augmented atmospheric constituents, may provide motivation for the use of biotechnology in several ways. First, there may be opportunities for optimizing photosynthetic and stomatal conductance responses to higher levels of atmospheric CO_2. Second, biotechnology techniques may offer the potential for creating effective adaptations to changing climatic circumstances. Enhanced heat and drought tolerance, both of crops and livestock, are likely to be required, as are strategies to cope with shifting and newly emerging weeds, pests, and plant diseases. Finally, improved mitigation options could also be developed in regard to the ability of crops to sequester carbon, production of biofuels, reduction of CH_4 emissions from rice-paddy and ruminant-livestock systems, and management of N_2O emissions from nitrogen fertilizers.

Several caveats are in order. Genetically modified organisms may not be able to cope with all of the effects of dynamic climate changes that occur in agricultural regions. For example, severe flooding may continue to be detrimental to crop production, regardless of genetic resources. Dissemination of new and severe crop pests may be so rapid as to bring widespread damage before development of appropriately modified crops. Finally, much research and testing of genetically modified crops is required, in any case, so that potential benefits and risks are more clearly understood.

CONCLUSIONS

Providing sufficient food for the world's people is one of the great challenges of the twenty-first century. The challenge will increase as human numbers grow towards 10 billion, and as land, water, and genetic resources are progressively degraded through intensified use. There is now real concern that global warming, with its potential for affecting the climate regimes of entire regions, will exacerbate the world's food-production problems.

Indeed, if atmospheric buildup of greenhouse gases continues without limit, sooner or later it is bound to warm the earth's surface. Such a warming trend cannot but affect the regional panoply of temperature and precipitation governing natural and agricultural systems. While increased atmospheric CO_2 alone might benefit crop growth due to enhanced photosynthesis, the combination of high CO_2 and higher temperatures may not always produce greater harvests. There is a grave danger in concluding that "in general" climate change does not pose a threat to national or world agriculture.

Agricultural systems may be more adaptable, being more subject to our control, than natural systems, and may shift into regions now primarily covered by forests and other less intensively managed ecosystems. Such interactions of agriculture and the natural environment under a changing climate will have large-scale reverberations: altering rates of soil erosion, increasing competition for water resources, expanding the use of agricultural chemicals, and affecting wildlife habitats.

While global warming offers challenges to agriculture, it also offers opportunities. Many good farm-management practices also buffer against climate changes and reduce greenhouse-gas concentrations in the atmosphere. Land conversion and restoration can increase soil organic matter through sequestration (i.e., enrichment of the soil's store of organic carbon), while simultaneously reducing emissions. Improvements in fertilizer efficiency —

timely application of environmentally preferred types — can reduce N_2O emissions. Finally, the production and use of biofuels "recycles" CO_2, thus providing a direct offset to emissions from non-renewable sources. If idle land is used for biofuel production, carbon sequestration may occur as well.

Global environmental change is a deceptively simple expression for what is actually an exceedingly complex array of dynamic processes, with specific combinations of interactions in each region. Climate change, sea-level rise, and increases in CO_2, ultraviolet radiation, and tropospheric ozone are but a few of the potentially fateful factors involved. While many studies have investigated these factors singly, there is much to be gained from studying their interactions. Although unknowns still thwart our ability to predict precisely the extent of future changes in agriculture due to global environmental changes, active response and systematic preparation are clearly in order.

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How Many Ways Can We Skin this Cat Called Earth? Risks and Constraints to the Biobased Economy

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My objective is to assess risks and constraints to realizing the hopeful vision of a biobased economy in the twenty-first century — a future in which agriculture and other managed biobased production systems provide society with food, fiber, medicinals, energy, chemicals, and materials. I will evaluate whether the biobased economy is possible and whether it is sustainable, given constraints to the quantity and quality of land, water, nutrients, and energy to propel the system.

Human societies already use 50 percent of all solar energy assimilated by plants (Pimentel et al. 1999), which utilize less that 1 percent of the solar energy they intercept. With a biobased economy, we risk negative consequences of asking yet more from the earth.

To approach this assessment, I created a very simple needs-based, bottom-up model, using the world as the unit of analysis and the twenty-first century as the time frame. The model develops four scenarios, projecting supply and demand in a biobased society. Absolute precision is not an objective of these simulations. And the projections of the model are not predictions. They are a wake-up call.

An underlying assumption of the model is that energy drives all enterprise and is the ultimate constraint. Energy relations — energetics — is the input-output accounting system of life. It underlies and orchestrates evolutionary as well as day-to-day processes. In using energy analysis, a tool of systems ecology, to assess human society and systems, I am applying simple arithmetic to illustrate the calculus of my mentors David Pimentel and Charles A. S. Hall, as well as others to whom I owe an intellectual debt, principally Howard Odum, Fred Cottrell, Lester Brown, Herman Daly, Jay Forrester, the Steinharts, and Earl Cook.

