NABC 12: An Overview

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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 dramati-

cally 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 downstream 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.