ENERGETICS: the total energy relations and transformations of a physical, chemical or biological system. 1855. (Merriam Webster's Collegiate Dictionary)

Energy analysis is a means of quantifying "sustainability," so that "sustainability" is the outcome of a positive or neutral energy balance, rather than only a lofty ideal motivating the search for alternatives to the fossil-energy-based economy of the industrial and post-industrial eras.

SUSTAINABLE: of, relating to, or being a method of using a resource so that the resource is not depleted or permanently damaged. (Merriam-Webster's Collegiate Dictionary)

Clearly, a fossil-energy-dependent economy is not sustainable over time: it is estimated that global supplies of oil and natural gas will last 50 years, and coal reserves at most several hundred, based on current population and production. Because of the pollution generated, an economy dependent on fossil fuel is not sustainable within a finite space — even a space as large as our earth and its atmosphere. Global pollution from the current use of fossil energy is shrinking the ozone shield, causing climate change, polluting air and waterways, and killing coral reefs.

Although fossil fuels will not suddenly "run out" — there are massive supplies of coal in China, for example — they are becoming more difficult and more energy-intensive to extract as high quality fuels are used up and lower quality fuels remain. These lower-quality fuels contain more impurities and thus will increase the pollution load. As an analogy, copper ores mined in the United States early in the twentieth century contained 2.5 percent metal, whereas by 1980 they contained only 0.5 percent metal, a trend typical for other extractable metals and fossil resources (Gever et al. 1985).

BIOBASED ECONOMIES

Although it is clear that a fossil-energy-dependent economy is not sustainable, the more interesting question is whether an information-rich and technologically sophisticated biobased economy — the "new biobased economy" envisioned in the NABC *Vision Statement* (NABC 1999) — is sustainable. The presumption might be that a biobased system would be in equilibrium because it runs on contemporary infusions of energy, rather than depending upon fossil resources that have been concentrated and stored over millennia.

History provides many examples, however, of pre-industrial human societies in which biobased resources were degraded or depleted at an unsustainable rate. These societies could be maintained for a significant length of time only because in a world with many fewer people, groups could move on to new areas — the impacts of their resource overuse temporarily ignored. This overuse, however, led to erosion, desertification, and to the loss of major food species.

Despite the limitations observed from history, “contemporary” solar energy almost certainly *must* be the engine of a sustainable society. The solar radiation that reaches the earth (at $3.6x10^{18}$ kcal/day) is the source of the heat and energy that move earth and mountains by way of weather patterns that cause wind and rain, and thus, indirectly, erosion, sedimentation, and soil formation. Only a small fraction (about 0.1 percent) of the solar energy reaching earth is converted by photosynthesis into plant growth to directly fuel the biobased economy. This energy is concentrated as it moves through the ecosystem, and matter is consumed by higher trophic levels of living organisms, including humans (Cook 1976).

“World Food-Needs” Model

Human demands for food and other goods are driven by the size of the world population and by its level of consumption. To assess the potential for success of a biobased economy driven by “contemporary” energy input, I calculate the area of land and other inputs needed to feed a growing world population, and compare this demand with the amount of arable land. For the purpose of this exercise, the needs and demands of all people are considered to be equal.

The “World Food Needs” model assumes a 100-percent rice diet[1] of 2,700 Calories/person/day, the current world-average caloric intake.[2] Converting from kilocalories (= Calories) to kilograms, we calculate that 1.65 billion metric tons of edible grain are needed to feed the 6 billion people on earth in the year 2000, with each person consuming about one-quarter ton of rice.

Production requirements, however, are greater than the demand for consumable grain. It has been estimated that about 45 percent of production is used for seed, wasted, or lost to pests or diseases (Buringh and van Heemst 1977).[3] Thus, 3 billion metric tons of grain must be produced in order to supply adequate food to the current population of 6 billion.

Calculating World Food Needs

- 2,700 Calories/person/day x 365 days/year = 985,500 Calories/person/year
- Round up to 1 million Calories/person/year
- Assume rice is the worldwide staple, 100 percent of food Calories
- 1 kg rice = 3,640 Calories
- $1x10^6$ Calories/person/year ÷ 3,640 Calories/kg = about 275 kg “rice”/person/year
- 275 kg = 0.275 metric ton [= tonne (t)]
- 0.275 t “rice”/person /year x 6 billion people = 1.65 billion t of consumable grain needed to feed current world population
- 1.65×10^9 t = 55 percent of production need, accounting for seed, waste, loss to pests
- 1.65×10^9 t ÷ .55 = <u>3 billion t</u> production needed to feed Year-2000 population

Land Needed for Food Production

The World Food Needs model is driven also by assumptions about yield (production per unit area of land), from which the total land area needed for production can be calculated. Table 1 shows a range of yields under various conditions and assumptions. Two of these yield levels are used as the basis for scenarios in the model:

- 2 t/ha — A "sustainable yield" with limited fossil-energy inputs. This yield level was selected based on results from two quite different methods of analysis. In one case, a theoretical world consumable grain production was calculated by looking at yields of crops grown in different soil types. Yield estimates in this model were 1.7 to 2.3 t/ha, assuming a "labor-oriented agriculture" (Buringh and van Heemst 1977).[4]

  In the other case, an agricultural ecologist looked at historical rice production in favorable areas under animal-powered agriculture. Historical yields were as high as 3.5 t/ha in China at the beginning of the common era, but more typically were in the range of 2 to 2.5 t/ha (Mitchell 1984).
- 4.5 t/ha — An "optimistic" world-average yield, based on a projected 20 percent increase in rice productivity over 1999 as a result of genetically engineering high efficiency C_4 photosynthetic capability from maize. [This is based on the work of Drs. John Sheehy, Maurice Ku, and others (IRRI 2000b).]

The model projections are based on the calculation that 1.5 billion ha of arable land would be needed to feed the current world population at a "sustainable yield," and that 0.7 billion ha would be needed in 2000 if the world were fed by genetically engineered rice produced at the "optimistic" yield.[5]

World Population Growth

The global population passed the 6-billion mark in early 1999, increasing at an annual rate of 1.4 percent (PRB 1999). The World Food Needs model reflects the fact that, at this growth rate, the population will double in 49 years. Table 2 shows population doubling times at higher rates of growth, because in many parts of the developing world growth rates of 2.5 percent are common. In the mid-1960s, the world population was increasing at 2 percent, leading to projections then that there would be 7 billion people by 2000. Projections were brought closer to 6 billion as growth rates declined to 1.7 percent in the mid-1980s (Drosdoff 1984).

Table 2 shows that the growth rate must decline below 0.75 percent in order to delay the doubling of the current population to beyond the twenty-first century. However most futurists predict a leveling of world population mid-century at 10 to 12 billion.

Table 1. Land needed for food under various productivity scenarios

Land ($x10^9$ ha)	Yield (t/ha)	Situation and assumptions
2.0	1.5	Marginal conditions, minimal inputs.
1.5	2	Sustainable productivity level for labor-intensive/ animal-powered agriculture.
1.2	2.5	Average yield in Costa Rica for the years 1970–84, with significant fertilizer input (33 kg N/ha) (Levitan 1988).
0.8	3.8	World average, 1999, with significant fossil-energy-derived inputs, as well as significant variability (FAOSTAT 1999). Also 1996 average in Asia, with yields in China = 6.1 t/ha (Dawe and Doberman 1998).
0.7	4.5	Optimistic world-average yield, reflecting a projected 20 percent increase in rice yield over 1999 as a result of genetically engineering high-efficiency C_4 photosynthetic capability from maize into rice. (IRRI 2000b). Also, this was the average yield for unmilled rice in Indonesia in 1996 (Dawe and Doberman 1998).

Table 2. Doubling of world population at various rates of increase

Annual rate of population increase (percent)	When year-2000 population will be doubled
3	2023
2.5	2028
2	2035
1.4	2049
1	2069
0.75	2092
0.5	2139

Agricultural Land

To assess sustainability from the supply side, we accept a frequently cited current estimate of 1.5 billion ha of arable land (Table 3), which is 11 percent of total world land area (Buringh 1989; WRI 1994). "Arable," from the Latin *arare*, to plow, means "fit for or used for the growing of crops." In other words, the area of arable land that may be put to the service of meeting world food needs is not fixed, but rather depends upon social and political factors, as well as on agronomic considerations. With greater demand and scarcity, land previously considered marginal or uneconomical to use is put into production and thus becomes "arable." History shows that yields from marginal lands are either lower than yields from more productive land or are more highly subsidized by inputs — in the forms of nutrients, water, pest controls, labor, etc. Use of marginal land for crop production also extracts a higher toll from the environment, with typically higher rates of soil erosion.

Table 3. World land quality and use (Pimentel et al. 1999)

Land use	Fraction of total (percent)	Billion ha
Arable	11	1.5
Pasture	26	3.5
Forest	30	4.0
Urban	9	1.2
Other	23	3.1
Total	100	13.3

We base our estimate of an upper limit on arable land on the area that Buringh and van Heemst (1977) deemed suitable for labor-oriented agriculture: 2.5 billion ha (approximately 18 percent of world land area).

The World Food Needs model factors in the loss of an estimated 10 million ha/year: land so severely degraded that it is abandoned for agriculture. At this rate, one-third of the arable land will have been lost by mid-twenty-first century due to erosion, nutrient depletion and salinization (Pimentel et al. 1995, 1999).

Simulation-Model Projections for the Twenty-First Century

Results of the simulation show the year when demand for land to grow food will exceed the supply of arable land on earth (Figure 1, Table 4). Four scenarios are projected: two at the 2 t/ha "sustainable" yield, and two at the 4.5 t/ha "optimistic" yield. Each yield level is paired with both of the estimates of arable land area just described. The model incorporates population growth at 1.4 percent, and annual loss of arable land of 10 million ha.

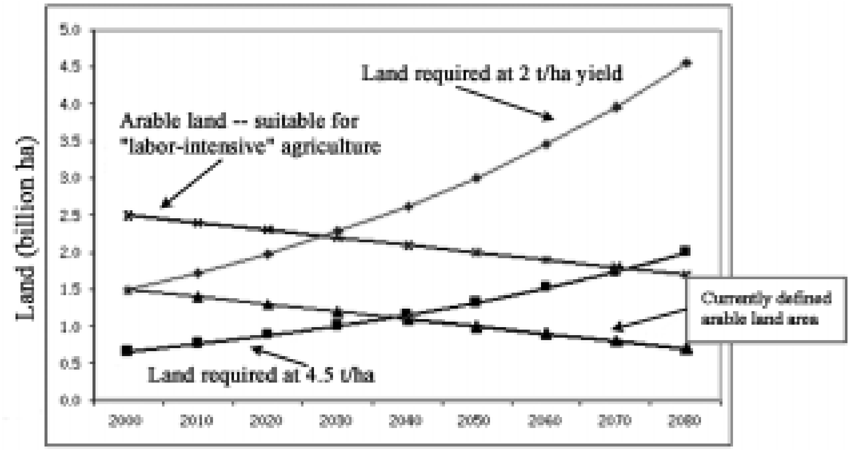

Figure 1. Land needed to grow food — a simulation assuming a 1.4-percent population growth and loss of arable land at 10 million ha/year. Two scenarios: "sustainable" yield = 2 t/ha, "optimistic" yield = 4.5 t/ha of rice genetically engineered with capacity for C_4 photosynthesis. Two estimates of arable land in year 2000: 1.5 billion ha and 2.5 billion ha.

TABLE 4. LAND NEEDED FOR FOOD PRODUCTION COMPARED WITH ARABLE LAND AVAILABLE

Year	Land needed (billion ha) at yields of		Arable land (billion ha)		Global population ($x10^9$)
	2 t/ha	4.5 t/ha	Current	High est.	
2000	1.5	0.7	1.5	2.5	6.0
2010	1.7	0.8	1.4	2.4	6.9
2020	2.0	0.9	1.3	2.3	7.9
2030	2.3	1.0	1.2	2.2	9.1
2040	2.6	1.2	1.1	2.1	10.5
2050	3.0	1.3	1.0	2.0	12.0
2060	3.5	1.5	0.9	1.9	13.8
2070	4.0	1.8	0.8	1.8	15.9

- At the 2 t/ha “sustainable” yield and the current typical estimate of arable land, theoretical basic food demand exceeds the supply of land in the year 2000.
- At the 2 t/ha “sustainable” yield and the higher estimate of arable land, demand exceeds supply in 2030.
- If genetically engineered rice attains the photosynthetic efficiency of corn, and if this product is successfully integrated into production strategies worldwide, demand will exceed supply of arable land (as currently defined) by 2040. However, with higher yields, demand for water and nutrient inputs will also certainly increase, very likely to levels beyond what is sustainable or available.
- The last scenario treads into territory that is probably foolishly optimistic: projecting yields on marginal lands that are greater than yields known today on more productive land. But, even if average yields of 4.5 t/ha can be maintained, demand will exceed supply by 2070.

In sum, we project that sometime between 2000 and 2070, land availability will be less than that needed to provide an adequate, but very basic, diet for the global population. Is this too pessimistic? We think not: already the World Health Organization has estimated that 3 billion people — one-half the world population — are malnourished in terms of micronutrients (WHO 1996). Moreover, the United Nations standard caloric requirement for the average person, 2,600 Calories, is just 100 fewer than the current world average intake used in these projections (Collins 1982).

Inputs, Outputs and Energy Relations in Agriculture and Other Sectors

Agricultural yield depends on soil quality, genetic potential of the crop, and external inputs to production. As availability of suitable land becomes constrained, energy-intensive inputs are more important and production practices shift from extensive to intensive. As Steinhart and Steinhart illustrated in their classic paper (1974), agricultural output correlates closely with energy-based inputs. While the Steinharts’ data are from 1920 to 1980, others have focused on a broader array of technologies and societies, all pointing toward the same conclusion. Pimentel et al. (1973), for example, calculated that high-yielding corn genotypes use sixteen times as much nitrogen as their low-yielding counterparts.

Nitrogen fertilizer is perhaps the most energy-intensive input to production. Manufacture of sufficient nitrogen to replace that taken up by rice, requires the equivalent of 7 percent of the food-energy value of the rice.[6]

Water use also closely correlates with agriculture productivity. Worldwide, demand for freshwater quadrupled between 1940 and 1990, with 69 percent of water usage for agriculture, 23 percent for industry and only 8 percent domestic

(PRB 1999). In India, this use-rate is twice the sustainable yield for the country's aquifers (Worldwatch Institute 2000) and 95 percent of water in developing countries is polluted (WHO 1992). Clearly, there is very little additional water available to support increased biobased production.

Yet, thus far, our model has addressed only the input costs for food production, whereas in a biobased economy, land and energy inputs would also be needed to generate fuels for cooking and heating, as well as for clothing, materials, and medicinals. Technological societies such as ours use more than 98 percent of energy for these non-food purposes. Note that the 3,500 Calories used for food in a technological society is less than 2 percent of the total 230,000 Calories used per person per day (Table 5). In a biobased society, this non-food energy demand would ostensibly have to be met by agricultural and natural-resource-based production.

TABLE 5. ENERGY USE (CALORIES/PERSON/DAY) IN VARIOUS SOCIETIES (PIMENTEL AND PIMENTEL 1996)

Society	Food	Industry agriculture	Commercial & residential	Transport	Total
Primitive	2,000	—	—	—	2,000
Hunting	3,000	—	2,000	—	5,000
Primitive agriculture	4,000	4,000	4,000	1,000	13,000
Advanced agriculture	3,500	7,000	12,000	1,000	26,000
Industrial	3,500	24,000	32,000	14,000	77,000
Technological	3,500	91,000	66,000	63,000	230,000

RENEWABLE ENERGY

To make an admittedly rough estimate of the level of energy consumption that could be maintained into the future, we could perhaps look at the percentage of energy now derived from renewable sources (Table 6). Renewable, solar-powered energy sources — biomass, biofuels, hydro, wind and geothermal — now provide about 21 percent of the energy used.

We can also get a sense of what *type* of society could be maintained into the future by looking at past societies that were maintained on 21 percent of our current per capita energy consumption level — the portion of energy from renewable sources (Table 6). From Table 5, we find that the amount of renewable energy now generated is sufficient to sustain an advanced agricultural/low-input industrial society at our current population level.[7] Of course as population increases, available energy per capita will decrease.

TABLE 6. WORLD ENERGY SOURCES		
Energy source	Fraction of Total (%)	Renewable?
Petroleum	34	No
Natural gas	19	No
Coal	22	No
Nuclear fission	6	No
Biomass	7	Yes
Hydroelectricity	6	Yes
Geothermal + wind	6	Yes
Biofuels (e.g. ethanol)	<2	Yes
(Total renewable)	(21)	

Increased production of biofuels, which now provide less than 2 percent of energy worldwide, is seen as key to increasing the availability of renewable energy while reducing environmental pollution. In the United States, corn has been the primary biofuel feedstock. Growing the crop is the most energy-expensive part of producing the ethanol fuel. Nearly 80 percent of the energy value of the ethanol made from fermented corn is put into the production of the crop in the forms of fertilizer and mechanization (Pimentel 1991).[8]

Thus, although corn-based ethanol production does result in a net energy advantage, its production remains highly dependent on fossil-derived energy. Moreover, corn grown for fuel faces the same environmental constraints as does corn grown for food: adequate arable land, soil degradation and pest problems. Corn is also the crop that uses the greatest total quantity of pesticides in the United States, and is responsible for much of the pesticide residue found in groundwater in the Midwest.

If corn-based ethanol were to meet the fuel needs of this country, it would require more than four times as much cropland as is actually and potentially available for all crops in the United States (Pimentel 1991). If corn is grown on less-productive land in order to meet this demand, it will require still greater inputs and lead to more erosion than when it is grown on higher-quality soil. Thus, unless alternative biofuel feedstocks are successfully developed and marketed (e.g. cellulosic biomass), the vision of biobased production meeting energy demand may be a mirage.

The potential for increasing the utility of biomass, especially waste products from agriculture and forestry, also provides a ray of hope for the success of a biobased economy. Now developing are biomass industries that make an array of commercial products, including fuels, electricity, chemicals, adhesives, lubricants and building materials, as well as new clothing fibers and plastics (polylactic acid polymer) (DOE 2000). Optimism is justified to the extent that biomass-based products can be derived from waste materials, thus reducing the waste stream. However, any increase in demand for biomass from the world's managed and natural forests will put greater stress on that diminishing resource. The forest-land base — now approximately 30 percent of the earth's land area — is declining at a rate of 1 percent every three years due to degradation of cropland and expansion of human settlements.

Biodiversity

Forests are a key repository, not only of biomass but also of biodiversity. While there are many compelling ecological and ethical reasons for maintaining biodiversity, the issue is perhaps particularly relevant to this consideration of a biobased economy because of the importance of biodiversity in developing medicinals. It can be expected that, in a biobased economy, the preservation of organisms will become even more critical as sources of genetic material for developing new means of alleviating and curing human diseases. However, this pool of genetic material is reduced as biodiversity declines.

The maintenance of biodiversity requires the preservation of diverse and productive habitats. However, as productive habitats are increasingly used for agriculture, biodiversity declines. The well-known report of the Brundtland Commission (World Commission 1987) recommended that 12 percent of ecologically productive land be left to non-human biota, but it is estimated that more than 90 percent of land area is already managed for agricultural or forestry production or occupied by human settlements (Western 1989).

Table 7. Threats to biodiversity in the United States. Percent of imperiled species affected by various factors; a single species may be affected by more than one factor. (The Nature Conservancy 2000)

Habitat destruction	85 percent
Alien species	49 percent
Pollution	~25 percent*
Overexploitation	17 percent
Disease	3 percent

*Primarily aquatic species

Biodiversity is affected also by run-off containing nitrogen and other pollutants from agricultural land to natural habitats. At a symposium at the February 2000 AAAS meetings, David Tilman noted that these imbalances give competitive advantage to invasive species. Experts at that symposium estimated that 50 to 70 percent of the decline and disappearance of species might be linked to invasive species that out-compete, infect or devour native species.[9] Thus, if high-input agriculture increases with greater use of nitrogen fertilizer, biodiversity is likely to decline.

Perhaps one statement can sum up the underlying threat to biodiversity: more human individuals are born each day than there are individuals in all the great ape species combined (Cincotta and Engelman 2000).

Summary and Conclusions

I want to summarize my conclusions by adding *redistribution* and *serious reassessment* to the three Rs of environmental protection: reduce, re-use and recycle. This reassessment should consider that:

- Human society is teetering close to the brink of an absolute limit to growth.
- While access to fossil energy and the inequitable distribution of the world's resources have masked the problem for some of us, it has neither been masked nor obfuscated for the malnourished half of the world's population (who also have access to few additional energy resources).
- While the transformation to a "new" biobased economy is essential, it is also likely in the short term to increase demand on stressed "renewable resources."
- In the long term, success of a biobased economy may be predicated on reducing the size, and level of consumption, of the human population.
- Land, energy and resource constraints must be factored into any creative envisioning of a "*new*" biobased economy in order to ground the proposals in the biophysical reality. Otherwise they are fantasy.
- "Recharting the course" will take tremendous political will, as well as creativity and intellectual resources.

In sum, because of resource constraints, I am skeptical that a sustainable biobased economy is possible if it is expected to continue at the pace and consumption level of the fossil-based economy that industrial and post-industrial societies have come to know in this recent snatch of human history.

The world economy will not suddenly run out of land to produce food and materials for the biobased economy. Rather, progression toward the ultimate limit to growth will be incremental, marked by increased pollution of air and water, declines in productivity of degraded soils, and reduced availability and access to fossil-fuel-derived inputs to production.

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1 In fact, rice accounts for 23 percent of world caloric intake (IRRI 2000a).

2 Data from 1992: 2,698 Calories/person/day world average; 3,732 Calories daily per capita consumption in US (IRRI 2000a).

3 In our basic grain model, we ignore the 38 percent of grain now fed to cattle.

4 The Buringh and van Heemst (1977) model assumes that two-thirds of cultivable land is cropped, that cropland is left fallow one-third of the time, and that only half of production is used for human nutrition — the rest is lost, used for seed or used as fodder. From this, they estimate the global carrying capacity for human beings at 3.5 billion, 58 percent of the current population.

5 If 3 billion tons of "rice" are needed to feed a population of 6 billion, and 0.5 tons of grain is required per person per year, four people can be fed per hectare at yield = 2 t/year and total land requirement = 1.5 billion ha (6 billion people ÷ four people/ha). At the optimistic 4.5 t/ha yield, 9 persons can be fed per ha (4.5 t/ha ÷ 0.5 t/person) and total land requirement is 0.7 billion ha (6 billion people ÷ 9 people/ha = 0.67 = 0.7).

6 Chemical synthesis of nitrogen requires about 14,700 kcal energy input per kilogram of nitrogen produced (Mudahar and Hignett 1982; Pimentel 1984). Production of a metric ton of rice removes 17 kg nitrogen from the soil. Thus 0.25 million kcal are used to manufacture nitrogen for 1 ton of edible rice (assuming for the purpose of these calculations that all nitrogen removed from soil is from chemical manufacture). The energy for nitrogen manufacture is thus about 7 percent of the 3.64 million kcal food energy value per ton of rice.

7 Twenty-one percent of the 230,000 kcal consumed daily per capita in a technological society = 48,000 kcal/person/day from renewable sources. This was the level of energy consumption in advanced agricultural/early industrial societies (Table 5).

8 One bushel of corn produces 2.5 gallons ethanol. At average United States output of 110 bushels corn/acre, 275 gallons of ethanol are produced per acre. Ethanol has only two-thirds the energy value of corn, however, so the 275 gallons has the energy equivalent of 174 gallons gasoline. The production of this ethanol has required an input equivalent of 137 gallons of gasoline for fertilizer, mechanization, etc. (an amount that will increase as corn production moves to less fertile land). Net gain is 37 gallons/acre/year (174-137=37). Fourteen acres of corn would be needed to fuel a typical car for a year, as compared with 1.5 acres cropland now used to feed each American — a nine-fold difference (Pimentel 1991).

9 This estimate is consistent with results from a recent Nature Conservancy study of threats to biodiversity in the United States, which found that habitat destruction affects 85 percent of imperiled or endangered species, and presence of alien species affects 49 percent (The Nature Conservancy 2000).

Summary Presentation

ANN THAYER
Chemical & Engineering News
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The twelfth annual meeting of the National Agricultural Biotechnology Council (NABC) brought together a collection of distinguished speakers on diverse subjects, with many different points of view espoused. The NABC strives to obtain a balance of opinions, and fosters communication on very challenging and often controversial topics. Its workshops are designed to serve as resources for broad-based discussion and policy-making.

The goal of this summary is not to give a chronological overview of the conference, but to search for common threads and possible disconnects among the ideas that were presented. To that end, I will seek answers to several simple questions — who, what, when, where, why, and how? — as they pertain to a biobased economy.

Speakers articulated many instructive and challenging ideas as they described their visions of the biobased economy. From examination of the definition of what the biobased economy is, several fundamental elements were outlined, including:

- raw materials from renewable resources
- highly productive agricultural systems both for food and industrial needs
- integrated, multidisciplinary approaches to R&D that combine agriculture, engineering, health, information technology, and other technologies and disciplines
- eventually 50 percent of fuels and more than 90 percent of organics and materials will be biobased
- beneficial effects on the environment, energy security, and rural economies.

Having defined the elements of a biobased economy, participants presented their views on its importance, anticipating the following benefits:

- sustainable production of needed materials, food, and energy
- revitalization of agriculture and better use of resources
- decreased dependence on foreign, and diminishing supplies of , oil-based raw materials
- political and economic self-sufficiency and security
- functionally superior, value-added products
- improved impact on global climate and the environment
- need to support and feed a growing world population.

Views were varied on when a biobased economy would take hold and become a reality. The question of time-scale generated the greatest discrepancy of viewpoints. Government representatives, largely from the USDA and DOE, cited goals and time frames established within President Clinton's Executive Order 13134, and the National Research Council report, "Biobased Industrial Products: Priorities for Research and Commercialization," issued in 1999. Thus, most major goals for a biobased economy are targeted for the years 2010, 2020, and 2090. There was little, if any, discussion of how these time-frames were derived and whether they are realistic.

Instead, most discussion focused on the current status of developments. While no one would claim that a biobased economy exists today, these discussions provided information on progress, and clues as to how fast we are advancing toward it. An apparent consensus existed that a technology-base is forming, that governmental forces are encouraging advances, and that some early developments are expected in terms of new commercialized products.

For many, these ideas were expressed by the frequently used phrase, "the stars are aligning." Government policy and agency efforts are promoting the development of a biobased economy. A clear response from academia is evident in the level of enthusiasm for creating new biobased technologies and the number of research projects undertaken. However, it is uncertain how much of the recent governmental push for a biobased economy hinged on the tripling of oil prices during 1999.

In contrast to the consensus, plenary speaker Ralph Nader offered a conflicting view. He described NABC's own position document on the biobased economy as "too optimistic, too self-assured, and too futuristically determined" that a biobased economy will become a reality. Nader suggested that a biobased economy will exist only as a promise as long as questions remain regarding the safety of some related technologies, particularly genetic engineering, and as long as power and decision-making lie within corporations.

Nader also stated that the biomaterial movement "depends on whether it is driven by a for-profit corporate structure or by arms-length government/ university research, a free exchange of scientific information between scientists and a different set of priorities." Lois Levitan also raised serious and thought-provoking questions about whether a biobased economy is even possible, much less sustainable.

On a more optimistic note, Jerry Caulder stated his belief that success is already apparent. As an illustration of success in creating biobased materials and products, he noted that "we can and are doing it... in not just producing proteins, but in controlling metabolic pathways."

With few industrial participants, the corporate/industrial view of a biobased economy was limited. DuPont, one of the most active and openly committed companies developing biomaterials, provided insight into its development and commercialization of 3GT, a new form of polyester. However, DuPont's commitment to the creation and development of biobased materials is a near exception among the dozens of chemical, oil and gas, and other companies with products based on petroleum feedstocks.

Nader suggested that the creation of a biobased economy could not take place under the current industrial and corporate structure. A contrasting view argued that corporations will be critical to the creation of biobased materials, as it is they who will make the investment to develop, commercialize, and market products. A greater industry presence at NABC meetings will be critical to expanding the discussion of the economic viability and industrial support needed to develop and further a biobased economy.

Obviously, there remain many issues, questions, and challenges to creating a biobased economy. This is a large part of the "how" question and involves not just the scientific and technological how, but the economic, political, and societal hows, along with questions of who (the roles various parties will play), where (what developments will occur first and in what markets), and when (how quickly technology will achieve the desired goals).

Some of the issues and challenges that still must be addressed are:

- moving technologies beyond their early stages of development
- ability and incentive to create new and desired products cost effectively
- modifications in processing and production systems including the creation of new supporting infrastructure
- integration with existing fossil-fuel approaches and infrastructure
- displacements and transitions on many fronts, most notably agriculture
- understanding environmental, societal, policy, and economic impacts
- opposition to new technology and products derived from that technology.

Many other questions were raised and challenges made. Among these were questions on intellectual property and its concentration in limited hands; on the impact of consolidation in industry and agriculture; on research funding and support; on the responsibility for demonstrating that technology is safe, advantageous or value-creating; and on the responsibility for educating the public and ensuring science-based decision-making.

In creating biobased products and a biobased economy, it is important to keep in mind the role that industry and market dynamics will play. Companies likely will evaluate biobased technologies that yield cost-effective, competitive, and successful products. Business sustainability is an important long-term issue, but companies are under many short-term pressures to create returns on their investments.

Only a few, although prominent, companies such as Dow Chemical and DuPont are viewing the combination of chemistry and biology as an opportunity for growth and new products in mature businesses. However, these companies tend to be exceptions and greater industrial "buy-in" and participation will most likely be needed.

Moving beyond niche markets with major product successes will do much to validate the acceptance of biobased technologies among current industrial players. Product commercialization milestones may also serve to convince shareholders and Wall Street of the viability of "biobased-business plans." On the horizon are Dow's commercialization of polylactic acid and DuPont's new polyester, 3GT. Polylactic acid is produced from corn-based starting materials, and one of the 3GT intermediates, 1,3-propanediol, can be produced via biocatalysis.

Industrial-scale production of biobased materials still faces many challenges in increasing yields and reducing costs. There are cost-related issues associated with raw-material production, transportation, processing, and operations. Many of these must still be addressed to gain and maintain industrial interest and long-term investments.

Pressures from Wall Street and shareholders can be serious constraints to a corporation's ability to maintain a long-term vision. Government is often no better. Currently, the federal government is backing biobased initiatives, which may change at any time for political, economic, or other reasons. Several speakers addressed this point with the message, "We've been here before." In addition, this is an election year with new initiatives being set, often for political reasons, and a new administration on the horizon with its own agenda.

Universities may be best suited to maintain the long-term vision and create the basic knowledge needed for technological progress. But visions need to be periodically reviewed in light of marketplace, political, and other realities.

In order for biobased products to succeed in the marketplace, there is much to be said for market-pull driving their creation, rather than technology pushing unwanted products on consumers. For example, Dow emphasizes the functionality of polylactic acid, at least as much as the polymer's biodegradability. Several years ago, a push to create biodegradable polymers was met with limited enthusiasm from the marketplace. Dow's development of polylactic acid strives to address potential customer needs rather than just have a biological origin.

Although at least one speaker suggested that technology has gotten ahead of the science, arguments can be made also that technology is ahead of the marketplace. Some argue that the initial products of agricultural biotechnology were designed only to leverage and perpetuate existing businesses. Whether this is true or not, companies do admit to a myopic view of their initial customers — namely, the farmers — and grossly underestimated consumer reaction and its impact on the agricultural value chain. Assumptions, if any, made about consumer reaction and acceptance of the first genetically engineered insect-resistant and herbicide-tolerant crops may have contributed to major miscalculations in marketing strategy.

Biotechnology has been more readily accepted where there was clear benefit to consumers — for example, in biopharmaceuticals. In the agricultural arena, producers now are working to develop "second-generation" products that many hope will alter consumer sentiment, including food and agricultural products with improved nutritional or health profiles. Consumer acceptance may be an important factor in the development of products that, although not containing genetically modified components, are produced through genetic engineering. There already is anecdotal evidence of protests against fibers from genetically engineered cotton, and questions are being raised about recombinant industrial enzymes.

To achieve the goal of creating a biobased economy, at least four major groups will be involved, each of which has its own role and array of contributions. The groups and their areas of impact and expertise, as envisioned by the participants, are listed below.

- Government: policy and regulation, create goals and road maps, economic and risk assessment, build on existing networks, technology creation, and funding and support.
- Academia: basic research, education, and integration and partnerships.
- Industry: product development, investment, commercialization, and marketing.
- Farmers: raw-material supply, creation of new business opportunities and partnerships.

In summary, the NABC represents a high level of enthusiasm for a vision of a biobased economy that promises the following:

- great potential and opportunities for expansion beyond food, feed, and fiber to include industrial products and energy production
- the future for agriculture
- cooperative interaction of government, academia, industry, and the public
- integrated approach through R&D and business partnerships
- improved quality of life, environment, health, security, and economics.

PART VI

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PART VII

APPENDICES